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Vijay P. Singh
Shalini Yadav
Ram Narayan Yadava *Editors*

Environmental Pollution

Select Proceedings of ICWEES-2016

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Water Science and Technology Library

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Preface

Fundamental to sustainable economic development, functioning of healthy ecosystems, reliable agricultural productivity, dependable power generation, maintenance of desirable environmental quality, continuing industrial growth, enjoyment of quality lifestyle, and renewal of land and air resources is water. With growing population, demands for water for agriculture and industry are skyrocketing. On the other hand, freshwater resources per capita are decreasing. There is therefore a need for effective water resources management strategies. These strategies must also consider the nexus between water, energy, environment, food, and society. With these considerations in mind, the International Conference on Water, Environment, Energy and Society (WEES-2016) was organized at AISECT University in Bhopal, MP, India, during March 15–18, 2016. The conference was fifth in the series and had several objectives.

The first objective was to provide a forum to not only engineers, scientists, and researchers, but also practitioners, planners, managers, administrators, and policy-makers from around the world for discussion of problems pertaining to water, environment, and energy that are vital for the sustenance and development of society.

Second, the Government of India has embarked upon two large projects: one on cleaning of River Ganga and the other on cleaning River Yamuna. Further, it is allocating large funds for irrigation projects with the aim to bring sufficient good-quality water to all farmers. These are huge ambitious projects and require consideration of all aspects of water, environment, and energy as well as society, including economics, culture, religion, politics, administration, law, and so on.

Third, when water resources projects are developed, it is important to ensure that these projects achieve their intended objectives without causing deleterious environmental consequences, such as water logging, salinization, loss of wetlands, sedimentation of reservoirs, loss of biodiversity, etc.

Fourth, the combination of rising demand for water and increasing concern for environmental quality compels that water resources projects are planned, designed, executed and managed, keeping changing conditions in mind, especially climate change and social and economic changes.

Fifth, water resources projects are investment intensive and it is therefore important to take a stock of how the built projects have fared and the lessons that can be learnt so that future projects are even better. This requires an open and frank discussion among all sectors and stakeholders.

Sixth, we wanted to reinforce that water, environment, energy, and society constitute a continuum and water is central to this continuum. Water resources projects are therefore inherently interdisciplinary and must be so dealt with.

Seventh, a conference like this offers an opportunity to renew old friendships and make new ones, exchange ideas and experiences, develop collaborations, and enrich ourselves both socially and intellectually. We have much to learn from each other.

Now the question may be: Why India and why Bhopal? India has had a long tradition of excellence spanning several millennia in the construction of water resources projects. Because of her vast size, high climatic variability encompassing six seasons, extreme landscape variability from flat plains to the highest mountains in the world, and large river systems, India offers a rich natural laboratory for water resources investigations.

India is a vast country, full of contrasts. She is diverse yet harmonious, mysterious yet charming, old yet beautiful, ancient yet modern. Nowhere we can find mountains as high as the snow-capped Himalayas in the north, the confluence of three seas and large temples in the south, long and fine sand beaches in the east as well as architectural gems in the west. The entire country is dotted with unsurpassable monuments, temples, mosques, palaces, and forts and fortresses that offer a glimpse of India's past and present.

Bhopal is located in almost the center of India and is situated between Narmada River and Betwa River. It is a capital of Madhya Pradesh and has a rich, several century-long history. It is a fascinating amalgam of scenic beauty, old historic city, and modern urban planning. All things considered, the venue of the conference could not have been better.

We received an overwhelming response to our call for papers. The number of abstracts received exceeded 450. Each abstract was reviewed and about two thirds of them, deemed appropriate to the theme of the conference, were selected. This led to the submission of about 300 full-length papers. The subject matter of the papers was divided into more than 40 topics, encompassing virtually all major aspects of water and environment as well energy. Each topic comprised a number of contributed papers and in some cases state-of-the-art papers. These papers provided a natural blend to reflect a coherent body of knowledge on that topic.

The papers contained in this volume, "Environmental Pollution," represent one part of the conference proceedings. The other parts are embodied in six companion volumes entitled, "Hydrologic Modelling," "Groundwater," "Energy and Environment," "Water Quality Management," "Climate Change Impacts," and "Water Resources Management." Arrangement of contributions in these seven books was a natural consequence of the diversity of papers presented at the conference and the topics covered. These books can be treated almost independently, although significant interconnectedness exists among them.

This volume contains five parts. Part I containing seven papers deals with some aspects of environmental pollution. Part II discusses pollution indicators. Part III focuses on generation of pollution as described in nine papers. Water quality assessment is described in Part IV containing 11 papers. Part V contains four papers that present water quality modelling.

The book will be of interest to researchers and practitioners in the field of water resources, hydrology, environmental resources, agricultural engineering, watershed management, earth sciences, as well as those engaged in natural resources planning and management. Graduate students and those wishing to conduct further research in water and environment and their development and management may find the book to be of value.

WEES-16 attracted a large number of nationally and internationally well-known people who have long been at the forefront of environmental and water resources education, research, teaching, planning, development, management, and practice. It is hoped that long and productive personal associations and friendships will be developed as a result of this conference.

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Acknowledgements

We express our sincere gratitude to Shri Santosh Choubey, Chancellor, and Dr. V.K. Verma, Vice Chancellor, Board of Governing Body, and Board of Management of the AISECT University, Bhopal, India, for providing their continuous guidance and full organizational support in successfully organizing this international conference on Water, Environment, Energy and Society on the AISECT University campus in Bhopal, India.

We are also grateful to the Department of Biological and Agricultural Engineering, and Zachry Department of Civil Engineering, Texas A&M University, College Station, Texas, U.S.A., and International Centre of Excellence in Water Management (ICE WaRM), Australia, for their institutional cooperation and support in organizing the ICWEES-2016.

We wish to take this opportunity to express our sincere appreciation to all the members of the Local Organization Committee for helping with transportation, lodging, food, and a whole host of other logistics. We must express our appreciation to the Members of Advisory Committee, Members of the National and International Technical Committees for sharing their pearls of wisdom with us during the course of the Conference.

Numerous other people contributed to the conference in one way or another, and lack of space does not allow us to list all of them here. We are also immensely grateful to all the invited Keynote Speakers, and Directors/Heads of Institutions for supporting and permitting research scholars, scientists and faculty members from their organizations for delivering keynote lectures and participating in the conference, submitting and presenting technical papers. The success of the conference is the direct result of their collective efforts. The session chairmen and co-chairmen administered the sessions in a positive, constructive and professional manner. We owe our deep gratitude to all of these individuals and their organizations.

We are thankful to Shri Amitabh Saxena, Pro-Vice Chancellor, Dr. Vijay Singh, Registrar, and Dr. Basant Singh, School of Engineering and Technology, AISECT University, who provided expertise that greatly helped with the conference organization. We are also thankful to all the Heads of other Schools, Faculty Members and Staff of the AISECT University for the highly appreciable assistance in different organizing committees of the conference. We also express our sincere thanks to all the reviewers at national and international levels who reviewed and moderated the papers submitted to the conference. Their constructive evaluation and suggestions improved the manuscripts significantly.

Sponsors and Co-sponsors

The International Conference on Water, Environment, Energy and Society was Jointly organized by the AISECT University, Bhopal (MP), India and Texas A&M University, Texas, USA in association with ICE WaRM, Adelaide, Australia. It was partially supported by the International Atomic Energy Agency (IAEA), Vienna, Austria; AISECT University, Bhopal; M.P. Council of Science and Technology (MPCOST); Environmental Planning and Coordination Organization (EPCO), Government of Madhya Pradesh; National Bank for Agriculture and Rural Development (NABARD), Mumbai; Maulana Azad National Institute of Technology (MANIT), Bhopal; and National Thermal Power Corporation (NTPC), Noida, India. We are grateful to all these sponsors for their cooperation and providing partial financial support that led to the grand success to the ICWEES-2016.

Contents

About the Editors

Prof. Vijay P. Singh is **University Distinguished Professor, Regents Professor,** and the inaugural holder of the **Caroline and William N. Lehrer Distinguished Chair in Water Engineering** in the Department of Biological and Agricultural Engineering and Zachry Department of Civil Engineering at Texas A&M University. He received his B.S., M.S., Ph.D., and D.Sc. degrees in engineering. He is a registered professional engineer, a registered professional hydrologist, and an Honorary Diplomate of American Academy of Water Resources Engineers.

Professor Singh has extensively published the results of an extraordinary range of his scientific pursuits. He has published more than **900** journal articles; **25** textbooks; **60** edited reference books, including the massive **Encyclopedia of Snow, Ice and Glaciers and Handbook of Applied Hydrology**; 104 book chapters; 314 conference papers; and **72** technical reports in the areas of hydrology, ground water, hydraulics, irrigation engineering, environmental engineering, and water resources.

For his scientific contributions to the development and management of water resources and promoting the cause of their conservation and sustainable use, he has received more than 90 national and international awards and numerous honors, including the **Arid Lands Hydraulic Engineering Award, Ven Te Chow Award, Richard R. Torrens Award**, **Norman Medal**, and **EWRI Lifetime Achievement Award**, all given by American Society of Civil Engineers; **Ray K. Linsley Award and Founder's Award**, given by American Institute of Hydrology; **Crystal Drop Award**, given by International Water Resources Association; and **Outstanding Distinguished Scientist Award** given by Sigma Xi, among others. He has received **three honorary doctorates**. He is a **Distinguished Member** of **ASCE**, and a fellow of **EWRI**, **AWRA**, **IWRS**, **ISAE**, **IASWC**, and **IE** and holds membership in 16 additional professional associations. He is a fellow/member of 10 international science/engineering academies. He has served as **President** and **Senior Vice President** of the **American Institute of Hydrology** (AIH). Currently he is editor-in-chief of two book series and three journals and serves on editorial boards of 20 other journals.

Professor Singh has visited and delivered invited lectures in all most all parts of the world but just a sample: Switzerland, the Czech Republic, Hungary, Austria, India, Italy, France, England, China, Singapore, Brazil, and Australia.

Prof. Shalini Yadav is Professor and Head of the Department of Civil Engineering, AISECT University, Bhopal, India. Her research interests include solid and hazardous waste management, construction management, environmental quality and water resources. She has executed a variety of research projects/ consultancy in Environmental and Water Science and Technology and has got rich experience in Planning, formulating, organizing, executing and management of R&D programs, seminars, and conferences at national and international levels. She has got to her credit guiding an appreciable number of M.Tech. and Ph.D. students. She has published more than 10 journal articles and 30 technical reports. Dr. Shalini has also visited and delivered invited lectures at different institutes/universities in India and abroad, such as Australia, South Korea, and Kenya.

Professor Shalini Yadav graduated with a B.Sc. in Science from the Bhopal University. She earned her M.Sc. in Applied Chemistry with a specialization in Environmental Science from Bhopal University and M.Tech. in Civil Engineering with a specialization in Environmental Engineering from Malaviya National Institute of Technology, Jaipur, India in 2000. Then she pursued the degree of Ph. D. in Civil Engineering from Rajiv Gandhi Technical University, Bhopal, India in 2011. Also, she is a recipient of national fellowships and awards. She is a reviewer for many international journals. She has been recognized for one and half decades of leadership in research, teaching, and service to the Environmental Engineering Profession.

Dr. Ram Narayan Yadava holds the position of Vice Chancellor of the AISECT University, Hazaribag, Jharkhand. His research interests include solid mechanics, environmental quality and water resources, hydrologic modeling, environmental sciences and R&D planning and management. Yadava has executed a variety of research/consultancy projects in the area of water resources planning and management, environment, remote sensing, mathematical modeling, technology forecasting, etc.

He has got adequate experience in establishing institutes/organizations, planning, formulating, organizing, executing and management of R&D programs, seminars, symposia, conferences at national and international level. He has got to his credit guiding a number of M.Tech. and Ph.D. students in the area of mathematical sciences and Earth sciences. Dr. Yadava has visited and delivered invited lectures at different institutes/universities in India and abroad, such as USA, Canada, United Kingdom, Thailand, Germany, South Korea, Malaysia, Singapore, South Africa, Costa Rica, and Australia.

He earned an M.Sc. in Mathematics with a specialization in Special Functions and Relativity from Banaras Hindu University, India in 1970 and a Ph.D. in Mathematics with specialization in Fracture Mechanics from Indian Institute of Technology, Bombay, India, in 1975. Also, he is a recipient of Raman Research Fellowship and other awards. Dr. Yadava has been recognized for three and half decades of leadership in research and service to the hydrologic and water resources profession. Dr. Yadava's contribution to the state of the art has been significant in many different specialty areas, including water resources management, environmental sciences, irrigation science, soil and water conservation engineering, and mathematical modeling. He has published more than 90 journal articles; 4 textbooks; 7 edited reference books.

Part I
Environmental Pollution

Socioeconomic Environment Assessment for Sustainable Development

Atul Kumar Rahul, Shaktibala, Bhartesh and Renu Powels

Abstract Sand mining is proposed at Alappad, Panmana, and Ayanivelikulangara of Kollam District within an area of 180 ha because of which nearly 550 families are being exposed to the impact of this mining. Families suffer from various problems associated with the mining activity, which includes environmental, social, and economical health. In addition, they have to be rehabilitated to other acceptable areas. The Resettlement & Rehabilitation (R&R) plans are an integral part of this EIA (Environmental Impact Assessment) study. Hence, this issue needs to be carefully studied and solved in an amicable manner. The objective of the present study is to ascertain the socioeconomic and other impacts on the people and on the area of operation and preparation of R&R plan for the project-affected families in the 180 ha mine lease area in line with Indian Rare Earth's (IRE's) R&R plans. We need to identify reasons of various social–political driving forces causing complaints and obstruction of existing in proposed mining and work out mechanisms for consultation with all stakeholders and influential forces in order to address issues related to mining.

Keywords EIA (Environmental impact assessment) · R&R (Research & development) and IRE · Social-economical · Mining activities · Sand mining Kollam district

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Introduction

Kerala is known for its 570-km-long coastline as one of world's most potential fishing grounds with unique biodiversity and as the abundant source of some of the rarest minerals in the globe, especially its southern coast. It is one of the ten 'Paradises Found' by the National Geographic Traveler, for its diverse geography and overwhelming greenery, in which, fall some of the sandy beaches and backwaters. It is situated on the southwest coast of Kerala between 9° 28′ and 8° 45′ latitude and 76° 28′ 77° 17′ north longitude. Kollam District is bounded on the north by Alappey and du, South by Trivandrum District and west by Lakshadweep Sea. South to Ernakulam is the commercial capital of the State. Kollam is connected to Ernakulum, by both road and rail. Indiscrete disposal of industrial waste leads to several geoenvironmental disasters on land and it has huge socioeconomic effects on the population residing in the impacted area, especially in terms of livelihood and health. Once this happens, it becomes a news item and comes into focus for geoenvironmental evaluation. Mining and processing of heavy and rare-earth minerals inevitably involves distress of the land environment, the magnitude and intensity of which depends on the type of chemicals, and processes used, the efforts taken in the management of waste as well as on environmental fragility of location.

Central Government laid strict mining rules and regulations (Atomic Energy Act, 1962), which prohibited individuals or private enterprises from undertaking such mining activity. The Policy Statement also allows selective entry of the private sector. Sandy beaches rank among the most intensively used coastal ecosystems by man (Schlacher et al. 2006). In many jurisdictions around the world, beach management has almost exclusively focused on maintaining and restoring sand budgets, with very little consideration for ecological dimensions (Nordstrom 2000; Wong 2003; Schlacher and Thompson 2007; Aarninkhof et al. 2010). A framework for integrated impact assessment of chemicals was proposed by Briggs (2008) with regard to integrated environmental health impact assessment, whereas Crane (2010) reported on approaches for converting environmental risk assessment outputs into socioeconomic impact assessment. The adoption of EIA procedure, in fact, with due differences, encompasses developed, developing, and transitional countries (Lee and George 2000). That means sustainable development should meet the needs of present generations while preserving the natural environment in its undisturbed state. Economic development must not compromise environmental integrity (Hilson and Murck 2000). Improper management of the industrial waste from the titanium dioxide (TiO_2) pigment producing industry is a cause for concern. The Census of Marine Life indicates that a number of marine biological resources have been depleted. Due to overfishing, stocks of species such as tunas, sharks, and sea turtles have declined sharply in the past decade, some even reduced by 90–95% (Ausubel et al. 2010; Hilson et al. 2011). People of the area live under the constant threat and fury of nature. Studies show that coastal erosion is prevalent in the coastal strip proposed for mining. As a study indicates 'towards south of Palakkad from Thrikkunnapuzha to Thottapally, a zone of 4.3 km is under moderate erosion'

(Seakale et al. 1997). Kerala has a history of environmental social movements, which has won victories many a time, environmental activists had been supporting the anti-beach sand mining movement scientifically and intellectually right from the initial stages onward. In the present, study the seriousness of the social, environmental, and health hazards that might result from the indiscriminate mining activity by a profit-oriented company. A statement validity analysis is also conducted in order to summarize the findings of the study. Shoreline changes of Kerala coast every year (Sreekala et al. 1998).

Objectives

- To assess the extent of socioeconomic impact and preparation of R&R for the project-affected families in line with IRE R&R in the areas of Alappad, Panmana, and Ayanivelikulangara of Kollam district.
- To ascertain the reasons and various social and political driving forces causing complaints and obstruction of existing and proposed mining.
- To work out mechanisms through consultation with all stakeholders and influential forces in order to address issues relating to mining.
- To make creative recommendations for getting the cooperation of local communities

Methodology

Description of the Study Area

The Kollam coast in *Kerala* is a blessed coastal belt with the best mineral sand deposit of the country. This belt commonly known as the *Chavara* deposit, after the main locality, is 22 km (14 mi) in length and about 8 km (5.0 mi) wide in the north and 6 km (3.7 mi) in the south. Around 60% of the Chavara barrier beach portion is composed of heavy minerals. *Indian Rare Earths Limited* (*IREL*) is a government-owned ISO 9002 Certified corporation in *India*. One of the four production plants of *IREL* is situated near *Chavara*, in the suburbs of Kollam city. The plant operates on a mining area containing as high as 40% heavy minerals and extending over a length of 23 km in the *Chavara* belt. Figure 1 shows the present annual production capacity of *Chavara* unit engaged in dry as well as wet (dredging) mining and mineral separation stands.

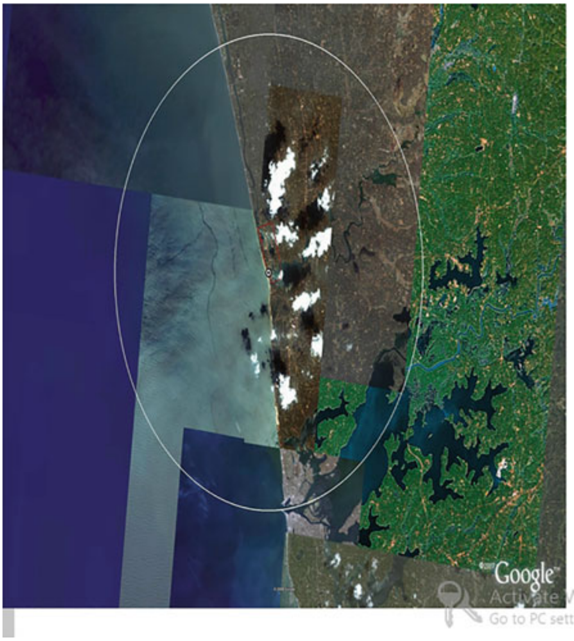

Fig. 1 Chavara unit mining and mineral site

Types of Data Collected

The following types of data were collected for the study:

- Documentary evidence mainly from records and published materials available in various related departments.
- Interview data from the families of the project-affected areas of Alappad, Panmana, and Ayanivelikulangara of Kollam district.
- Field notes by the researcher through observation and discussion with the knowledgeable persons, local leaders, and other resource persons.
- Focus group discussions with the stakeholders.

Tools of Data Collection

Data for the empirical study were collected mainly through interview schedules and focus group discussions. The schedule-elicited information on areas required for getting the information given in the objectives. Wherever possible the responses in the schedule were pre-coded to facilitate easy tabulation and analysis. Most of the questions had distinct options for answers and only a few qualitative parameters were elicited through open-ended questions.

Data Collection Analysis

Quantitative analysis rests judgmental conclusion based purely on data. Qualitative assumptions are about how the world works, what are suitable categories for data. Figure 2 describes what constitute good data, and the validity of scientific procedures to explain the descriptive and inferential statistics. For future projections, the role of qualitative assumptions is significant.

Personal Profile

The socioeconomic and demographic profiles of the respondents are given which covers detailed information on the various dimensions of the families in the project-affected areas of Alappad, Panmana, and Ayanivelikulangara of Kollam district. The personal information gives a benchmark data of the families in these areas, which will be useful to understand the general characteristics of the areas under study.

Fig. 2 Quantitive assumption of Chavara site

Age

Maturity is an index to understand the issues of the sand mining in an intelligent way. The age-wise classification of the occupants of the mining lease area is given in Table 1.

Sex

Male-to-female ratio in these three villages are given in Table 2. It is clear from the table that men are more exposed to the issues of the sand mining, as they are more in touch with many people in the areas (Fig. 3).

Table 1 Age analysis

Age group (years)	Frequency	Percentage
15–25	14	2.6
26–35	53	9.9
36–45	127	23.8
46–55	159	29.9
56–65	110	20.6
66–75	52	9.8
Above 75	18	3.4
Total	533	100

Table 2 Sex analysis

Sex	Frequency	Percentage
Male	393	73.7
Female	140	26.3
Total	533	100

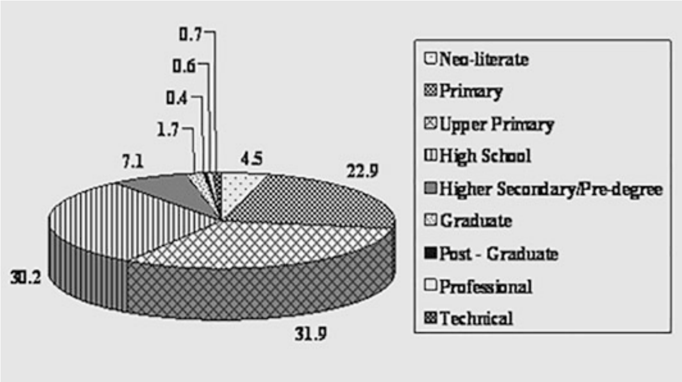

Fig. 3 Education analysis

Table 3 Matrital status analysis

Marital status	Frequency	Percentage
Unmarried	4	0.8
Married	473	88.7
Widow	49	9.2
Widower	1	0.2
Separated	6	1.1
Divorced	0	0
Total	533	100

Marital Status

Generally, married persons are more responsible in decision-making process concerning family and connected important affairs, as they understand the issues that affected the family and society in a broad and in-depth manner (Table 3).

Literacy

Literacy plays a key role in determining factors of decision-making process. Education contributes significantly to one's ability to change attitudes and modify behavior pattern. Highly educated persons are more flexible and susceptible to changes than less educated. This is mainly because education provides scope for broadmindedness and thinking capacity.

Occupation

The main occupation of the people in this area is fishing and other allied minor activities as they reside near the coastal areas of the sea. Table 4 clearly shows that the majority (34%) of them are engaged in fishing followed by other (22.7%) type of work like agriculture, commercial contracts or contract laborer of IRE, working outside the lease area, transport section, etc.

Assessment and Mitigation

Impact Assessment

The identified impacts due to mining and associated activities have been studied in relation to the following areas.

Table 4 Occupation analysis

Occupation	Frequency	Percentage
Unemployed	77	14.4
Employed in Govt/Pvt	35	6.6
Business	43	8.1
Farmer	5	0.9
Daily-waged	45	8.4
Student	2	0.4
Retired	24	4.5
Fishing	181	34.0
Others (specify)	121	22.7
Total	533	100

Topography and Land Use

Original topography of the beach sand mining extension area will change due to future mining operations. As the backfilling system is integrated into the mining process, the excavated land will be subsequently reclaimed and the ground surface of the reclaimed land will be brought back to the contours matching with surrounding topography. Excavation and backfilling will take place simultaneously so that the affected land can be made ready for further use without any appreciable loss of time. The ground elevation of the beach zone is at 2–4 MRL (Mean reduce level) which very gently rises to about 7–8 MRL toward the east to places which are relatively far away from backwaters. There will be some interim impact on topography and landform due to the destruction of original landform. Overall landscape shall improve in a phased manner when greenbelt development/plantation shall cover stretches subsequent to backfilling.

Drainage

The deposit is totally isolated from the landside by T.S canal. Seasonal/perennial streams join T.S canal at places instead of directly discharging into the sea. The canal is connected with the sea at two ends of the deposits. In certain parts, dredging will be carried out for the sand deposits underlying T.S canal. Floating of the dredge on the canal water or sand extraction at the canal bed for some period will not have any appreciable impact on drainage. Thus, beach sand mining will not have any impact on the network of backwater bodies including T.S canal.

Air Environment

Due to beach sand extraction, primary concentration, and backfilling, there will not be an appreciable rise in gaseous or particulate pollution level in ambient and work zone environment. Sand extraction process (dredging) is a wet primary process and backfilled mass is a moist in form which does not release dry dust in the mining area. Therefore, in the proposed area, pollution will be insignificant. At stack at MSP-monitored particulate matter, SO_2 and CO values, in general, are within permissible limits. Monitored SPM, SO_2, NO_x, and CO values at AAQ stations and at work zone are also well within respective permissible limits. The predictions of ground level concentration of pollution from the two stacks of 30 t/day FBD and 3 t/day FBD have been carried out with the help of air quality simulation model ISCST3, released by USEPA. At the present EIA study, GLCs (Ground level concentration) are predicted for 24 h for SO_2 and SPM. As a first step, actual monitored site meteorological data for winter season have been considered. The meteorological data were generated near plant site for a 1-month period on an hourly basis. Stabilities have been determined with the monitored data by using Turner method (insulation-based classification). Up to a height of 30 m, SO_2 and NO_x values will remain stable. The maximum height at Cochin has been taken as a reference for the present study. The locations are located with respect to 16 radial wind directions (N to NNW) and the radial distances have been fixed based on physical stack height, as the major stack height is 30 m, the receptors in each of the radial directions were fixed at 75, 150, 300, 600, 825, 900, 975, 1050, 1200, 1350, 1650, 2100, 2700, 3300, 4200, and 5000 m (Table 5).

Water Environment

Water from T.S Canal is utilized for supplying makeup water to dredge pond. Water is utilized for primary concentration at MRP. In CUP (and BWP) the pumped out water from T.S canal is circulated in gravity spirals. Freshwater drawn from bore wells is used for washing the CUP concentrate. At present 30 m^3/h of bore water is drawn from the bore wells. After expansion, 60 m^3/h of freshwater shall be required. No trace of saline water ingress has been noted because groundwater is drawn from a depth of 230 m only. Entire mining lease on a narrow strip of sandy

Table 5 Predicted GLC results

Description	Height (m)	Flow rate (nm^3/h)	Top dim (m)	SPM		SO_2		Temp (°c)	Location	
				mg/Nm^3	kg/h	mg/Nm^3	kg/h		*X*	*Y*
30 t/day FBD	30	12,400	0.5 dia.	150	1.8	363	4.5	80	0	0
3 t/day FBD	12	1250	0.3 * 0.3	150	0.1°	363	0.45	80	92	2

formation being surrounded by saline water on either side and freshwater has been very thin in the locality.

Impacts of Ecology

The existing and proposed core zones are the sea beach and inland areas close to the beach. The inland areas are covered by coconut groves and backwaters. In addition, coconut trees are present at the edges of the beach. In order to carry out mining, the coconut trees will have to be cut down. The herbs and shrubs growing on the beach and inland will also have to be removed. Due to mining the beach fauna (consisting of crabs, mole crabs, bivalves, and small gastropods) will perish. Similarly, the benthic flora and fauna in mining areas in the backwaters will also perish due to mining. However, the effects of mining will be temporary. The coconut trees which will be cut down will be replaced by new saplings after backfilling the mined out areas. Ipomoea pes-caprae and spinifexsps, which are the main plants growing on the sand, will be planted soon after backfilling to stabilize the sand. Seeds of other plants are airborne and will recolonise the backfilled areas within a few months. Larval forms of the beach fauna are present in the sea water and will start recolonising the backfilled areas within a few days after completion of mining. The air pollutants released by diesel powered machinery will be of very small quantity and will be easily diluted and will have no impacts on the ecosystems.

Impacts on Soil and Agriculture

The core zone soil is basically sandy soil. The mining will involve extraction of this sandy soil, and dumping back the tailings in the mined out areas. Since the heavy mineral extraction is a simple physical process, the sand which is dumped back will not differ chemically from the pre-mining sand except that the heavy minerals are no longer present. The physical changes which will occur will be minor and will have no lasting impacts. Mining will involve cutting down of coconut trees leading to loss in coconut production. But these trees will be placed by new saplings of improved variety which will actually improve the agricultural yield. The emission from MSP is also too less to have any impact on the soil or agriculture production in the study area.

Land Use

Excavated land will be subsequently reclaimed by backfilling with reject tailings. Backfilling is integrated into operating system. Land areas under the four blocks are

Table 6 Mining stage analysis

Mining blocks	Land									
	Total excavated area	Pre-mining stage					Post-mining/operational stage			
		1	2	3	4	5	1	2	3	5
Block 2	35.70	25.7	0	10	0	0	26.418	0	8.390	0.892
Block 4	31.933	25	0	6.933	0	0	23.629	0	7.504	0.799
Block 6	11.76	3.76	0	7.8	0	0.2	8.583	0	2.726	0.45
Block 8	0	0	0	0	0	0	0	0	0	0
Total	79.393	54.46	0	24.733	0	0.2	58.632	0	18.62	2.141

devoid of forest land. In Block 2 existing infrastructure, e.g., guest house, roads, mineral separation plant, etc., exists. Out of 402.76 ha lease area in four blocks, proposed excavation shall take place in 322.76 ha land in phases. Substantial quantity of this land is now locked under settlements (villages) and agriculture.

Five yearly land use alteration plan in all the two blocks is in Table 6.

Land use category:

1 Agriculture land
2 Water body (T.S. Canal + backwater + sea wall approach canal)
3 Settlement (land under villages/resettlement area of outsets)
4 Barren sandy beaches
5 Others (mainly roads)

Conclusion

With the increase of extent of mining activities in Chavara, the following changes in socioeconomic features are expected to take place especially within 2 km from beach stretch. Uprooting of villages from the proposed excavation area and settlement elsewhere shall impart profound disturbance not only to the people who are directly affected but also secondary establishment. Distance/location correlation with amenities (hospitals/school, etc.) shall be disturbed at least temporarily. The project is not going to cause any damage to the existing agricultural situation. Agriculture will get a boost due to increase in agricultural land in backfilled area.

The project is going to have a positive impact on consumption behavior by the way of raising average consumption and income through multiplier effect. The project is likely to bring about positive changes in lifestyle and quality of people located in the area, especially around the proposed blocks. People in the study area perceived that the project will help in the development of social infrastructures.

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Research Need on Environmental Gains in Conservation-Induced Relocation

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Abstract Relocations are made for developmental- and conservation-induced scenario. Conservation-induced relocations are different from developmental-induced relocations, in the sense that site is vacated due to it is environmentally improved. There are a lot of studies on social impact of conservation-induced relocation, but very few studies have been undertaken on environmental gains through it. With more emphasis on maintaining ecological balance and sustenance of biodiversity, nowadays conservation-induced relocation is taking place, specially, within the protected areas. Therefore, research to assess ecological and environmental gains is needed, so as to judge objectively very aim of such relocation. Studies related to pros and cons, need and necessities, and areas of existing studies about relocation for biodiversity conservation with reference to protected areas have been dealt in this paper. Based on the above studies, broader fields are assessed, in which further research and study are required, toward environmental gains through such relocation.

Introduction

Protected areas are considered to be biodiversity hub of planet earth. Protected areas, which today accounts for only 1.4% of the Earth's surface, are home to almost half of the plant species and more than one-third of all vertebrates (Heltberg 2001). Ever since the publication of Hardin's articles 'The Tragedy of the Commons', there has been a growing debate on common pool resources, property rights, and resource degradation. The concept has been used to explain

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overexploitation of forests and fisheries, overgrazing, air and water pollution, abuse of public lands, population problems, extinction of species, and other problem of resource misallocation (Stevenson 1991). Due to overexploitation of natural resources, of the protected areas, voluntary conservation-induced relocation is used as a management tool.

The fragile nature of biodiversity in many nature reserves, ongoing conflicts, and the demand from people for better living standards necessitate the conservation community to examine relocation as a possible conservation solution (Karanth 2002; Karanth and Karanth 2007). There are two opposite sides of conservation-induced relocation; first socialists and second biologists. Both have almost antagonizing views over the subject. There is a dearth of studies about conservation-induced relocation, especially environmental gains of such relocation. This paper deliberates about the need for research and studies about environmental and ecological gains of conservation relocations, so as to have a more qualitative assessment of the issues.

Relocation

Relocation of the people is broadly classified into two categories, i.e., development-induced relocation (DIR) and conservation-induced relocation (CIR). Conceptually development-induced and conservation-induced displacements are indistinguishable, either from the perspective of the state (both are due to state management of resources as part of plans to increase prosperity and well-being) or from the point of view of people evicted (for whom the precise cause of eviction is of little importance) (Brockington and Igoe 2006). Although DIR and CIR have above similarities, they differ in nature, as ecologically and environmentally the land vacated due to relocation undergoes change. The characteristic change in DIR is totally different from original land use, e.g., in construction of irrigation dam, the land is submerged and has adverse environmental impact, whereas in CIR the vacated site is environmentally improved.

Protected Areas

A protected area is a clearly defined geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (IUCN Definition 2008). Protected areas—national parks, wilderness areas, community conserved areas, nature reserves, and so on—are a mainstay of biodiversity conservation, while also contributing to people's livelihoods, particularly at the local level. Protected areas are at the core of efforts towards conserving nature and the services it provides us—food, clean water supply, medicines, and protection from the impacts of natural disasters. Their role in helping mitigate and adapt to climate change is also increasingly recognized; it has been estimated that the global network of protected areas stores at least 15% of terrestrial carbon. Protected areas are considered to be biodiversity hub of planet earth. Protected areas, which today accounts for only 1.4% of the Earth's surface, are home to almost half of the plant species and more than one-third of all vertebrates (Heltberg 2001).

India also has ten biogeographic realms and is one of 17 mega-diversity countries that together support two-thirds of the world's biological resources (Rodgers and Panwar 1988; Briggs 2003). Thirty-three percent of the country's 49,219 plant species are endemic (MoEF 1999). Although India covers just 2.4% of the Earth's area, it harbors 7.3% of the world's terrestrial vertebrate species and 89,451 faunal species (MoEF 2000). India has several charismatic mammal species, including 40% of the world's tigers, and most of the world's Asian elephants. Overall, some estimates suggest that 20% of Indian mammal species face imminent extinction, and several have already disappeared from over 90% of their historic range (Madhusudan and Mishra 2003). India has less than 5% under-protected areas, but harbors more than 50% of its biodiversity. This calls for better protection and management of these sanctum sanctorum areas for conservation of biodiversity and sustainable use of natural resources.

Classification of Protected Areas

Based on objects, purpose of constitution and level of protection, PAs are classified into various categories. The International Union for the Conservation of Nature and Natural Resources (IUCN) protected area management categories are a framework for organizing and understanding protected lands around the world. The categories came into to being following many efforts to establish a "common understanding of protected areas" when countries had very different ways of looking at protected areas, used different terms, and assigned different meanings to similar or identical terms. There are six categories (IUCN published its revision of category definitions in 2008) into which protected lands can be sorted.

India has the following kinds of protected areas, in the sense of the word designated by IUCN:

National parks (IUCN Category II): India's first national park was Hailey National Park, now Jim Corbett National Park, established in 1935. By 1970, India had five national parks; today it has over 120 national parks. All national park lands then encompassed a total 39,919 km^2 (15,413 sq mi), comprising 1.21% of India's total surface area (MoEF website). Animal sanctuary (IUCN Category IV): India has over 500 animal sanctuaries, referred to as Wildlife Sanctuaries (MoEF website).
Biosphere reserve IUCN (Category V): There are 18 biosphere reserves in India.
Reserved forests and protected forest (IUCN Category IV or VI, depending on protection accorded): These are forested lands where logging, hunting, grazing, and other activities may be permitted on a sustainable basis to members of certain

communities. In reserved forests, explicit permission is required for such activities. In protected forests, such activities are allowed unless explicitly prohibited. Thus, in general reserved forests enjoy a higher degree of protection with respect to protected forests (Indian Forest Act 1927).
Conservation Reserve and Community Reserve (IUCN Category V and VI, respectively): These are areas adjoining existing protected areas which are of ecological value and can act as migration corridors, or buffer zone. Conservation reserves are designated government-owned land from where communities may earn a subsistence, while community reserves are on mixed government/private lands. Community reserves are the only privately held land accorded protection by the government of India (Indian Forest Act 1927).
Village and panchayat forests (IUCN Category VI): These are forested lands administered by a village or a panchayat on a sustainable basis, with the habitat, flora and fauna being accorded some degree of protection by the managing community (Indian Forest Act 1927).

Need for Conservation of Biodiversity

Why is there a need to conserve biodiversity? The reasons are neither obvious nor widely agreed upon. Environmental philosophers identify two very different sets of arguments, based on the utilitarian (or instrumental) versus the intrinsic (or inherent) value of nature. The utilitarian value of nature refers to the product or function that nature can provide, whereas intrinsic value inheres in the natural object or system itself, irrespective of whether it has any use. Arguments for conserving biodiversity that are based on the utilitarian value are often labeled anthropocentric (human-centered), whereas the arguments predicated on intrinsic value are often called bio-centric (or eco-centric) since the value exists independent of its use to human beings. The utilitarian value of biodiversity may be divided into four basic categories: goods, services, information, and spiritualism (Table 1) (Mulder and Coppolillo 2004). Intrinsic value is a much more subjective matter. While most people take the intrinsic value of humans for granted, the view that "Nature" (often personalized in this sense) has inherent rights and is as such subject to the same moral, ethical, and legal protection afforded humans is more controversial.

Table 1 Categories of utilitarian values

Category	Examples
Goods	Food, fuel, fiber, medicine
Services	Pollination, recycling, nitrogen fixation, homeostatic regulation, carbon storage
Information	Genetic engineering, applied biology, pure science
Psycho-spiritual	Aesthetic beauty, religious awe, scientific knowledge, recreation, tourism

Biodiversity is to be conserved for maintaining the following services:

Maintenance of ecosystem includes recycling and storage of nutrients, combating pollution, stabilizing climate, protecting water resources, formation and protection of soil, and maintaining eco-balance. Provider of biological resources includes provision of medicines and pharmaceuticals, food, ornamental plants, wood products, breeding stock and diversity of species, ecosystem, and genes.

Social benefits include recreation and tourism, cultural value, and education and research (Cardinale et al. 2012).

Need for Conservation-Induced Relocation

The importance of biodiversity conservation has been discussed as above. Most of the biodiversities in the present days are within the limits of protected areas. These protected areas account for less than 5% of the geographical area of the India. Globally, large terrestrial mammals are among the most threatened taxa in the world, with 25% of species facing extinction (Ceballos et al. 2005; Schipper et al. 2008). Recent studies suggest that South Asia harbors the most threatened terrestrial mammals (Schipper et al. 2008). For India, in particular, conservative estimates suggest that 20% of large mammal species may face extinction, and several species have already disappeared from over 90% of their original range (Madhusudan and Mishra 2003). The Indian subcontinent harbors more than 500 mammal species, but also has a 'modern' conservation history of regulating land uses to protect natural areas that date back over a century (Blythe 1863; Jerdan 1874; Russell 1900; Prater 1948; Stebbing 1920; Rangarajan 2001).

The tiger (Panthera tigris) or the greater one-horned rhino (Rhinoceros unicornis) occupy just one to five percent of their historical range. Races of some species such as the Asian lion (Panthera leo persica) and the hardground barasingha (Cervus duvauceli branderi) are confined to single site, microscopic remnants of a once vast range (Divyabhanusinh 2005; Karanth 2006). In Sariska Tiger Reserve, adverse changes in vegetation structure and plant species composition were caused by chronic biomass extraction that was likely affecting forest avifauna as well (Kumar and Shahabuddin 2005). The Biligiri Rangan Hills Temple Sanctuary in southern India reports reduced recruitment of some extracted NTFP species and changing tree species composition of forests due to long-term use (Murali et al. 1996; Shankar et al. 1998). Studies in Pin Valley National Park in the Indian Himalaya indicate that there may be competition for pastures between domestic goats/sheep and wild ibex, given the coincidence of diet choice (Bagchi et al. 2004).

Ever since the publication of Hardin's articles 'The Tragedy of the Commons', there has been a growing debate on common pool resources, property rights, and resource degradation. The concept has been used to explain overexploitation of forests and fisheries, overgrazing, air and water pollution, abuse of public lands, population problems, extinction of species, and other problem of resource misallocation (Stevenson 1991). When property rights to natural resources are absent and unenforced, i.e., when there is open access, no individual bears the full cost of resource degradation. The result is 'free riding' and overexploitation, what Hardin termed the 'Tragedy of the Commons' (Hardin 1968).

Available reports suggest that between 50 and 100% of stricter protected areas in South America and Asia are used or occupied by people (Kothari et al. 1989; Amend and Amend 1995; Bruner et al. 2001; Rao et al. 2002; Bedunah and Schmidt 2004). Growing human population and shrinking natural resources have disturbed ecological balance in some areas. There are many studies which suggest it. An increasing number of scientific studies point to the habitat degradation caused by biomass extraction such as grazing, fuelwood collection, and commercial non-timber forest produce (NTFP) extraction inside areas, set aside for biodiversity conservation (Siebert 2004; Karanth et al. 2005).

Biologists therefore emphasize the fact that *some* amount of inviolate zone (strictly protected area) is required to maintain the entire spectrum of biodiversity as well as to minimize conflicts with large mammalian fauna (Terborgh et al. 2002; Ministry of Environment and Forests 2005). The fragile nature of biodiversity in many nature reserves, ongoing conflicts, and the demand from people for better living standards necessitates the conservation community and examines relocation as a possible conservation solution (Karanth 2002; Karanth and Karanth 2007).

It is evident that human activities in some parts of the protected areas have affected habitat and ecology adversely. People living within these protected areas for their economic well-being have also been opting to move voluntarily out of the area. Case of people willing to be relocated appears to be a win–win situation for the both park managers and people. The National Tiger Conservation Authority of India has come up with legal provisions for voluntary relocation from Tiger Reserves. The provisions therein incorporate willingness of people, social, and ecological studies to make the whole process transparent and people friendly.

Following are provisions made in section 38 V (5) Wildlife (Protection) Act 1972:

Save as for voluntary relocation on mutually agreed terms and conditions provided that such terms and conditions satisfy the requirements laid down in this subsection; no Scheduled Tribes or other forest dwellers shall be resettled or have their rights adversely affected for the purpose of creating inviolate areas for tiger conservation unless:

(i) The process of recognition and determination of rights and acquisition of land or forest rights of the Scheduled Tribes and such other forest dwelling persons is complete;
(ii) The concerned agencies of the State Government, in exercise of their powers under this act, establish with the consent of the Scheduled Tribes and such other forest dwellers in the area, and in consultation with an ecological and social scientists familiar with the area, that the activities of the Scheduled Tribes and other forest dwellers or the impact of their presence upon wild animals are sufficient to cause irreversible damage and shall threaten the existence of tigers and their habitat;

(iii) The State Government, after obtaining the consent of the Scheduled Tribes and other forest dwellers inhabiting the area, and in consultation with an independent ecological and social scientist familiar with the area, has come to a conclusion that other reasonable options of co-existence are not available;
(iv) Resettlement or alternative package has been prepared to provide the livelihood for the affected individuals and communities and fulfills the requirements given in the National Relief and Rehabilitation Policy;
(v) The informed consent of the Gramsabha concerned, and of the persons affected, to the resettlement program has been obtained; and
(vi) The facilities and land allocation at the resettlement location are provided under the said program, otherwise their existing rights shall not be interfered with (Wild life (Protection) Act 1972, Section 38 V (5)).

Need for Study of Environmental Gains Due to CIR

CIR even being a contagious issue has philosophers both for and against it, but there is hardly any complete and detailed study about the consequences. It has taken many months of burrowing through libraries, reading through back issues of journals and trawling through bibliographic databases to produce this list. Just as the literature is not well ordered, the activities of researchers examining relocation from protected areas have also not been systematic. Only recently, Schmidt-Soltau's work (2005a), there has been an attempt to build up a retrospective assessment of the patterns of eviction (Brockington et al. 2006). There is an extraordinary dearth of good information about the social impacts of protected areas. Protected areas have expanded threefold in recent years, and the stricter category 1–4 protected areas now some 49,000 and cover 6% of the land surface of the planet. One should expect this to have involved some evictions. Yet when two of us recently reviewed as much literature on protected area displacements as we could, we found just under 250 books and papers containing information on just over 150 protected areas. A significant proportion of reports and case material (nearly half) merely stated that people had been moved. There was no further discussion of these moves, let alone good investigation of their consequences (Brockington et al. 2006).

Only a few studies, that we are aware of, systematically use consistent methodology to assess involuntary resettlements and evictions from protected areas at the regional level (Cernea and Schmidt-Soltau 2003, 2006). We now review the main environmental, socioeconomic, and other impacts of the displacement of local communities from PAs in India. As far as possible, we do this for both the old and the new sites (before and after relocation). Unfortunately, the information is rather incomplete, as we found a very few studies of post-relocation, and almost none have assessed the situation over a long-term period (Lasgorceix and Kothari 2009). In India, there is as yet no full-length study of conservation-related displacement that can compare with those in eastern or southern Africa. In Tanzania and South Africa, cases of forceful eviction of pastoral peoples from game reserves are becoming increasingly common (Carruthers 1995; Neumann 1998).

There could be two possible reasons for the paucity of cases. Either few cases have been reported because few have happened, or eviction has been ignored. The appropriate answer may well vary according to country and region. We will argue below that in some regions there is good evidence that eviction from protected areas has been substantially overlooked. Second, in many cases the quality of the information is poor. A significant proportion of reports and case material (nearly half) merely stated that people had been moved. There was no further discussion of these moves, let alone good investigation of their consequences. This sort of report might be found in conservation literature in which the movement of people was mentioned in connection with the establishment of a new protected area. But it also characterized a significant proportion of the literature about indigenous peoples. Much of this was protest literature, whose purpose was to alert the world to the losses of indigenous groups. The significance of such events for livelihoods and cultures is often not explored (and for good reason, the main impacts will be obvious) nor are methods made clear (again for good reason, these are not academic publications). Third, and most importantly, this literature is not (yet) a catalogue. These works are diffused and often hard to locate. It has taken many months of burrowing through libraries, reading through back issues of journals and trawling through bibliographic databases to produce this list. Just as the literature is not well ordered, the activities of researchers examining relocation from protected areas have also not been systematic. Only recently, Schmidt-Soltau's work (2005a), there has been an attempt to build up a retrospective assessment of the patterns of eviction, and this is only for one region, and, as we shall see, from an unusually complete coverage of protected areas in existence.

Countless workshops, lectures, and discussions delved into topics such as poverty alleviation, social injustice, indigenous peoples' rights, community management of protected areas, and gender equity in conservation. All these have their place in a global agenda but for me they dominated and drowned out the discussion of themes more directly related to conserving nonhuman life on this planet (Terborgh 2004). Detailed quantitative assessments of the consequences of displacement for conservation are few, the literature on the historical erasures and reinventions of place, people and landscape is rich (Carruthers 1995; Ranger 1999). This signifies that studies related to conservation-induced relocation are few and whatever has been taken place deals with social angle only and almost negligible about ecological point of view.

Conclusion

Biodiversity is an important issue and needs to be conserved. Globally protected areas are harboring bulk of biodiversity, which is in percentage terms is too large in comparison to the area of protected areas. In India too the scenario is similar to it. Therefore, efficient protection and management of these areas are of utmost importance. As a conservation tool, voluntary relocation of human population from such area has been on the agenda of biologist. This kind of conservation-induced relocation has two facets of it, namely social and ecological sides. Socialist and biologist have antagonizing views over CIR. As the review of literature reveals that there is paucity of enough literature on both the angles. Whatever studies are available are not comprehensive and focused on multilateral issues.

Among the available literature, focus has been mostly towards human-centric issues and no concrete study of ecological and environmental gains at vacated site has been taken up. The authors could not find any study/research which deliberates on this issue. It is therefore required to have ecological and environmental studies, taking into account pre- and post-relocation scenario of the vacated site and develop a model for future reference to assess environmental gains in similar cases.

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Environmental Issues Due to Fire in Coal Mines: Its Impact and Suggestions for Implementing Precautionary and Control Measures

R.V.K. Singh, D.D. Tripathi, N.K. Mohalik, A. Khalkho, J. Pandey and R.K. Mishra

Abstract There are several factors responsible for polluting the environment and creating pollution; and especially in coalfields, fire in coal mines is one significant of them. Presently, about 70% of the production of coal is being carried out by opencast mining (from coal benches) over underground developed galleries in Jharia and its adjoining coalfields. Most of the mines developed earlier by underground are presently being excavated by opencast method to meet the production target. Due to intrinsic characteristics of coal with add-on of prevailing practices of mining operation, the spontaneous heating/fire has occurred in most of the galleries of developed coal seams. Fire in the developed galleries affects the normal production during excavation by the opencast method. It releases noxious gases, heat, smoke and dust and poses a serious health hazard. Fire in mines also causes direct loss of equipment, damage to the surface structure and loss of country's precious coal reserves. In addition to these, it affects the normal production. The objective of this paper is to describe the environmental impacts due to fire in coal mines, and issues that affect society as well as to render suggestions for taking precautionary and control measures.

Introduction

The problem of spontaneous combustion is very common in coal mines worldwide. Coal faces are exposed to the atmosphere and react with oxygen (air) as a result of which it catches fire, depending on the incubation period, the quality of the coal and other factors inherently associated with the coal. The phenomenon of the spontaneous combustion is caused by two interrelated process, viz. the interaction between oxygen and coal (oxidation) and the exothermic reaction (heat shedding process), leading to heat build-up in coal due to the property of its non-conductivity

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of heat. In Indian coal mines, spontaneous combustion (fires) commonly occurs in the underground-developed workings during extraction by the opencast methods. Spontaneous combustion incidence can occur anywhere in coal mines (underground and surface) during or after mining operations. Spontaneous heating initiates in coal mines particularly in pillars, in developed galleries, faces, benches, stockpiles, and dumps. Environment is badly affected due to release of noxious gases in all the above-mentioned cases after the occurrence of spontaneous heating (Banerjee 1985). Different types of fire require a different approach for prevention and control of spontaneous heating. In Indian mines, spontaneous combustion/fires in the developed galleries worked by opencast method pose a serious problem. When the exposed developed gallery mouth is left idle for a longer time after extraction of coal, then the fire aggravates very rapidly and damage the surface structure such as roadways, buildings and important structures available on the surface. One such case that happened in Giddi colliery being operated by Central Coalfields Limited has been discussed in this paper.

Environmental Pollution

Fire affects the direct loss of equipment, damage to surface structure and loss of country's precious coal reserves. In addition to these, they affect normal production and pollute the environment. Due to fire in coal mines (underground and opencast), the basic elements of environment, i.e. air, water and land, are seriously affected. Fire continues and causes atmospheric and thermal pollution. Coal that is burning in the underground as well as surface mines around the world is adding tonnes of soot, toxic fumes and greenhouse (GHGs) into the atmosphere. Coal fires burn to produce large quantities of CO_2 along with several other gases such as oxides and dioxides of sulphur and nitrogen. CO_2 from coal fires contributes significantly to the greenhouse effect, a phenomenon which is a prime concern for Planet Earth. It is worth mentioning here that complete combustion of 1 gm of coal having about 70% carbon content produces about 3 gm of CO_2 and thus burning of one million tonne of coal per annum can produce 3×10^9 kg of CO_2. Quantitative global estimate of the amount of CO_2 produced due to fire in coal mines is difficult to access. However, main greenhouse gas (CO_2) is occurring in China producing 2−3% of the world's total annual production of CO_2. This was more than double the CO_2 produced by the Netherland from all source of CO_2. A Dutch team concluded that underground fires in China release up to 360 Mt of carbon dioxide.

Air—Burning of coal releases noxious gases like carbon monoxide, oxides of nitrogen and sulphur, unburnt hydrocarbons and other particulate and heat are being continuously discharged to the atmosphere and polluting the environment.

Water—Fire pollutes water, increasing its acidity as well as contaminates it with tarry distillation products. Due to the presence of 1–2% sulphur in coal in the form of pyrites, mine water may be acidic: it cannot be used directly and requires some treatment by various methods.

Land—Due to fire in the underground, surface structure is damaged; cracks have been developed and nearby vegetation is badly affected due to heat, smoke, dust and high temperature causing soil sterilisation. Surface structures like production pits, plants, railways, jorebeds, roads and houses are affected due to fire.

The environmental problem is caused by fires mainly from the release of noxious gases into the atmosphere. In situ coal is a mixture of mineral matter and coal matrix; the main constituents are not only carbon and hydrogen but also the presence of small quantities of oxygen, nitrogen, sulphur and other trace elements. When coal burns, the carbon is converted to CO or CO_2, sulphur mainly to SO_2 and the nitrogen gets converted to NO_2. But in cases of mine fire, what proportion of coal gets burnt or distilled depends upon the condition of combustion. If the fire is of shallow depth then the formation of CO and CO_2 will be high due to complete combustion. On the other hand, a deep-seated fire of a thick seam may result in incomplete combustion and renders more CO. The emissions from fire areas consist of toxic gases as SO_2, NO_X, CO/CO_2 and particulate matter of soot and condensed vapours. Fine ash particles are also emitted if a strong draught is created by the fire and the resistance of the air path in the burnt bed gets reduced. This phenomenon is seen when a burning bed of coal seam is excavated out by a shovel in the developed pillars being worked by opencast mining (Singh 2013).

The coal seam contains higher percentage of sulphur (1–2%) in the form of pyrites, which oxidises easily in the presence of air and moisture at ordinary temperature as shown by the following equation:

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2H_2SO_4 + 2FeSO_4 + 316\ \text{kcal}$$

The above reaction is highly exothermic compared to oxidation of carbon:

$$C + O_2 \rightarrow CO_2 + 94.5\ \text{kcal}.$$

Thus, the oxidation of pyrites accelerates the in situ temperature very fast and also cracks up the solid coal mass—since the volume of the product is more than the volume of the reactant. This increases the exposed coal surface area and thereby enhances the rate of rise of temperature favouring spontaneous heating. Direct hazards to humans and the environment posed by coal fires include emissions of pollutants, such as CO, CO_2, nitrogen oxides, particulate matter, sulphur dioxide, toxic organic compounds and potentially toxic trace elements, such as arsenic, Hg and selenium (Finkelman 2004).

Case Study

There are several fire problems existing in different coal mines, where fire creates environmental pollution, damage to the environment and loss of natural resources. Here, authors are presenting a case study of fire at Giddi colliery, Argada Area, CCL, where successful site-specific comprehensive technology has been applied and the fire was totally combated/controlled. The project Giddi 'A' is accessible from Ramgarh Ranchi Road and Patratu railway station which lies on the National Highway No. 33. The project was started in June 1958 for the operation of both underground mine and mechanised opencast mine. Mining activities were started in both underground and opencast mines in Argada, Argada-A, Sirka, Bansgarha, Hatidari and Semana seam. Underground mine working was stopped in March 1984, whereas coal production continued by opencast only. Fire was noticed in the year 1997 near Giddi workshop and surface was subsided from the quarry side. The colliery authority tried to control the fire using overburden material. But after some time, filled up overburden material was also heated and fire reached very near to workshop and sub-station (11).

Location

The Karanpura coalfields in Jharkhand form the westernmost patch of the lower Gondwana of the Damoder Valley situated within latitude 23° 28′ and 23° 56′ North and longitude 84° 46′ and 85° 28′ East. This coalfield is extended over an area of 550 sq. miles (1424.50 km^2). An elongated patch of the Lower Gondwana rocks covers an area of 75 sq. miles (194.25 km^2). Giddi-A block comprises almost a rectangular patch 1.75 sq. miles (4.50 km^2) situated in the district Hazaribagh, Jharkhand. The Damodar River which forms the western and southern block boundaries takes 'Z' blend here. The southern margin is also marked by the confluence of Damodar River and Nakri Nallah. In the northeast, the mine is bounded by the mining lease of Religara colliery (Giddi-B block). To the north lies "Kurkutta Block", on the west the subleases of Khas Karanpura and the Associated Karanpura collieries are situated. To the southwest and south Sounda B block, working mines of Bhurkunda collieries of CCL are lying.

Geology of the Seam

The coal seam occurring in Giddi-A block belongs to Barakar formation. Thirty-two coal seams have been proved varying in thickness from 0.76 to 24.28 m. Out of 32 seams, the Sirka, Argada, Argada-A and Argada-B is considered as working seams due to their thickness and persistence. Argada seam varies from 15.85 to 24.28 m. Parting between Sirka seam and Argada seam varies from 43.28

to 62.33 m. Argada-A seam varies in thickness from 7.92 to 13.89 m; and parting between Argada and Argada-A seam varies from 18.6 to 45.90 m. The seam wise thickness, gradient, grade and present status are given below.

Particulars	Name of Seam			
	Sirka	Argada	Argada-A	Argada-B
Average thickness (m)	12.0	18.0–20.0	10.0	6.0
Gradient	1:3.54	1:2.96	1:2.75	1:2.75
Direction	N70° 29′W	N82° 40′W	S85° 30′W	S80°15′W
Grade	B new grades	C–D may be given	C–D in between	C–D G (1–17)
Present status	Standing on pillar	Standing on pillar	Standing on pillar	Virgin
Estimated reserve below Washery (million tonne)	Nil	1.600	1.320	0.125

Scientific Investigation

Fire site of Giddi-A colliery nearby Giddi workshop, substation and Giddi Washery was visited and it was observed that Argada and Argada-A seam have been developed on pillar lying below the Giddi workshop, whereas Argada-A seam extends below Giddi washery and substation also. Both the seam partially quarried by opencast mining method. Argada-B seam is virgin and lying below the Giddi workshop and Giddi substation at a depth of 54 m. Argada seam was quarried before March 1986, whereas Argada-A seam quarried before 1976. Fire is observed in September 1997 near Giddi workshop from the quarry mouth edge due to the presence of loose coal (Fig. 1). The area is subsided near road and workshop which has created several cracks and facilitates passage to ingress of oxygen leading to spontaneous heating/fire. The blazing flame is coming out through the mouth due to further progress of spontaneous heating and chemical chain reaction. Mine authorities tried to control the fire by filling the overburden material but it could not be controlled and the problem became more serious when filling material also got heated near the mining workshop (CSIR-CIMFR Report 2009).

Temperature was measured with the help of Heat Spy Infrared thermometer at different locations near the Giddi workshop, substation, Washery, mine road and the quarry edge (Fig. 2). The maximum temperature was observed as 492 °C near Washery boundary and roadside. Firefighting chemicals/inhibitors have been applied which reduced the flame and to extract the heat near mining workshop. Different chemical inhibitors were mixed with water in different proportions and applied on the blazing flame as per intensity of the fire and site-specific condition. Continuous firefighting operation was carried out for 5–6 months and after that the combated portion was covered with binding material and top soil (Fig. 3).

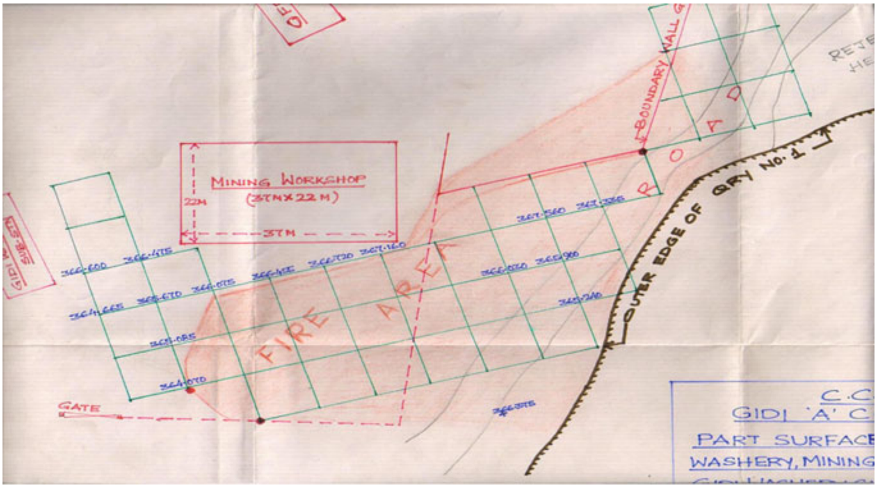

Fig. 1 An overview of fire area near substation, mining workshop and Giddi Washery, CCL

Fig. 2 Thermal investigation using heat Spy infrared thermometer near Giddi substation and mining workshop, CCL

Fig. 3 Fire combated portion treated with binding material with top soil near mining workshop and Giddi power substation, CCL

Results and Discussion

During thermal investigation, it was found that fire was present in most of the portion nearby area of roadways and substation; and fire was under blazing condition near Giddi workshop. Temperature was in the range of 265–307 °C at workshop and 492 °C observed near the washery boundary towards roadside. After application of firefighting chemical inhibitors/additives temperature reduced to the range 35–46 °C. Combated fire surface was treated with different binding materials to minimise the ingress of air which was applied on an area of 3750 m^2 on surface area using 7250 m^3 of topsoil. Detailed thermal profile was marked on surface lay out before application of fire fighting chemicals to the final surface sealing operation as per requirement. Finally, temperature was found to be near about ambient after surface sealing. Mine authorities were trained for application of firefighting chemicals. Suggestion was also given for making two benches using top soil in quarry side for checking the penetration of air from the mouth of gallery and blanketed area should be compacted time to time. Early implementation of the control and combating technology has given successful result for control of fire near

Giddi workshop and substation. After controlling the fire, the valuable national properties like Giddi substation and washery have been salvaged and the environment was also protected from the release of noxious and other greenhouse gases.

Suggestions

As per studies carried out during the project work and site-specific fire condition, the following preventive and control measures are suggested for control of fire and protection of environment:

1. Thermal monitoring should be carried out using Heat Spy Infrared thermometer regularly for detection of fire, so that immediate control measures can be planned as per site situation.
2. Fire should be combated by application of firefighting chemical additives/inhibitors for suppressing the fire and extracting the heat and it should be continued till the temperature reduces to ambient level.
3. Dozing/compaction is very much essential in the compacted area after some interval to minimise the air ingress.
4. Minimum two benches should be formed from bottom to top using top soil in quarry side for checking the ingress of air from the mouth of gallery to save the mine roadways, washery and substation.

Conclusion

After carrying out a scientific investigation for control of fire near my workshop and substation, it is concluded that speedy implementation of the control and combating technology has given successful results. After control of fire, the valuable national property has been saved. Environment was also protected from the release of noxious gases. Under these circumstances, direct application of firefighting chemical inhibitors will be much effective for suppression of flame, extraction of heat and cooling the hot mass. Author has taken a new R&D Project under Planning Commission (earlier); presently, *Niti Aayog* Research work of this project is being continued and rigorous laboratory work is going on.

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Redevelopment of Urban Slum Dwellings: Issues and Challenges

Dhrupad S. Rupwate, Rajnit D. Bhanarkar, Vishakha V. Sakhare and Rahul V. Ralegaonkar

Abstract Urbanization has created a large housing demand of urban poor. Although different stakeholders are involved, there is a challenge to meet the redevelopment of urban slum dwelling projects in an effective manner. The concept is discussed with a case study of a slum in Nagpur City. Physical data was collected from stakeholders (construction material choices and cost incurred) and site monitoring (indoor temperature and light). The study revealed the possible issues and challenges related to project execution, i.e. resource and time management. The outcome of the study is to suggest a suitable strategy for improving the functionality of the project to increase the speed and conserve the resources that ultimately benefit government as well as end user.

Introduction

Urbanization can be termed as by product of economic and social development. Rapid advancements in science and technology have made remarkable changes in the settlement pattern and living habits of the people. Urban areas are viewed as places with potential for greater economic opportunities and improved standard of living in urban areas attracts rural migrants which are leading to the emergence of slums. Slums are the products of failed policies, bad governance, corruption, inappropriate regulation, dysfunctional land markets, unresponsive financial systems and a fundamental lack of political will (Sufaira 2013).

World's population is projected to be 8.1 billion by 2030 out of which 5 billion (61%) of world's population will live in cities and 90% of growth will be in developing countries (UNFPA 2000). Indian urban population will increased to

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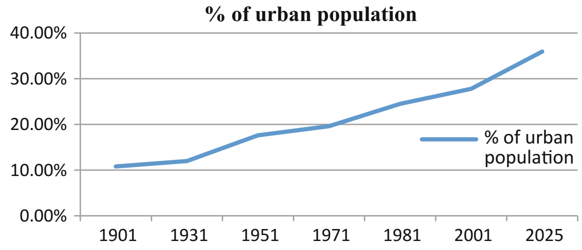


Fig. 1 Growth of urban population in India. *Source* UNFPA 2000

36% by 2025. The trends in growth of urban population can be observed from Fig. 1. And the share of urban population will be as 68.7% of urban population lives in class I cities, 27.8% in medium cities and 9.4% in small towns (Fig. 1). This shows the pace of rapid urbanization in India and challenge to reach needs of growing population.

Problems reinforced with urbanization can be noted as poverty, unemployment, education (illiteracy), crime, waste generation, environmental degradation, pollution, health problems, safety and security, infrastructure and amenities, lack of community sense, social polarity, **HOUSING** (Squatters and Slums). This paper deals with the issue of housing urban poor and redevelopment of urban slum dwellings.

Background and Need of Study

A slum is defined by the United Nations agency UN-HABITAT, "is a run-down area of a city characterized by substandard housing and squalor and lacking in tenure security". Slums were initially viewed as nothing more than nuisance; the economic contribution of slum dwellers was never acknowledged. Slums were treated as refuse of the cities and demolished often for cleaner cities. They were not considered for planning and marked as 'vacant land' in Indian city's Master plans. Till 1970 slums were treated as illegal squatters. Needs of these Informal habitats are not considered for planning various amenities such as housing and other supporting services while subsidized housing is provided for poor through schemes like Subsidized Industrial Housing Scheme (SIHS) 1952, EWS Housing Scheme and LIG Housing Scheme (LIGHS) 1954 (Bouddha Charumitra). After 1970 slum improvement works have come up as slums reappeared after demolition and demolitions are termed as in human. India's Fifth 5-year plan focused on physical improvement of slums. Environmental Improvement in Urban Slums (EIUS) in 1972–73 Integrated with Urban Development Programme (IUDP) improved infrastructure services of notified slums. After 1990s a new concept has evolved. The underlying land of the slums was treated as a resource incentive FSI is given for constructing tenements for sale in open market. Profits generated from the sale of these tenements used for cross-subsidizing the free houses to the slum

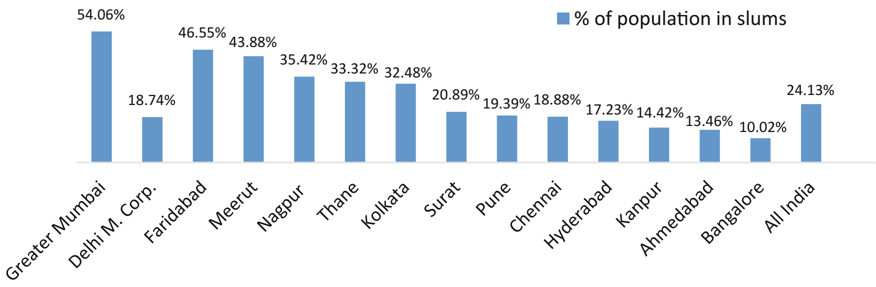


Fig. 2 Percentage of population living in slums of Indian cities

dwellers. Special autonomous Slum Rehabilitation Authority was established to ameliorate the problems of slums dwellers. The Government of Maharashtra appointed a committee chaired by the Chief Secretary of Maharashtra, to devise a scheme to rehabilitate slum dwellers (Fig. 2).

Housing Scenario in India

India is passing through a phase of acute housing shortage like any other developing country. Housing in India varies greatly and reflects the socio-economic mix of its vast population. In the last decade, there has been tremendous growth in the country's housing sector, along with demographic changes, rise in income, growth in the number of nuclear families and urbanization.

According to 11th plan estimate housing requirement in India can be noted as 26.53 million units for 75.01 million households.

Requirements to Achieve the Vision by 2022

By 2022, India needs to develop about 11 crore housing units requiring investment of more than USD 2 trillion or about USD 250–260 billion annual investment until 2022. Urban housing is to account for about 85–90% of the total investments; the focus should be on affordable urban houses, which is 70% of the total urban housing requirement. About 1.7–2.0 lakh hectare of land is expected to be required to fulfil urban housing need by 2022. About 70% of the housing needs till 2022 should be concentrated in ten states. These states are Uttar Pradesh, Bihar, Maharashtra, West Bengal, Madhya Pradesh, Andhra Pradesh, Telangana, Rajasthan, Tamil Nadu and Karnataka (Urban Housing Shortage 2012–17).

The state of Maharashtra is witnessing rapid urbanization. As per National Census 2011, Maharashtra has the highest urban population of more than 5 crore. By the year 2022 the housing need in Maharashtra is expected to grow to 1 crore housing units (50 lakh each in urban and rural), with more of the housing requirements in the urban regions. The State Government has resolved to provide 19 lakh houses by the year 2022, with the main thrust for Economically Weaker Section (EWS), Lower Income Group (LIG) and Middle Income Group (MIG) housing. This time-bound objective has given a dimension of urgency to revise the earlier government housing policy. Thus a new housing policy needs to be in place in view of the new dynamic scenario by defining the role of the State as a Facilitator, Catalyst, Builder and Regulator. As per the census of 2011, out of 3.36 crore census houses 2.98 crore houses were occupied in the State. The population of the rural houses in the total census houses was 52.2 and 47.8% in urban areas. A survey by the National Housing Bank (NHB) reveals a national housing shortage of 18.78 million in 2012–13, with Maharashtra's shortage estimated at 1.94 million houses. Urbanization in Maharashtra has increased from 42.43 to 45.23% in 2001–2010. All indicators project an ever increasing trend of urbanization. All indicators indicate the gravity of the housing deficit in the State particularly in the affordable housing segment and hence affordable housing needs a big push (Source: New Housing Policy and Action Plan 2015).

Strategies for Increasing Supply of Affordable Housing

- Government lands for affordable housing.
- Public–private partnership.
- Employee housing.
- Affordable housing scheme.
- Inclusive housing in all housing projects.
- Rental housing.
- Affordable housing through Town Planning Scheme (TPS)/Special Township (STS) on private.
- And by CIDCO.
- Townships/Industrial Townships/IT Townships by private developers.

Strategies for Optimum Use of Existing Land Resources by Encouraging Redevelopment

- MHADA housing initiative.
- Redevelopment of MHADA transit camp.
- Redevelopment of cessed building.
- Urban renewal scheme.
- The Bombay Development Department crawls redevelopment.
- Slum redevelopment: Slum up gradation, rehabilitation and redevelopment.
- Slum declaration and acquisition of private slums.
- Scheme for D-Class Municipal Corporation and A-Class Municipalities.

- Housing for conservancy workers.
- Land acquired for Special Economic Zone (SEZ) by private developers.
- Development of land owned by Central Government/Central Government Undertaking such as LIC/RBI/ESIC, etc.
- Smart city centres in cities with population of more than 10 lakhs.

Strategies for Improving Quality of Life, Overall Living Standards with Concern for Environment

- Conservation of water, environment and heritage structures.
- Preventing unauthorized/informal housing

Strategies for Ease of Doing Business

- Use of Information Technology (IT) by ULBs.
- Dematerialisation of Transferable Development Rights (TDR).
- Using of land as collateral security.
- Built-up area in lieu of development charges.
- Reimbursement

Objectives of the Study

1. Bring to light the issues and challenges related to the redevelopment projects.
2. Providing a solution for timely completion of projects through resource allocation methods.
3. To study the impact of new technology bricks on the cost of the project.

Methodology

Study Area

Nagpur with total 446 slums out of which 289 are notified as authorized slums. The city has nearly 36% of its population living in these slums. Nagpur stands as fourth largest slum population in the country. It is facing the challenge of providing housing to the slum population. According to City Sanitation Plan (CSP) prepared by Nagpur Municipal Corporation's health department (sanitation) almost 8.58 lakh people living in 1.41 lakh structures in slums have poor basic facilities.

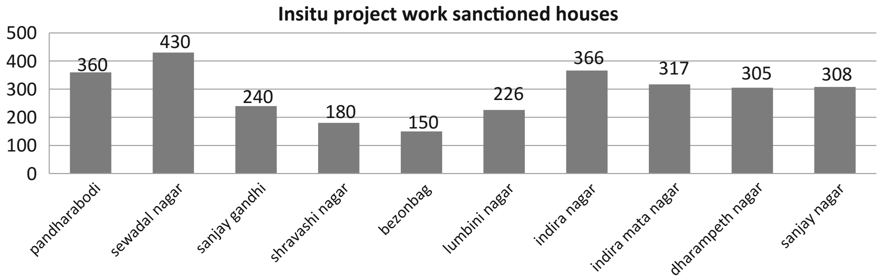
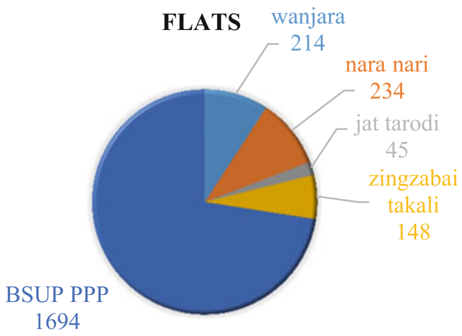


Fig. 3 In situ houses sanctioned at different slums

Fig. 4 Distribution of flats at different areas



Current Project

Government of India approved the construction of 6357 dwelling units with total project cost of Rs. 402.29 crores in the 60th meeting of the Central Sanctioning & Monitoring Committee (CSMC) on 21 February 2009. Out of 6357, 2720 are in situ housing and 3637 is the flat scheme (Fig. 3).

Flat Scheme for Slum Rehabilitation

As per the government's scheme for smart cities, 100 smart cities shall be developed across the country in the next 5 years. Simultaneously, cities in the country have been selected for urban renewal—upgradation of facilities, especially the drainage and sanitation facilities and infrastructure in these parts. Slum Rehabilitation Authority sanctioned 3637 numbers of unit for flat scheme out of 6357 dwelling unit in different regions of Nagpur. For people who do not have their own land and living illegally. For commercial development, land near public area, industrial area, business area is very important. A number of sanctioned flat in different regions are as follows (Fig. 4).

Detail of Money Contribution

The share of GOI, GOM, NMC and beneficiary is as given below:

Total project cost (in lakhs)	Central share (in lakhs)	State share (in lakhs)	NMC share share (in lakhs)	Beneficiary share
40229.26	18286.03	10142.80 + 3657.21 (other charges)	5943.66	2199.55

In this project the cost for one in situ house = 449,724.00 Rs.

Central share for one house (50%) = 224,862 Rs.
State share for one house (30%) = 134,917 Rs.
Beneficiary share in one house (11%) = 49,469 Rs.
Local Body share for one house (9%) = 40,475 Rs.

Total carpet area for one house (sq. feet) = 270–320 sq. feet for a different type of house.

Cost per sq. feet = 1405–1665 Rs.

Sanctioned Cost of Single House Type A

The completion of a house was carried out in four stages. Specifications of work done and the estimate according to schedules have been presented in Table 1. The percentage composition is mentioned as remarks. The progress report and detailed bar charts of work procedure are provided in the later sections.

Cost requirement in four stages is given in Table 1.

One of the sites of ongoing SRA projects in Nagpur that is Pandharabodi has been chosen for study assuming that similar conditions are prevailing in other sites as well, as there are limitations of time and other parameters.

Pandharabodi Area

Sanctioned in situ houses details are below:

- Name of Slum: New Pandharabodi.
- No of Dwelling Units: 360 Dues nos.
- Carpet area of each DUS: 250–300 sq. feet.
- Built-up area of each DUS: 270–350 sq. feet.
- Contractor appointed: 2
- Completed DUS: 150 dunes
- In progress DUS: 55 no. (Fig. 5)

Table 1 Cost requirements at different stages

S. No.	Components	As per schedule	Remark (%)
1	STAGE I: Complete work up to plinth including plinth slab and sintex tank	140,808.77	31.31
2	STAGE II: Complete RCC frame structure up to RCC slab	77,607.01	17.26
3	STAGE III: Complete brick work of 4″ and 6″, internal–external plaster, doors, window, ventilators, kitchen otta, etc.	1,45,330.25	32.32
4	STAGE IV: Full and final bill including painting, tiles, plumbing and electrical fitting extra items complete	85,978.56	19.121
5	TOTAL (Rs.) for type A unit	449,724.59	100
	Difference	449,724.59	

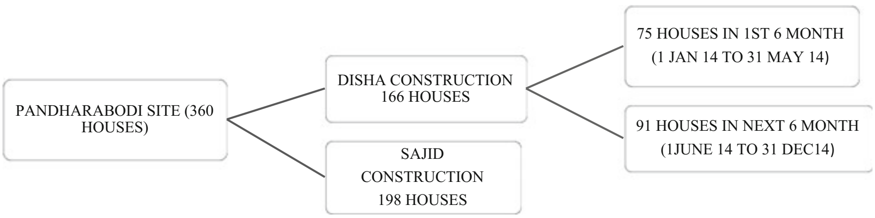


Fig. 5 Flow chart of project for pandharabodi area

Different plans are prepared by NMC for in situ housing, according to plot size available.

Problems on Site During Construction

- Time overrun
- Material quality
- Scarcity of skilled labour
- Problems during operation.

Time Overrun

- Out of 15 houses all are taking more than 6 month for completing work.
- For construction of one house 50–60 days are sufficient.
- In group construction it can be completed in 40–50 days.
- First Government gives a contract of 75 dwelling units out of 166 units for the time of 6 month on 16 November 2013.

Causes of Time Overrun

- Resource Problem.
- Dispute between owner and contractor.
- Poor time management.
- Coordination between Govt. authority and contractor.
- Rework and design changes.
- Delay in revised estimate.
- Delay in handing over site to contractor by owner.
- Bad weather condition.
- Shortage of human resources.
- Shortage of material on site.

Material Quality and Quantity

- Delay of construction due to lack of materials
- Material quality is not tested as recommended as per IS guidelines.
- Unsatisfactory methods of testing bricks and sand are followed.
- Reinforcement and bar bending works are not up to mark.
- Materials were not stored properly and dumped along roadside
- Bricks are not watered and improper construction methods are followed (Fig. 6).

Scarcity of Skilled Labour

The following graphs will give the detailed explanation about the actual number of labourers required to complete the work on time versus the number of labourers employed which again led to stalling of work (Fig. 7).

Fig. 6 Aggregates are mixed with improper graded stones and last picture shows poor mixing of concrete. *Source* Authors

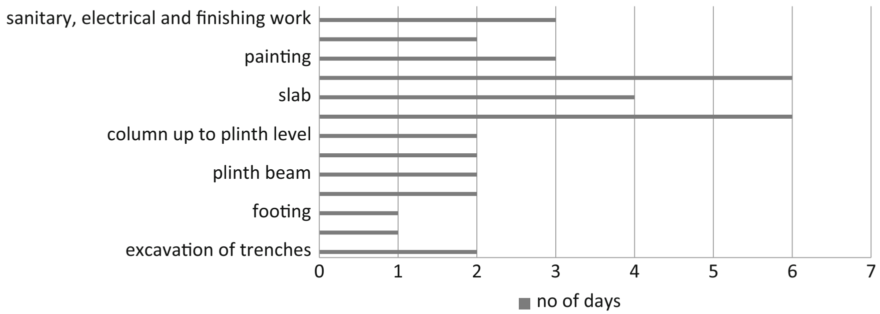


Fig. 7 Activities and time requirement

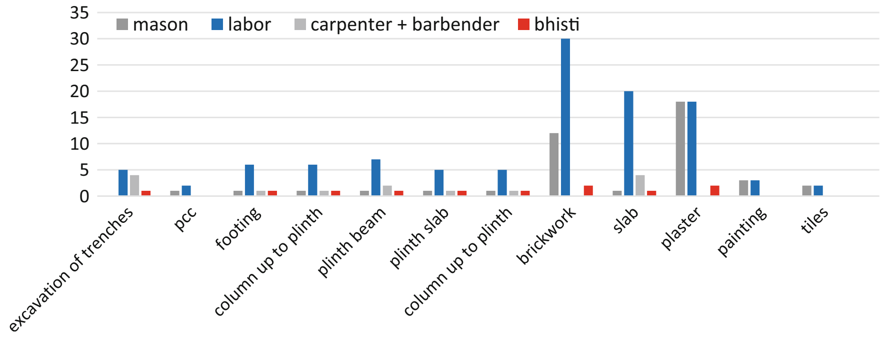


Fig. 8 Activities and human resources requirement

On the basis of work, potential of workers and quantity required for different activity requirements of human resources are calculated. Time required for particular activity and calculation of skilled, semiskilled and unskilled labour are evaluated (Fig. 8).

The human resources requirements from first day to 40 days are displayed. The following chart gives inflation in demand of human resources for the designed result. The buffer is required for healthy progress of project. For reduction of time and human resources the group construction is very important.

Actual labour requirement for single house is 40 working days (Fig. 9).

It can be observed from the charts that it is imperative to use resource levelling/allocation techniques. This deep fluctuation damages the work order. It also becomes difficult to plan things for future endeavours. Planning is a prime aspect when handling such projects.

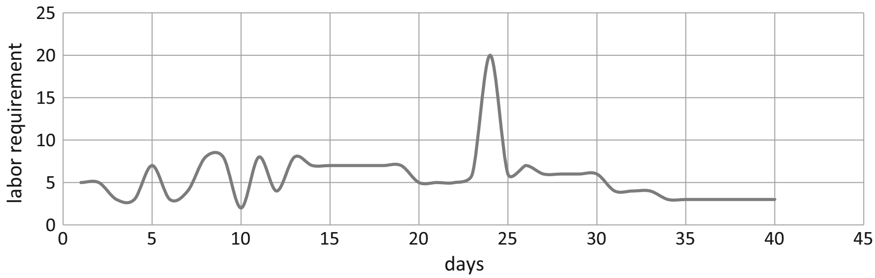


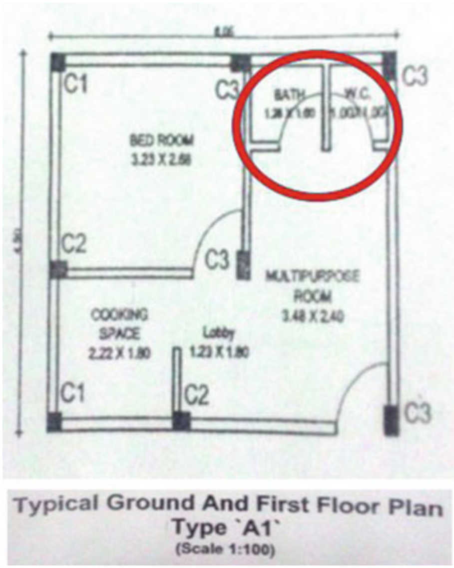
Fig. 9 Human resources require per day for single house

Fig. 10 Seepage of water from joint of beam and brickwork. *Source* Authors

Problems During Operation

- Being a government project, it has provided only a single site engineer for a vast area due to which there was not enough inspection of site leading to dissatisfactory work.
- Daily reports were not submitted as a result of which pending work kept piling on and caused wastage of time the next day.
- Improper storage of materials which lead to misuse and wastage brought work to a standstill on some days (rainy season).
- During the site inspection it was noticed that site engineer responsible left the job for a month and the head mason lead the work of advising and supervising, which in turn again lead to poor quality of work.
- Lack of adequate sanitation facilities for workers.
- Interference of owners and general public in day-to-day activities, the residents interfered in the work demanding small changes in the activities which hampered the progress of the work (Fig. 10).
- Non-compliance to the approved drawings by SRA and challenging and disrupting the work of workers by the owners. Water closets provided were aesthetically not acceptable to the people as they were part of living room as shown in Fig. 11.

Fig. 11 Plan showing closet



- Improper drainage and open drains leading to stoppage of work.
- Seepage of water from recently constructed houses. The joints and beams of brickwork had water seeping through it just after a month it was constructed (image below).
- Delay in sanctioning of money and resources.

Grouping of work

Using software Primavera activity chart has been prepared for a single house as shown in Fig. 12. It can be seen that the activity has started on 5 May and ended 24 June 2015, i.e. 50 days for single house. Details of construction work have been shown in bar chart (Fig. 13).

Construction work for 8 houses was started simultaneously. Activity chart and bar chart for 8 houses have been prepared by primavera software as shown in Figs. 14 and 15; it can be seen that the work was started on 2 January 2014 and completed on 14 March 2014, i.e. 72 days.

It is evident that the construction of 8 houses together as group is time saving and efficient.

Work Breakdown Structure for 75 Houses

See Fig. 16.

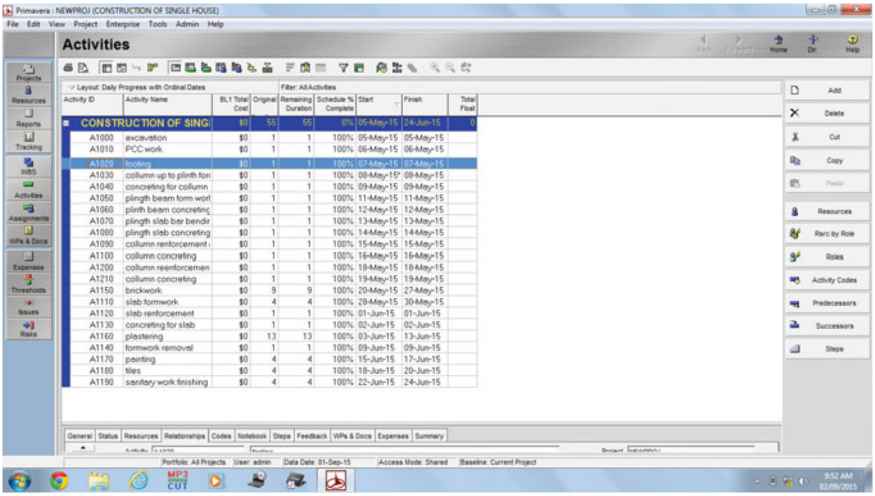


Fig. 12 Activity chart for one house

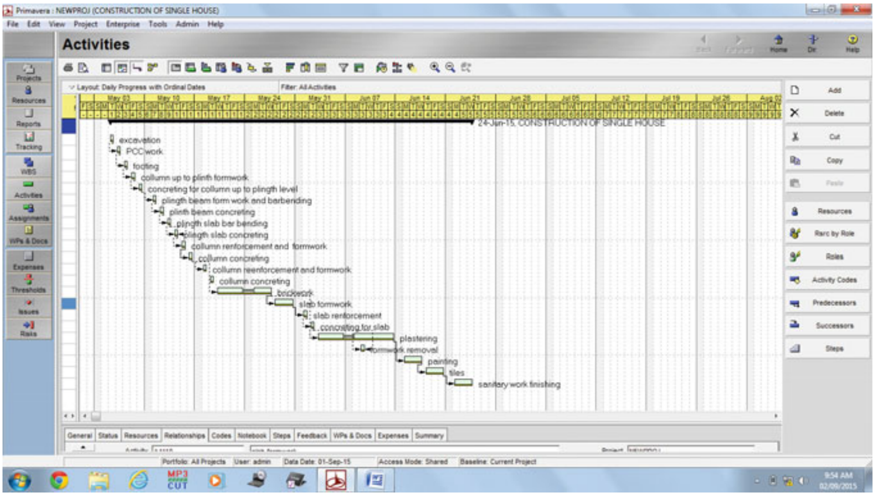


Fig. 13 Bar chart for one house

Limitation

Grouping of houses for construction together was proved to be more time saving; however, there are limitations upfront. The construction of 8 houses studied was in a row, whereas the ongoing project has plots scattered all over

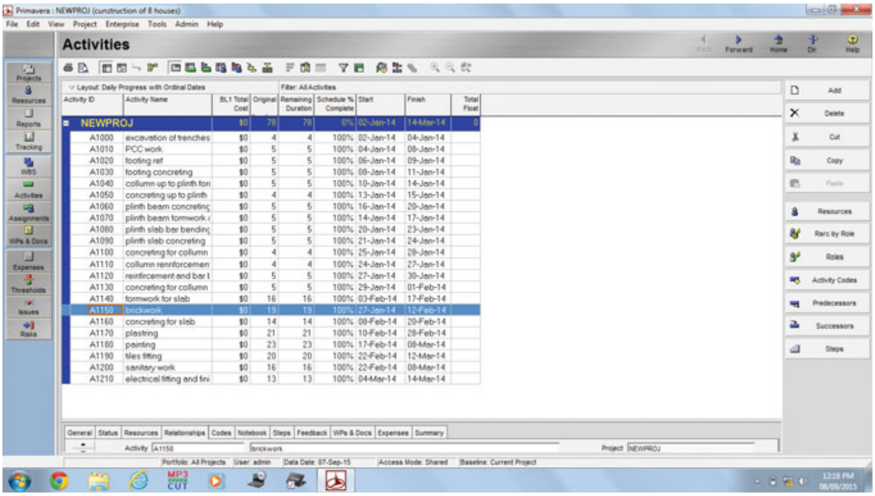


Fig. 14 Activity chart for 8 houses

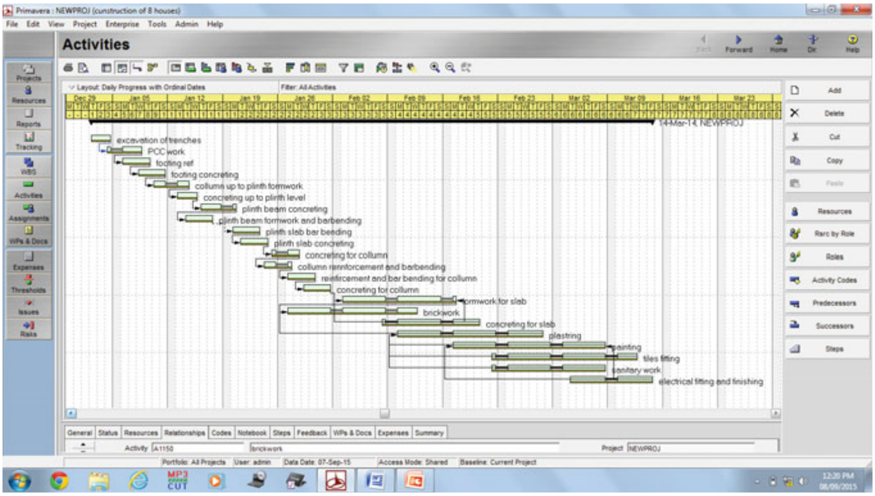


Fig. 15 Bar chart for 8 houses

the slum. Government should be able to provide temporary residence for the dwellers so that grouping of houses can be done and the work would be finished before time.

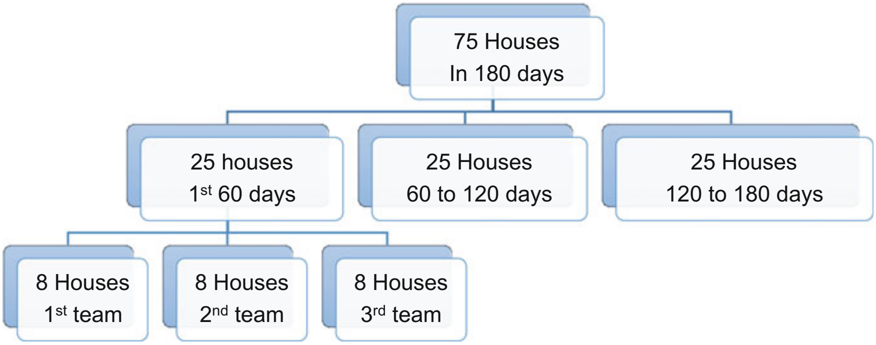


Fig. 16 Flow chart showing work breakdown

Conclusions and Findings

Slum redevelopment projects deal with major allocation of money and resource. Many studies have been done to maximize the efficiency of resource usage, but there exist gaps and limitations on ground; this study has brought up the issues and problems faced on site. The following are few recommendations through which the problems can be rectified.

- Planning and managing skills should not be ignored.
- Resource allocation techniques to be followed.
- Drainage patterns should be looked after.
- Basic requirements of end users should not be ignored.
- Temporary residence for the inhabitants should be provided by government which is both beneficial for construction by grouping house and also dwellers as it is financial burden to them.
- Primavera shows that grouping of houses leads to immense savings of time as well as cost.
- New technology bricks used in our sample house proved to reduce the cost of construction by %. Large-scale projects such as slum redevelopment can be benefited by using these bricks.

The key to success for a developing nation is to fulfil the basic needs of the common man and hope this paper has contributed in finding the issues and also provided certain means to control them.

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Importance of Indoor Environmental Quality in Green Buildings

Alisha Patnaik, Vikash Kumar and Purnachandra Saha

Abstract One of the primary aims of green buildings is to minimize negative impacts on their occupants by creating a healthy, comfortable and productive indoor environment. The performance of indoor environment is described as indoor environmental quality (IEQ). The quality indoor environment can result in increased occupant satisfaction, enhanced performance and productivity, reduced liability, marketing advantage and lower operations and maintenance costs. The objective of this paper is to study and discuss IEQ and its parameters and effect on green buildings. Building characteristics such as location, climate, design and construction contribute significantly to the IEQ. Thermal, visual and acoustic comfort and existing levels of volatile organic compounds (VOCs) help to measure the IEQ of a green building.

Keywords Green buildings · Indoor environmental quality (IEQ)
Building characteristics · Thermal comfort · Volatile organic compounds (VOCs)

Introduction

In recent times, global warming is a problem for every country and hence it is necessary to deal with such problems and at the same time, develop sustainably. That is why nowadays, a lot of emphases is given to the design and construction of green buildings. The construction of a green building is economical in the long run and at the same time beneficial to the environment (Pei et al. 2015).

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A green building is constructed using environmentally friendly methods. The main objective of green buildings is sustainability, energy efficiency and productiveness, which reduce the effect of buildings on the environment. In the later part of 1980s, green building design began when the term "sustainability" was defined at the UN World Commission on Environment and Development (1987). The United States (US) and Europe first started the design and certification of green buildings in the earlier part of 1990s. In United Kingdom, BREEAM (BRE Environmental Assessment Method) was developed to certify green buildings, likewise US, France had also developed methods for certification of green buildings. Consequently, all the countries across the globe started making their own code and design specifications for construction of green buildings. The design methodologies adopted varied according to the environmental conditions of that particular area (Wei et al. 2015). Buildings use 30–40% of total worldwide primary energy (Holopainen et al. 2015). The energy used for the construction of green buildings is approximately equal to 20–40% of the total emission of harmful greenhouse gases. By the construction of energy efficient buildings, the emission of these harmful gases can be reduced (Wells et al. 2015).

A wide variety of techniques is used for the construction of energy efficient buildings. Some examples of these technologies are air tightness, proper insulation, heat recuperation and superior window. Some of the techniques used to preserve the energy of a building like air tightness can cause poor ventilation resulting in inferior quality of air inside the building (Langer et al. 2015).

According to the World Health Organization (WHO), "Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (WHO 1999; Bluyssen and Cox 2002). Studies have shown that most people living in urban areas spend approximately 80% of their total time inside a building. So poor quality and pollution of indoor air causes many problems in the health of people and sometimes triggering many diseases (Asadi et al. 2013).

In the design of IEQ of a building, various equipment are utilized for luminance, sound system, temperature control and other purposes. Providing quality indoor environment, while at the same time, making the building energy efficient, environment-friendly (by reducing greenhouse gas emission) is a process which requires proper balance between comfort providing systems and energy economizing devices (Ncube and Riffat 2012).

There is a lot of focus on sustainable use of energy and maintaining IEQ. The parameters which characterize IEQ are thermal comfortableness and IAQ (Indoor air quality) which is affected by the concentration of carbon dioxide and other harmful compounds (Sarbu and Pacurar 2015).

Numerous studies have been carried out from the 1970s for understanding occupant satisfaction with the comfort conditions in indoor environments (Crociata et al. 2012). In the US, twelve buildings were studied by Fowler and Rauch (2008); they stated that the residents of the buildings were concerned about the overall IEQ but were relieved with the acoustics and thermal performance of these buildings at levels below national benchmarks. Paul and Taylor (2008) evaluated the IEQ perception of the inhabitants between a conventional building and a green building located in a couple of Australian universities and did not observe a superior level of comfort among the inhabitants of the green building. In the UK, Leaman and Bordass (2007) analysed occupant surveys from 177 buildings and reported a higher rate for green buildings in the performance of ventilation and air quality compared to the level determined in conventional buildings. However, it was noted that the indoor environment of the green buildings tended to be warmer, less dry and stuffier during the summer. In South Africa, Thatcher and Milner (2012) conducted a longitudinal comparison between the occupants in green buildings versus conventional buildings, and concluded that the Green Star-accredited building did not increase the physical fitness, mental health or perceived productivity of the occupants at a significant level (Liang et al. 2014).

Indoor Environmental Quality (IEQ)

A simplified definition of IEQ is the interior conditions of the building. In addition to quality of air, accessibility of sunlight, view of natural scenery, enjoyable condition of acoustics, thermal comfort and resident access to control lighting, the space and dimensions of the room are also important. The availabilities of required tools, equipment and people are also important; so rather than focussing on one or two parameters, the building supervisors can increase the gratification of the building inhabitants by taking into consideration all the different aspects of IEQ. Table 1 shows some of the general problems and their causes faced by building occupants with regard to IEQ.

Quality indoor environment is a fundamental principle of green buildings. It results to increase in satisfaction of the residents, improved functioning, merchandising benefits, reduction of cost of functioning and maintaining the building.

While certifying a green building, IAQ is taken into consideration in almost all cases. Figures 1 and 2 show that the weightage of IAQ in the twenty points based on the certification of green buildings is 7.5% worldwide. Some countries like US give additional importance on IAQ in comparison to other nations. The approximate contribution of IAQ to the certifying process of green buildings in different countries is shown in Fig. 1. The highest share of IAQ is 10.6% in Thailand, while US has 9.4%.

In schemes of green building, the IAQ is preferably maintained by supervising emission sources, proper air circulation and assessing the indoor quantity of air. The various phases of the lifespan of a building are covered by these three paths. Supervising emission source consists of choosing paints and other materials used in

Table 1 Issues, difficulties and causes of IEQ (Bluyssen 2000)

Issue	Difficulties	Cause
Wetness in the air	Dry/dusty air, problems with eyes	Low RH, moulds
	Allergy	Condensation, moulds
Humidity building	Crystallized spot, humidity circles	Leaks in buildings, precipitation, accumulation of water
	Mould growth	Non-existent insulation, bad ventilation, leaks in pipes
	Condensation	Bad ventilation, leaks in pipes, Improper insulation
Noise	Excessively high sound level	Noisy neighbours, Loud Speakers, Vehicles in road
Thermal comfort	Too cold	Inefficient temperature control system
	Too warm	Inefficient temperature control system
	Draught	Improper ventilation of air
	Temperature differences	Improper ventilation of air, improper insulation
	No control	Deficiency of control
Air quality	Pungent odour, annoyance in throat and eyes	Improper cleansing, pollution
Lighting	Too much light	Use of improper lights
	Too little light	Use of improper lights
Safety	The feeling of insecurity	Lack of sufficient security at the entry area
Apartment utilities	Unacceptable quality of water supply	Water flow, water temperature, taps

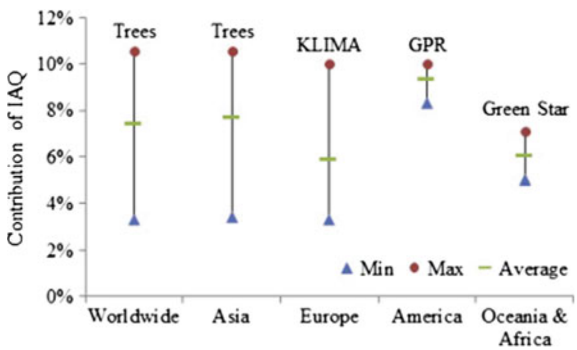

Fig. 1 Continent-wise share of IAQ in the certifying process of green buildings (Wei et al. 2015)

the interior of a building in such a way that they have a low discharge of harmful gases. The system for air circulation should allow proper commutation of air between the interior of the building and the outside environment. The efficiency of the air circulation system and supervision of energy source can be checked by assessing the indoor air.

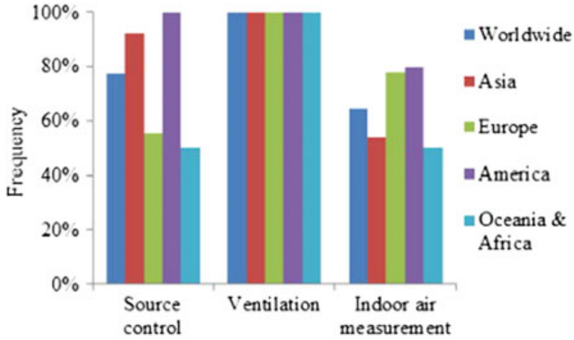

Fig. 2 IAQ management in green building certifications (Wei et al. 2015)

Effect of Poor IEQ on Human Health

In the year 1984 in a report of the World Health Organization (WHO), it was mentioned that thirty percent of recently constructed and resituated buildings across the globe face problems relating to inferior quality of air inside the building. The word "sick building syndrome (SBS)" was introduced by WHO which refers to circumstances wherein the residents of the building face severe deterioration in health and experience discomfort if they spend higher amount of their time inside the building. This syndrome can be caused by improper insulation, air circulation and inefficient air conditioning devices. Other reasons like harmful microorganisms and chemicals can also be responsible for SBS. Some problems which may develop due to the inferior quality of indoor are cough, cold, respiratory problems, irritation in skin and also problems in heart. These problems might also lead to development of diseases like asthma. Moreover, mental skills and thinking availability of a person are also deteriorated. Some common interior environmental contaminants that have a negative impact on human health include carbon monoxide and other harmful chemicals like pesticides, high reactive compounds, etc.

Parameters of IEQ

In this study, the focus is laid on the following parameters of IEQ—building characteristics, thermal comfort, visual comfort, acoustic comfort and volatile organic compounds.

Building Characteristics

Buildings are constructed to shelter the inhabitants from the exterior environment and furnishing high-quality internal conditions. A building secures its residents from the severe environmental conditions like precipitation, earthquake or storm

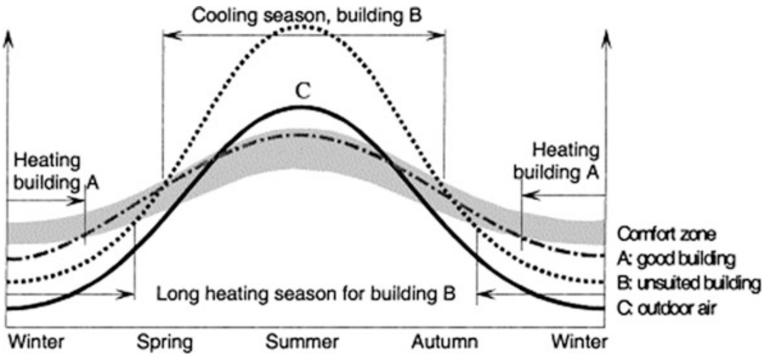

Fig. 3 Development in temperatures in a free-floating building in one year (Roulet 2001)

and at the same time maintains a suitable and comfortable internal environment. According to Chatelet et al. (1998), the indoor environment of a freely floating building (a building without any air temperature control system) must not be more uncomfortable than the external climate. This scheme is described in Fig. 3.

As per the type of clothes, residents ask for dissimilar temperatures in different seasons. So the optimal temperature zone is higher in summer and lower in winter. The Curve for building A shows that it is well-insulated thermally, suitable devices for controlling solar energy and efficient air-circulating devices. During summer season, it is protected from the heat waves but during winter season it can utilize this solar energy to increase the indoor temperature. So luxury and comfort are provided in the building by making minimum use of energy sources other than solar energy. The amount of energy which is used for temperature control (i.e. cooling or heating) is saved in such buildings. The curve for building B shows that it does not have appropriate thermal insulation and is unable to utilize solar energy effectively. So energy sources other than solar energy have to be used to control the internal temperature of the building.

Thermal Comfort

In accordance with the ASHRAE/ANSI Standard 55-2010, thermal comfort may be described as “that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation”. The perception of thermal comfort may vary from person to person, any specific range of temperature cannot be declared. One way to find out whether the inhabitants of the building are satisfied with the indoor thermal conditions is to go door-to-door and ask people, thus performing a detailed survey in that building. The internal thermal conditions are good if the majority of the residents (80%) are satisfied with the thermal conditions.

The conditions which affect the thermal comfort can be categorized as personal factors (type of clothing, physical condition) and environmental factors (moisture in air, temperature of air, velocity of wind). Both these factors play a vital part in determining the thermal comfort of the building (Hua et al. 2014).

The situations responsible for the increase of internal temperature in a building are heat transfer from outside the structure and heat emitted from internal electric devices (Nasir et al. 2011).

Another environmental factor is humidity which is defined as the quantity of moisture present at a particular place. The quantity of moisture is affected by the temperature. The higher the temperature, the higher is the moisture content (Nasir et al. 2011).

For the growth of moulds wet surfaces are required. Low-temperature and humid air can contribute to the growth of moulds which deteriorate the IEQ (Nasir et al. 2011). In single-paned windows there is a proper facility of air circulation and heat exchange between the internal and external environments of the building; hence, the walls which are improperly insulated have no risk of condensation on their surface. In case of double-paned windows with air-sealed glazing, there is minimum air circulation and heat exchange. So there is increased presence of indoor moisture and hence there is a risk of mould growth on walls which are improperly insulated.

Visual Comfort

Light and vision are related to each other; vision enables us to observe the nature and interact with others. So for the purpose of visual comfort, light is a necessity. In lighting, proper balance of blaze and contrast is essential. Day lighting is the utilization of blaze-free sunlight for illuminating the indoor of a building and it is undeveloped in most architectural design due to lack of information of its usefulness and depending on over-optimistic energy savings (as in simulations and blind usage) that are really met in open-plan offices. Lighting is of a paramount concern to the design of office space, as in a typical new building, it consumes up to 25% of the amount of energy required and this indirectly affects visual comfort which is one of the models of IEQ. The use of natural light is indeed an inevitable practice internationally, as it saves energy in buildings which involve bioclimatic passive solar design. Although sustainability in the context of sustainable architecture has been narrowed to ‘low energy’, energy performance boils down to energy efficiency and IEQ. Research has shown that visual comfort relates today lighting research significantly as it contributes to the well-being and performance of the users. Access to natural daylight and fenestration with pleasant views contributes to the reduction in stress levels in an office environment, and research has also shown that most people find natural lighting from day lighting better than fluorescent, incandescent lighting, help in psychological comfort and increase their productiveness; and it has advantages in our health and well-being. Day lighting is an element used to improve occupant's psychological health and productivity as office buildings require more intellectual work than physical work, which suggests that the indoor environment of the office should ensure proper well-being of the workers and in turn could reduce occupant's productivity rate probably due to building-related illness (BRI). The condition of brightness or lights in a building has an impact on the tiredness, security and comfort of its inhabitants. Research in a green building required baseline and this is difficult to achieve in Asia region as fewer green buildings exist. There have been some problems across most green buildings with daylight and glare control as a repetitive one and occupants comfort is neglected for energy savings (Dodo et al. 2014).

In the course of evolution of Homo sapiens, the eye has adjusted itself to sunlight. The natural source of sunlight allows more visual comfort to the human eye than any other artificial source of light. So maximum utilization of daylight must be made as it does not consume any energy and is most suited for the human eye. The lesser the number of artificial lights used in a building, the more efficient are the systems of day lighting. Use of anabolic reflectors can reduce the number of artificial lights required (Courret et al. 1996) and thus reduce energy consumption significantly as shown in Fig. 4.

The quality of indoor lighting has an effect on satisfaction of residents, aesthetic appearance, blaze and contrast. All these things have to be balanced and maintained for a specific function inside the structure. Some guidelines and codes have been developed for ensuring sufficient light for residential buildings, commercial buildings as well as office. A code called CIBSE provides specifications and suggestions for superior quality indoor lighting inside workplaces (CIBSE 1994). Some specific tasks require specified level of lighting; for example, at workplace, the minimum level of illumination should be 500 lx (Ratcliffe and Day 2003). According to Burnet et al. at workplaces the amount of illumination of a working surface or horizontal surface is important and hence can be regarded as a necessary guideline (Chung and Burnett 2000). The effect of increasing the lighting at the

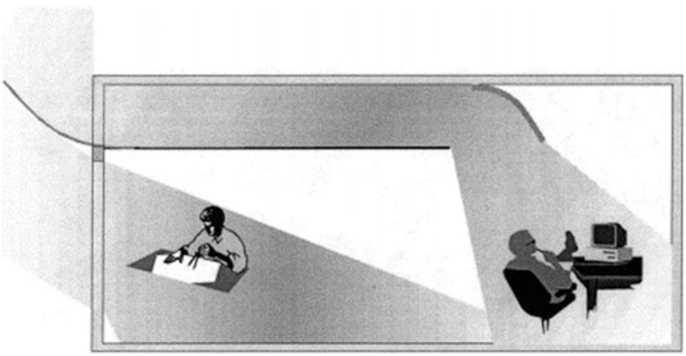

Fig. 4 Mirrors positioned at specified positions reflect the light and illuminate the room (Roulet 2001)

workplace and its effects on the working staffs were studied by Saunders (1969). Equation (1) shows the relation between lighting index and the illumination of a horizontal surface.

Saunders showed the effects of increasing working plane illumination on workers' satisfaction with the quality of lighting and Eq. (1) is derived from the results (Saunders 1969). The basis of lighting index is the amount of light falling on the working surface:

$$L_{\text{index}} = -176.76X^2 = 738.4X - 690.290. \quad (1)$$

In the above equation, $X = 10 * [\ln\{\ln(\ln x)\}]$.

Acoustic Comfort

Acoustic comfort is the capability of a building to offer an unnecessary noise-free internal environment. The source of the undesired noise could be from sources inside the building as well as external sources like loudspeaker, traffic, etc. (Bies and Hansen 2009). The desirable level of noise inside a building can vary with the purpose for which the room is used. In case of a library the desirable level of noise will obviously be lesser than a classroom, and a classroom's desired noise level will be lesser than an auditorium. The optimum noise level may also vary from person to person in a building. Wong et al. (2007) collected data relating to the level of noise in various office environments. Several specifications and standards have been developed for good quality acoustic system like Kosten's noise rating (NR) technique, Blaizers's room criterion (RC), etc. Bies and Hansen (2009) described the different standards and ratings for evaluating acoustic comfort. Terms such as "very quiet", "quiet", "noisy", etc. have been used in various studies to describe the acoustic condition and comfort (Bies and Hansen 2009; WHO 1985; Kjellberg et al. 1997; Nilsson 2007; Sabnis 2015). Equation (2) provides a relation between percentage of people unhappy with the noise levels and the actual noise level in dB:

$$PD_{ACc} = 2\left(\text{Actual}_{\text{Soundpressurelevel}} - \text{Design}_{\text{Soundpressurerange}}\right), \quad (2)$$

Y Percentage of people unhappy with the noise levels.
x Actual noise level in dB.

Equation (3) can be used to find out an index related to acoustic comfortableness:

$$ACc_{\text{index}} = 100 - PD_{ACc}[10]. \quad (3)$$

Volatile Organic Compounds (VOC)

Volatile organic compounds (VOCs) may be released from a variety of substances which can be liquid or solid. Some harmful and toxic chemicals are also included under VOCs, and these toxic chemicals can cause deterioration of health of occupants. The amount of VOCs may be more inside the building as compared with the external environment. VOCs are extensively utilized for various indoor operations like painting, varnishing of furniture, perform cleansing operations, disinfection of household items and other daily use products. During the tenure of their use, these products continue to emit harmful organic compounds which effect the health of the people inside the building (Table 2).

Table 2 Sources of VOCs and other harmful organic chemicals (Zabiegała 2006)

Sources of VOCs and other harmful organic chemicals	
Interior of the building	Exterior of the building
Source of origin is the building • Construction and design items • Repair and maintenance of building • Tools and machinery used inside the building • Actions of microorganisms	Chemical and oil industry
Originating from human and human activities inside the building • Household and consumption goods (hygiene products, aerosols) • Processes connected to indoor cleaning • Cooking • Social functions • Interior flora • Human waste • Household (stoves, ovens) • Electronic machines	Small-scale business (printing, photocopying)
	One time pollution sources • Break down of valves, pipelines, and pumps • Leaks during loading/unloading • Safety valves • Cleaning of tanks
	Emissions of biological origins • Green plants • Agriculture • Global ocean surface
	Underground water and water bodies in the earth's surface
	Grounds in which soil is polluted by human activities
	Use and discarding unnecessary materials • Sewage treatment plants • Recycling of wastes

Conclusion

The green building movement has revolutionized the way the architectural industry envisions and designs buildings for the promotion of environmental sustainability. However, the majority of researchers till date have shared a strong focus on the effectiveness of green buildings in energy-saving and less on keeping an IEQ appropriate for indoor occupants.

IEQ is an important parameter in the majority of the certifying processes for green buildings all over the world. The average worldwide weightage to IEQ is about 7.5%. VOCs and other harmful chemicals and pollutants are considered in the majority of the certifying process as they contribute to deterioration of health. Different certifications use different methods to control IEQ, almost all of them use air circulation or ventilation as a very important parameter. In 77% of the certifying processes, controlling the source of release of pollutants has been included as an important parameter. Assessing the air present in the interior of the building is considered in many of the certifying processes. It was observed that the methodology used for measuring the indoor air was different in different cases. It can be concluded that IEQ and its parameters are of paramount importance to make a building 'green'. To achieve a sustainable building, designers and engineers need to find the right balance between energy-saving imperatives and the quality indoor environment.

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Meteorological Factors Influencing Dispersion of Vehicular Pollution in a Typical Highway Condition

Rajni Dhyani and Niraj Sharma

Abstract Vehicular dispersion models, particularly highway dispersion models are used worldwide, including India, for assessment and management of air quality along the major roads/highways. However, dispersion of vehicular pollutants is influenced by various factors such as traffic, receptors and land use along with meteorological factors. In the present study, CALINE4, a Gaussian-based vehicular pollution dispersion model has been used in Delhi, along Ring Road Corridor near Indraprastha Park. Sensitivity analysis of CALINE4 model has been carried out for identification and quantification of meteorological parameters, viz. wind speed, wind direction, mixing height and P–G stability class influencing the model's output. These input parameters in the model were systematically varied for assessing their influence on model's output, i.e. predicted concentrations. The study revealed that wind speed and wind directions have significant impact on dispersion of vehicular pollutants as compared to mixing height and stability class.

Introduction

Use of these highways dispersion models has increased over the years in policy support for large road infrastructure projects (Bennett et al. 2013). Accuracy of various highways dispersion models like any other the air pollution dispersion model results relies on the accuracy of its input parameters. It is important to identify those input variable(s) (or combination of two or more inputs) which significantly influences the output of the model most. In order to establish the importance of individual parameters in the model, models are subjected to sensitivity analysis under wide

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range of conditions. Sensitivity analysis indicates how much of the overall uncertainty in the model predictions is associated with the individual uncertainty in each model input(s) (Nossent et al. 2011; Zhan and Zhang 2013). Sensitivity analysis of the model is carried out to identify key variables in modelling system and helps in focussing on collection and estimation of those influencing parameters (Trueman 2007). The CALINE4 (Benson 1989) line source dispersion model is used extensively throughout the world including India for predicting air quality along highways under prevailing traffic and meteorological conditions. CALINE4 model requires relatively lesser expertise and has comparatively less input data requirement than other vehicular dispersion models (Gimson et al. 2010). In India, CALINE4 vehicular pollution dispersion model is extensively use for prediction of air quality along the highway corridors (Sharma et al. 2013; Dhyani et al. 2013; Majumdar et al. 2009; Lao 2010). However, few studies have been carried out in India regarding validation and performance evaluation of CALINE4 under mix traffic conditions (Majumdar et al. 2010; Dhyani et al. 2014; Konar and Chakrabarty 2012). Most of the vehicular pollution dispersion models like CALINE4 used in India are developed in western countries for their traffic and meteorological conditions. Further, most models developed in western countries (homogeneous traffic conditions and meteorological conditions) are unable to do fair representation real-world complexities (e.g. mixed traffic conditions) common (in the form of meteorological and traffic condition) are still unresolved (Karim et al. 1998). Sensitivity analysis is an important tool to examine model performance in the presence of uncertainty in the model input variables and development of new models.

Few studies have been carried out to identify the influential parameters in CALINE4 model and for further improvement in new models. Benson (1989) comprises most of its input parameters of CALINE4 model, such as, P–G stability class, mixing height, wind speed, wind direction, highway width and highway length; under homogeneous traffic and open terrain conditions for which model has been developed. Sripraparkorn et al. (2003) used CALINE4 and reported that wind direction, traffic volume receptor heights and composite emission factors affect the output of the model most and atmospheric stability and mixing height affect the output least. Batterman et al. (2010) developed the multiplicative emission and dispersion sub-models by identifying the influential variables through sensitivity analysis of MOBILE6.2 (USEPA 2004) and CALINE4 model, respectively. The sub-model (a reduced-model form of CALINE4) did not include the mixing height and stability class due to their minor contribution in CALINE4 output (i.e. predicted concentrations). However, no such study has been carried out under mixed traffic conditions. In the present study, an effort has been made to identify the input parameters, which influence the output of the CALINE4 model most under mix traffic condition.

Methodology

Site Characteristics

The present study was carried out in Delhi, India. Delhi has the highest vehicular population in India with nearly 8.5 million (GNCTD 2015) vehicles, which constitute nearly 4.6% of the vehicular population of India (MoRTH 2013). Delhi has mixed traffic conditions (or heterogeneous traffic condition with both motorised and non-motorised vehicles, no lane following by traffic). For the study, Ring Road Corridor, near Indraprastha Park was selected. The selected corridor is a part of major city road connecting outer Delhi areas to Central Delhi. The stretch selected is nearly 2 km in length and width of the study corridor is 30 m. Intercity commercial vehicles do not ply during peak hour. The selected stretch is fairly open terrain with good dispersion conditions and free flow traffic. The corridor has been selected as it represents the typical highway conditions that exist in western countries for which model has been developed (Fig. 1).

Traffic Characteristics

The traffic volume count was carried out through videography at Ring Road Corridor, near Indraprastha Park, further, videopad editor software was used for

Fig. 1 Ring Road Corridor, near Indraprastha Park

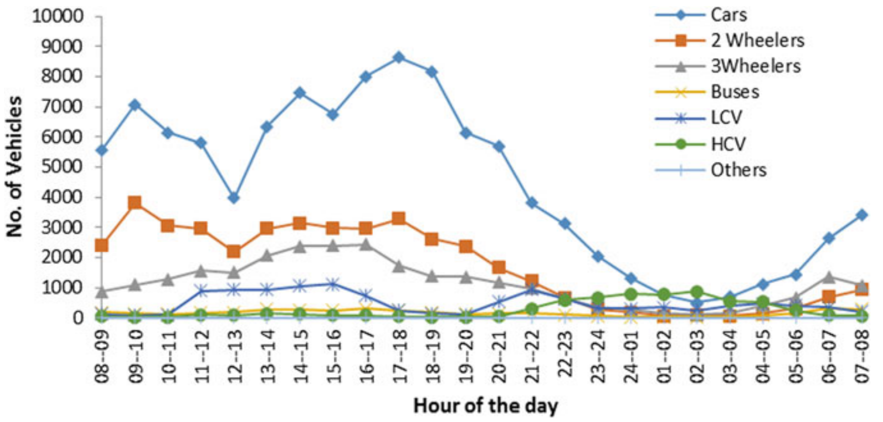
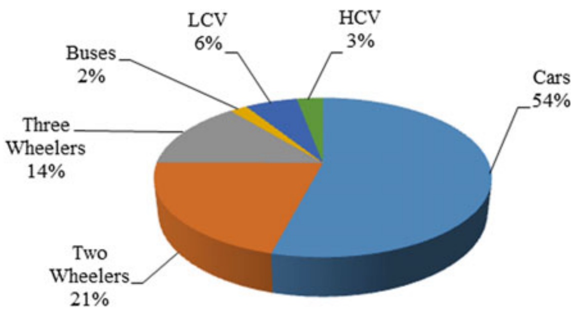


Fig. 2 Diurnal distribution of traffic volume along Ring Road Corridor near IP Park

counting the vehicles from the recorded video. The total number of vehicles were 196,440 (~0.2 million) vehicles per day. Diurnal distribution of various categories of vehicles has been shown in Fig. 2. Unlike the typical urban roads, no distinct morning and evening traffic peaks were observed, during morning hours (0900–1000 h) there was 12,213 numbers of vehicles. High traffic counts were observed during 1400–1500 h (~14,400 vehicles) and during 1700–1800 h (14,158 vehicles). Fuel station survey was carried out along the selected road corridor to know the age profile of vehicles, engine technology (2 stroke or 4 stroke) and fuel type (petrol, diesel, CNG and LPG) used by various categories of vehicles. From fuel station survey it was observed that share of cars was highest followed by 2Ws, 3Ws, LCV, buses and HCV (Fig. 3). The results (in terms of their age profile, engine technology and composition) obtained from fuel station surveys were applied on the traffic volume of selected corridors assuming that the vehicles plying on the road have the similar characteristics as captured during the fuel station surveys. It was observed that ~62% of vehicles were petrol driven followed by ~20% diesel vehicles, CNG 17% and LPG 1%. The information obtained through

Fig. 3 % share of different categories of vehicles at Ring Road Corridor near IP Park



fuel station survey and traffic volume videography (e.g. percentage of 2W-2S and 2W-4S vehicles, percentage of petrol- and diesel-driven vehicles in 4W categories) were used to estimate weighted/composite emission factors (WEFs or CEFs) as an input in the CALINE 4 model.

The WEF (input parameter for CALINE4) is a function of vehicle emission factor (vehicle category, type, fuel type, age profile, vintage, etc.) and vehicle activity (traffic volume). For estimation of WEF (gm/mile) (representative values for all categories of vehicles), emission factors for Indian vehicles were used (ARAI 2008).

The study was carried out in winter season in the month of February. The micro-meteorological input parameters such as, wind speed, wind direction and relative humidity, were measured on-site with the help of Air Pollution Mobile Van fitted with meteorological sensors. The hourly mixing height values were obtained from the Indian Meteorological Department (IMD) (Attri et al. 2008). In addition, hourly P–G stability class was estimated using wind speed, solar insolation and cloud cover (daytime and night time) (Turner 1994). The predominant wind condition was blowing from south-east. The ventilation coefficient is a function of wind speed and mixing height. It is a product of wind speed and mixing height and represents the mixing potential and ventilation capacity over a region. During daytime ventilation, coefficients have higher values (unstable conditions with high mixing height) and low during night time (Table 1). Higher the ventilation coefficient the more will be pollutant dispersion and vice versa (Lu et al. 2012). However, it is not directly used in CALINE4 model as an input (Fig. 4).

CALINE 4 Model Description

CALINE4 model is the fourth generation simple line source Gaussian plume dispersion model. It predicts the concentrations of CO, NO_2 and $PM_{10}/PM_{2.5}$ near roadways. It employs mixing zone concept to characterise pollutant dispersion over the roadway (Benson 1989). CALINE4 model uses the concept of mixing zone width, i.e. region above roadway as zone of uniform emissions and turbulence (Benson 1989) which accounts for vehicle induced turbulence. Mixing zone width includes sum of roadway width, median width and 3 m on either side of the roadway. Under standard run (1-h) conditions, the model uses given meteorological parameters to predict CO concentrations at pre-identified receptors points. The CO being the indicator pollutant for vehicular activities was chosen for the present study.

Table 1 Summary of the on-site meteorological parameters at selected IP site (Feb, 2015)

Time (h)	Wind direction (°)	Wind speed at 10 m (power formula)	Stability class	Mixing height (m)	Wind direction standard deviation (°)	Temperature (°C)	Relative humidity (%)
8:00	113.3	3.7	B	50	18	22.1	75.1
9:00	117.7	3.8	B	60	18	23.6	70.6
10:00	119.9	3.8	B	175	18	23.9	70.6
11:00	127.3	3.8	B	325	18	24.2	65.9
12:00	123.8	3.8	B	450	18	26.2	61.8
13:00	129.2	3.8	B	700	18	27.0	59.6
14:00	126.5	3.8	B	725	18	27.2	61.1
15:00	121.5	3.7	B	825	18	27.0	62.7
16:00	125.3	3.8	C	850	13	26.9	64.8
17:00	127.6	3.9	C	738	13	25.9	69.4
18:00	128.4	3.9	C	600	13	25.0	72.2
19:00	133.8	4.2	D	400	10	24.2	75.7
20:00	147.1	3.7	E	300	6	23.9	76.0
21:00	126.8	3.8	E	225	6	23.1	82.4
22:00	128.5	3.9	E	200	6	22.8	81.0
23:00	131.0	3.8	E	150	6	22.5	81.3
0:00	132.1	3.9	E	125	6	22.2	82.7
1:00	132.0	3.5	E	100	6	21.8	84.4
2:00	126.0	3.5	E	75	6	22.1	81.6
3:00	131.1	2.9	F	50	6	22.2	77.5
4:00	134.1	2.5	F	52	6	21.7	74.9
5:00	156.2	3.5	D	40	10	21.6	73.3
6:00	161.8	3.5	D	45	10	21.2	76.1
7:00	111.8	3.7	C	60	13	21.4	75.9

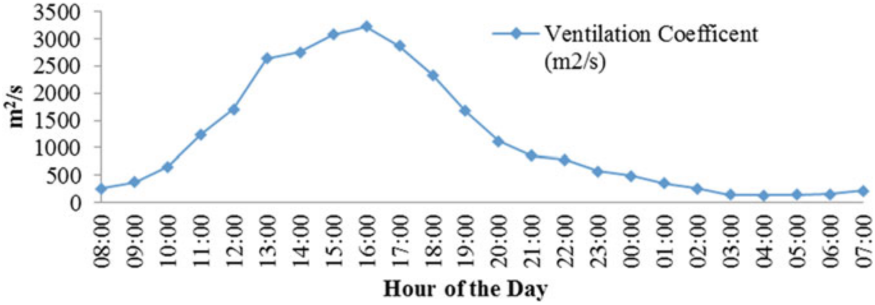


Fig. 4 Diurnal variation in ventilation coefficient (m^2/s) at selected corridor

Table 2 Data set selected for sensitivity analysis

Time (h)	Wind direction (°)	Wind speed (m/s)	Stability class (P–G)	Mixing height (m)	Wind direction ±SD	Pollutant background	Temperature (°C)	Traffic volume (no. of vehicles)	WEF (g/mile)
1000	119.9	3.8	B	175	18	0	23.9	10,701	3.75

Sensitivity Analysis of CALINE4 Model

Sensitivity analysis of CALINE4 model was carried out to determine the significance and contribution of each input variable in the model's output. According to Benson (1989), all input parameters act independently within the model and interaction between two or more variables was presumed to be insignificant. Therefore, for sensitivity analysis, selected input variables were changed systematically changing one input variable at a time keeping other variables constant and effect of each input variable on predicted concentration was observed. Morning peak hour (1000 h) data set has been selected for the sensitivity analysis of the CALINE4 model. Primarily meteorological parameters like wind speed, wind direction, P–G stability class and mixing height were considered for sensitivity analysis (Table 2).

The sensitivity analysis results consist of CO concentration-wind angle (PHI or roadway to wind angle) graphs. Wind angle has been taken with respect to roadway, thus, 0° means parallel to the roadway and 90° means perpendicular to roadway. The CO concentration was observed/ estimated at pre-identified receptors locations selected at a distance of 1, 5, 10, 25, 50, 100, 150 and 200 m at either side of the mixing zone width. The sensitivity analysis was carried out for standard run (1-h) condition.

Results and Discussion

Sensitivity Analysis of CALINE4 Model

Meteorological parameters namely, wind speed, wind direction, stability class and mixing height were varied systematically from the selected input data set. CO concentration-wind angle (PHI or roadway to wind angle) graphs have been presented at four distances from the mixing zone width—5, 10, 25 and 50 m to explain the CALINE4 sensitivity for selected input parameters of the model. CO concentration-wind angle (PHI or roadway to wind angle) graphs were presented to explain the CALINE4 sensitivity for selected input parameters of the model. Wind angle was taken with respect to roadway, i.e. 0° PHI means parallel to the roadway and PHI = 90° corresponds to perpendicular wind conditions w.r.t. roadway. Wind direction is an important parameter in air pollution dispersion, as it fixes the course

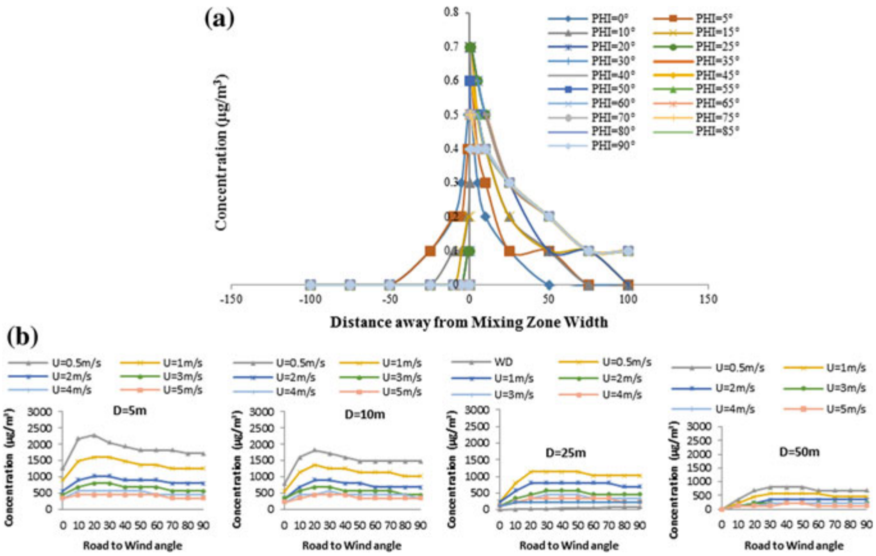


Fig. 5 Sensitivity analysis for wind angle, PHI (°) and wind speed (m/s)

of pollutant dispersion. From sensitivity analysis of CALINE4 model, it was observed that model is most sensitive to PHI between 0° and 30°. Maximum concentration was observed at PHI = 10°. Minimum pollutant concentration was observed when PHI = 80°–90° or perpendicular to roadway. During parallel PHI (0°–25°), pollutant concentrations were observed on both upwind and downwind direction (Fig. 5a). Wind speed impacts the dilution and dispersion of pollutants. In the CALINE4 model Gaussian equation, wind speed is inversely proportional to predicted pollutant concentration (Benson 1989; Batterman et al. 2010; Bhaskar and Mehta 2010). Wind speed was varied from 0.5 m/s (calm) to 5 m/s in 1 m/s interval. With every 22% increase in wind speed, i.e. 1–2 m/s, 22% decrease in predicted concentration was observed. Maximum concentration was observed during parallel wind direction (10° and 20° PHI) Fig. 5b.

Mixing height defines the structure of turbulence in boundary layer. Mixing height along with wind speed determine the volume available for mixing and dispersion of pollutant (Khandokar et al. 2010; Banta and White 2003). Vehicular emissions are near ground emissions, therefore, the influence of mixing height is not expected in dispersion of pollutant. Moreover, in the CALINE4 model thermal turbulence from exhaust of emission and mechanical turbulence generated from vehicles are the main forces, which influence the dispersion of pollutants in mixing zone width (Benson 1989). For sensitivity analysis, mixing height was varied from 25 to 2500 m (Fig. 6a). It was observed that negligible change occurred when mixing height was varied. The data set selected for the study has B (unstable atmosphere) P–G stability class. Model uses Pasquill–Gifford stability class only, P–G stability class is a function of solar insolation intensity, wind speed, cloud

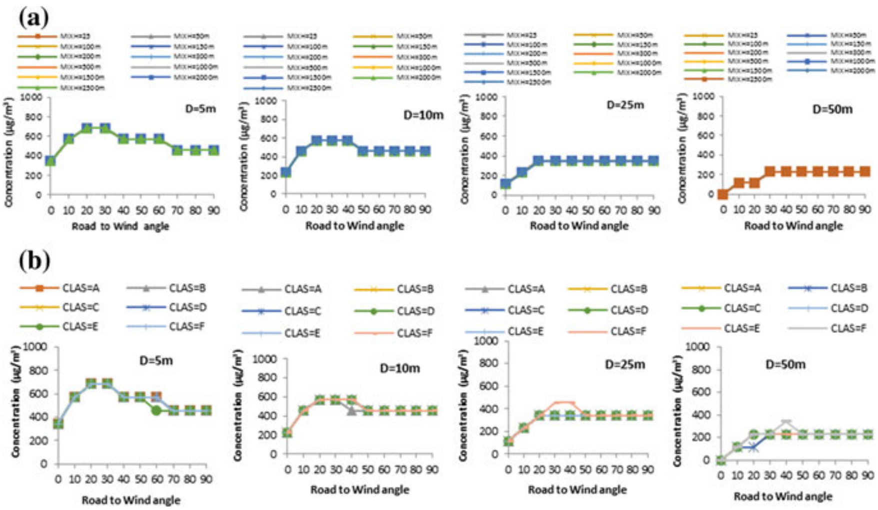


Fig. 6 Sensitivity analysis for mixing height (m) and stability class (P–G)

cover and time of the day. Stability class was varied from Class A (highly unstable) to Class F (highly stable). However, insignificant impact of change in stability class was observed on predicted concentration near mixing zone width. However, slight increase (15–30%) in concentration was observed as we move away from mixing zone width (25 and 50 m) (Fig. 6b). Thus indicating the importance of mixing zone width concept, where mechanical and thermal turbulence are predominant forces for dispersion. As we move away from the influence zone (mixing zone width), atmospheric features like stability class, mixing height become significant forces for dispersion and dilution process of air pollutants.

Conclusions

Sensitivity analysis of model was carried out to identify the most influencing input parameters in the CALINE4 model. The impact of wind speed and wind direction was more significant on dispersion of vehicular pollution. CALINE4 was found to be most sensitive to parallel wind direction. Maximum concentration was observed at PHI = 20° (parallel wind direction). Wind speed has significant impact, it is inversely proportional on predicted concentration. Nearly, 22% increase in wind speed (0.5–1 m/s) results in 22% decrease in predicted concentration. Stability class was observed to be influencing at a nearly 50 m away from mixing zone width. The impact of stability class is more prominent at receptors away from mixing zone width. Mixing height had insignificant influence on model prediction capability, therefore, it could be concluded that any default value could be used for the pollutant concentration prediction. Vehicular pollution or release of exhaust is near to ground level, where vehicle-induced turbulence and mechanically induced turbulence are the most significant forces for dispersion of vehicular pollution. Therefore, effect of stability class and mixing height is not significant in that zone or near roadway receptors. Thus, it could be concluded that among meteorological parameters, wind speed and wind direction have comparatively more influence on model prediction capabilities followed by stability class and mixing height.

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Study of Air and Noise Pollution in Mega Cities of India

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Abstract Public health studies are linked to both air and noise pollution in terms of common adverse health effects attributed to severity of such pollution such as increased blood pressure, heart diseases, and other respiratory ailments. In urban areas of mega cities, air and noise pollution originating from different sources such as traffic, industries and construction activities, etc., is on gradual and alarming increase. In view of the same, objective of this study was to analyze the air and noise pollution levels in three megacities of India, namely Delhi, Kolkata, and Mumbai during 2006–2011 at different locations categorized as industrial, commercial, and institutional areas. Following the analysis, the equivalent noise levels (L_{eq}) of all the cities were found to be slightly greater than permissible limits of CPCB guidelines whereas the criteria pollutants SO_2, PM_{10} and NOx showed a positive relation between noise levels and air pollution. This statistical comparative analysis as an important outcome will help understand the actual trend of air and noise pollution during different years in various Indian mega cities and subsequent mitigation measures.

Keywords Air pollution · Criteria pollutants · Mega cities
Noise pollution · Public health

Introduction

Air pollution in urban areas is contributed from various sources which can be grouped into mobile, stationary, and open burning sources with examples being vehicular pollution, industrial pollution, and domestic fuel (Zeinab and Mounir 2010). The single source for the most significant air pollutants such as sulfur dioxide (SO_2), nitrogen oxide (NOx), carbon monoxide (CO), volatile organic

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compounds (VOCs), and particulate matter (PM) is fossil fuels (Kumar et al. 2014). Noise pollution is taken in other pollution categories due to its source and diffusion characteristics. There has been an increase in noise from man-made sources for last 100 years, which is now doubling after every 10 years. World Health Organization (WHO) analyzed the available air quality data from 1,100 cities across the world and the position of Delhi was reported at the top of the list of 20 most air polluted cities (WHO 2014).

Delhi being the capital of India, has grown across all sectors such as industry, transport, and housing, and all of them have contributed to an increase in air pollution (Narain and Bell 2006; Goswami and Baruah 2008; Firdaus and Ahmad 2011; Sahu et al. 2011; Guttikunda and Gurjar 2012; Guttikunda and Goel 2013). According to Center for Science and Environment (CSE), the Central Pollution Control Board (CPCB 2000, 2009) considers air to be "clean" if the levels are below 50% of the prescribed standards for pollutants. Commonly found air pollutants (also known as "criteria pollutants") assuming the criteria pollutant to be PM_{10} during 2007, only 2% cities have low air pollution. At least one pollutant exceeded the annual average from ambient air quality standards in about 80% of cities (of a total of 127 cities/towns monitored under the National Air Quality Monitoring Programme, NAMP). There are very few cities which can be referred to be clean if the designated criteria pollutant is PM_{10}. However, the level of SO_2 has reduced in many cities below the standards of CPCB but the NO_2 levels are increasing in many cities.

Exposure on Health

Studies in India and in other countries have consistently demonstrated higher rates of respiratory and cardiovascular disease in populations exposed to PM, NOx, and Ozone pollution (Chhabra et al. 2001; Pande et al. 2002; Gupta et al. 2007; Siddique et al. 2010; Balakrishnan et al. 2011; WHO 1999, 2014). According to WHO (2014), high concentration of small particulates such as PM_{10} and $PM_{2.5}$ causes increased mortality and morbidity as if the concentration of same is reduced taking other parameters as they are the mortality will also go down. Human health studies for long-term exposure of NO_2 show the symptoms of bronchitis in asthmatic children increase while SO_2 causes irritation of the eyes and may affect the respiratory system and the functions of the lungs. Exposure to road traffic noise and air pollution has both been studied and associated with problem of stroke. Few studies, including exposures to both gaseous pollutants show inconsistent results. Fatal stroke was reported to be because of air pollution and not because of traffic noise. Ischemic stroke was because of traffic noise only while only air pollution caused risk of fatal strokes (Sørensen et al. 2014).

Due to the rapid increase in industrialization, urbanization, and transport systems, noise pollution has increased to a disturbing level. The effect of noise pollution is hearing defects, increased blood pressure, and sleeplessness, effect on work performance, etc. (Evans and Hygge 2000). Human health studies show that after long-term exposure to noise with LAeq, 24-h values of 65–70 dB cardiovascular effects occur (WHO). This is more associated with heart disease than that with hypertension. Traffic emissions contribute to both air and noise pollution and studies conducted to find effect of these pollutants due to traffic on blood pressure in children fetched the result that air pollution was not related to blood pressure problem, noise was independently and positively cause of blood pressure in children (Liu et al. 2014).

In view of the above, present study was planned and undertaken so as to analyze the air and noise pollution levels in three megacities of Delhi, viz., Delhi, Kolkata, and Mumbai and find out the trend of change in annual concentration of such pollutants over a period of 6 years. Further, such analysis of trends of gaseous, particulate matters, and noise will help formulate more focused approach in reducing the urban air pollution which has already assumed alarming levels.

Research Methodology

Population mostly lives in urban areas. Gurjar et al. (2016) estimated the megacities in India (Delhi, Mumbai, and Kolkata) collectively have >46 million inhabitants. Increasing population and prosperity results in rapid growth of the already large consumption of energy and other resources, which contributes to air pollution, among other problems. Megacity pollution outflow plumes contain high levels of criteria pollutants. The study sites are megacities in India, namely, Delhi, Mumbai, and Kolkata as shown in Fig. 1. The present study is based on secondary data which were collected from the Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs) of corresponding states of Delhi, Maharashtra and West Bengal. The data collected from the aforesaid sources are annual averages of all monitoring stations in Delhi, Mumbai, and Kolkata either from CPCB or SPCB of the respective city.

Results and Discussion

The annual trend of noise level, PM10, NO2 and SO2 has been presented in Figs. 2, 3, 4, and 5, respectively. The noise level in three megacities Delhi, Mumbai, and Kolkata was found to be varying from 60–64, 67–75, and 64–72 dB, respectively, during monitoring years 2006–2011 (CPCB 2009). The noise level was much higher than the permissible limit of 55 dB(A) as prescribed by CPCB for residential areas during day time. There is, however, no significant variation of noise was found in these years. Mumbai has higher noise level as compared with Delhi and Kolkata.

Fig. 1 Location map of megacities in India

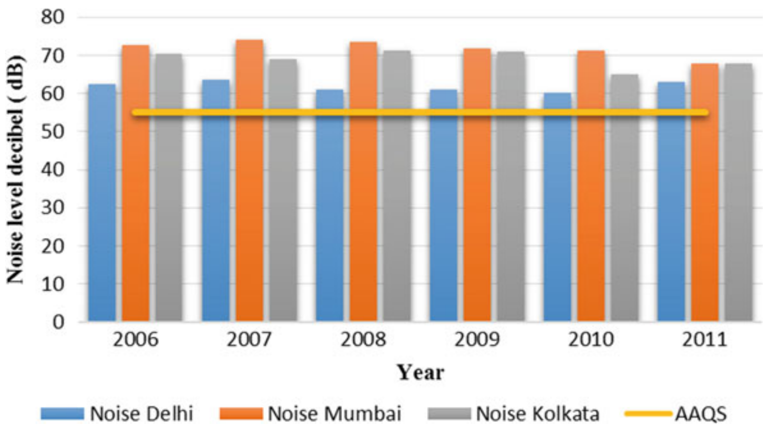

Fig. 2 Annual variation of ambient noise levels (2006–2011) in Indian mega cities

During the years 2006–2011, the SO_2 level in Delhi, Mumbai, and Kolkata were found varying from 5–10, 5–12, and 8–12 μg/m^3, respectively. The SO_2 level was found within permissible limit for all megacities in India and is not considered a problem in India anymore. Its levels in most cities are already very low and

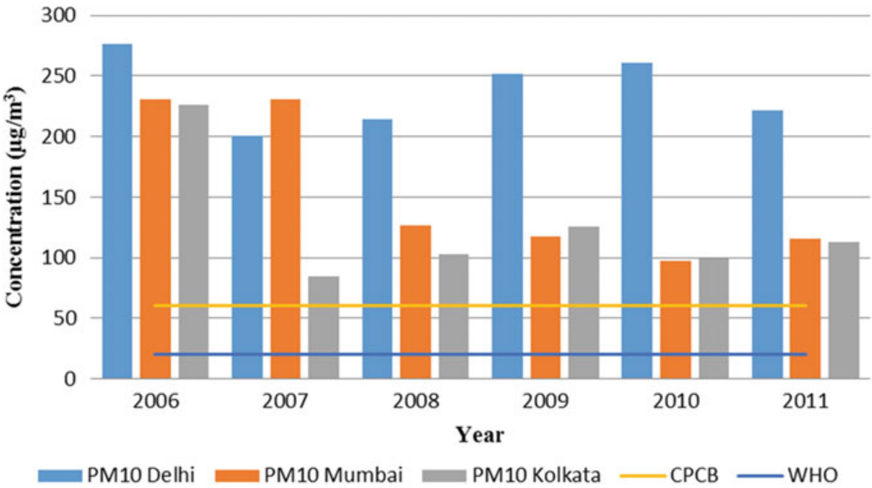

Fig. 3 Annual variation of ambient PM_{10} levels (2006–2011) in Indian mega cities

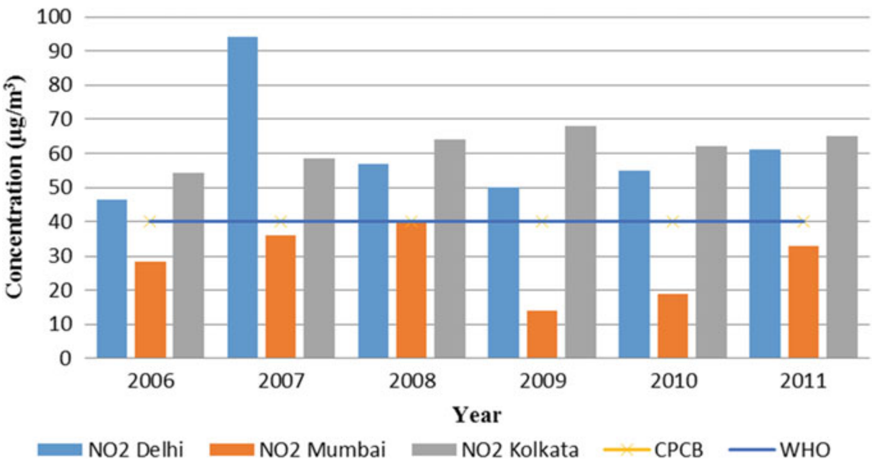

Fig. 4 Annual variation of ambient NO_2 levels (2006–2011) in Indian mega cities

declining. A decreasing trend has been observed in sulfur dioxide levels in residential areas of Delhi and Mumbai from year 2006–2011 (Mishra et al. 2016; Gurjar et al. 2016). The NO_2 level in Delhi, Mumbai, and Kolkata were reported varying from 46–94, 14–40, and 54–68 μg/m^3, respectively, from year 2006–2011. The NO_2 level exceeded the permissible limit for Delhi and Kolkata whereas it was within permissible limit in Mumbai. The vehicles were found to be one of the major sources of NO_2. According to CPCB, various actions are taken to reduce NO_2 levels

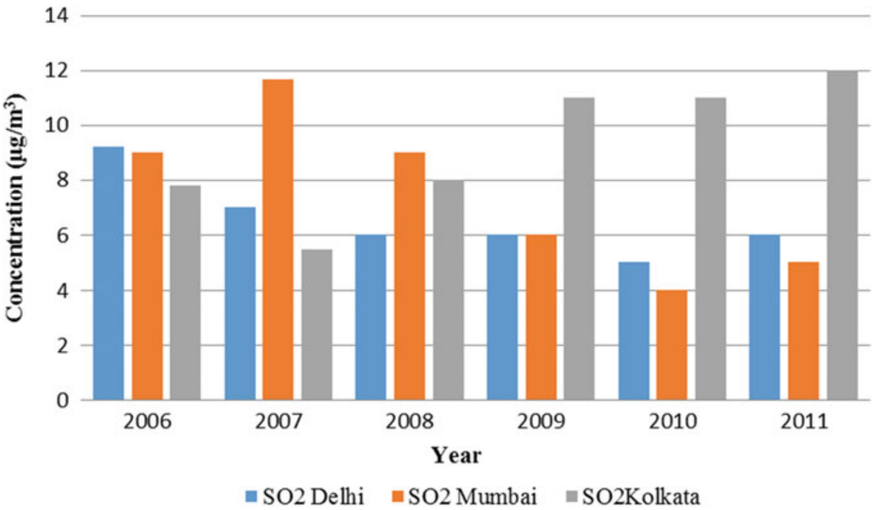

Fig. 5 Annual variation of ambient SO_2 levels (2006–2011) in Indian mega cities

but the numbers of vehicle are increasing drastically thereby limiting the desired outcome (Mishra et al. 2016).

The PM10 level in Delhi, Mumbai, and Kolkata were found to be varying from 201–276, 97–230, and 85–225 μg/m^3, respectively between monitoring years 2006 and 2011. The particulate matter concentration is also in excess of the permissible limit as prescribed by CPCB and WHO which is 60 and 40 μg/m^3, respectively for annual average. Most Indian cities outdo limits of particulate matter defined by CPCB. This may be because of increase in activities like refuse and biomass burning, vehicles, power plant emissions, and industrial sources (Gurjar et al. 2010).

Conclusion

The study reports that the ambient air of Delhi city is more polluted as compared to Mumbai and Kolkata. The annual average concentration of NO_2 is found more than prescribed limit by CPCB in Delhi and Kolkata. On the other hand, the concentration of SO_2 in all the megacities is reported to be within the permissible limit. All the megacities in India showed very high concentration of particulate matter than the standard prescribed by CPCB and WHO, while the noise pollution level of Mumbai is higher than the noise pollution level in Delhi and Kolkata. The noise pollution level is almost similar in all respective cities from 2006 to 2011. Noise pollution is more than the permissible limit in all megacities of India. The noise pollution also has the significant role in adversely affecting the environment.

Therefore, it has become a matter of great concern to improve the air quality for developing and maintaining a cleaner and healthier environment.

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Part II
Pollution Indicators

A Critical Review on Air Quality Index

Shweta Kumari and Manish Kumar Jain

Abstract Air quality index (AQI) is used worldwide to inform the public about levels of air pollution (degradation or improvement) and associated to different biological effects. Different types of anthropogenic activity mainly transportation have an enormous impact on the ambient air quality in several ways. The transportation dependence continues to grow; it is adversely affecting the quality of human life. Due to pollution, the ambient air quality in major cities (Delhi, Agra, Kanpur, Lucknow, Varanasi, Faridabad, Ahmedabad, Chennai, Bangalore and Hyderabad) in India is very poor. According to WHO surveys, India is one of the most polluted countries in the world. Concentrations of air pollutants affect Air Quality Index. Air Quality scenario in most of the Indian cities presents a harsh picture, the majority of national monitoring stations have recorded particulate concentrations exceeding the WHO recommended guideline. The higher the AQI value, the greater the level of air pollution and greater the health concern. This review paper is helpful to understand the development of Air quality Index in India with the experience of the world.

Keywords Ambient air quality · Air quality index · Air pollution
Transportation · Health effect

Introduction

Unpolluted air can be considered a basic requirement of human health and well-being. Today, air pollution is a well-known environmental problem associated with urban areas around the world (Beig 2010). Urban air pollution is the largest

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contributor to the regional burden of disease. There are a profound relation between human health and well-being from the one side and air pollution levels from another side. The high concentration of air pollutants can be life threatening causing breathing problems, headache, and dizziness; sometimes they even result in heart attacks (CPCB 2014).

Awareness of pollution levels is important not only to those who suffer from illnesses aggravated by air pollution but also to members of the general public, who, if conscious of daily variations in air pollution levels, may choose to alter their activities accordingly. In order to oppose air pollution problems and to plan abatement strategies, both the scientific community and the relevant authorities have focused on monitoring and analysing the atmospheric pollutants concentration. Various monitoring programmes have been undertaken to know the quality of air by generating the vast amount of data on the concentration of each air pollutant (e.g. SPM, CO, NO_x, SO_2, etc.) in different parts of the world (Pandey et al. 2014). The large data often do not convey the air quality status to the scientific community, government officials, policymakers and in particular to the general public in a simple and straightforward manner. So, in recent years air quality index (AQI) has become an adequate tool to understand pollution levels of an area and is of utmost importance for local and central governments (Ott and Thorn 1976). AQIs are synthetic indices summarizing multiple and multiscale measurements in a unique indicator, being air quality monitored with respect to many stations and different pollutants and inform the citizens about the levels of pollution in an adequate and understandable way and also to be used by the relevant authorities to take a series of predetermined measures to protect the health of the population (Air Quality Index 2003).

Objective

The main objective of the present study is to review for the daily Air Quality Index, which can provide the timely information to the public to take precautionary measures to protect their health (Kyrkilis et al. 2007)

Air Quality Index (AQI)

Air quality index (AQI) is an integral part of the environmental quality index (EQI), which was developed and used by National Wildlife Federation of U.S. in the late 1960s (Inhaber 1976). In 1971 the EQI, with a numerical index scale from 0 to 100 (0 for complete environmental degradation and 100 for perfect environmental conditions). In 1976, the USEPA established PSI which rated air quality from 0 to 500. The daily PSI is determined by the highest value of one of the five main air pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM10 and PM2.5) and sulphur dioxide (SO_2) (EPA 1999). Lohani (1984) applied factor analysis approach for finding the environmental index for Taiwan (Kumar and Goyal 2011).

Definition

An "air pollution index" may be defined as a scheme that transforms the (weighted) values of individual air pollution related parameters (for example, carbon monoxide concentration or visibility) into a single number, or set of numbers. In other words, an index is an equation which combines many pollutants in some mathematical expression to arrive at a single number for air quality (Bishoi et al. 2009). According to EPA Air Quality Index is defined as "the AQI is an index for reporting daily air quality. It tells how clean or polluted ambient air is, and what associated health effects might be a concern for you. The AQI focuses on health effects one may experience within a few hours or days after breathing polluted air" (Air Quality Index 2003) (Table 1).

Classification of Indices

There have been several Air Quality Indices proposed in the past. These indices are described in the following subsections.

Table 1 Pollutant concentration for each AQI category according to EPA

Category	Good	Moderate	Unhealthy for sensitive groups	Unhealthy	Very unhealthy	Hazardous	Severe
Index value	0–50	51–100	101–150	151–200	201–300	301–400	401–500
Pollutant	Conc. range	–	–	–	–	–	
CO 8 h (ppm)	0.0–4.5	4.5–9	9–12	12–15	15–30	30–40	40–50
NO_2	–	–	–	–	–	1.2–1.6	1.6–2.0
O_3 daily max (ppm)	–	–	–	–	0.20–0.40	0.40–0.50	0.50–0.60
O_3 8 h	0.00–0.06	0.06–0.08	0.08–0.10	0.10–0.12	0.12–0.37	–	–
PM 10 daily mean (ppm)	0–50	50–150	150–250	250–350	350–420	420–500	500–600
SO_2	0.0–0.03	0.03–0.14	0.14–0.22	0.22–0.3	0.3–0.6	0.6–0.8	0.8–1.0

US EPA Air Quality Index

Initially, the US EPA produced an Air Quality Index known as the Pollutant Standards Index (PSI) to measure pollutant concentrations for five criteria pollutants (particulate matter, sulphur dioxide, carbon monoxide, nitrogen dioxide and ground-level ozone). The measurements were converted to a scale of 0–500. An index value of 100 was ascribed to the numerical level of the short-term (i.e. averaging time of 24 h or less) primary NAAQS and a level of 500 to the significant harm levels (SHLs). An index value of 50, which is half the value of the short-term standard, was assigned to the annual standard or a concentration. Other index values were described as follows: 0–100, good; 101–200, unhealthy; greater than 200, very unhealthy. Use of the index was mandated in all metropolitan areas with a population in excess of 250,000. The EPA advocated calculation of the index value on a daily basis for each of the four criteria pollutants and the reporting of the highest value and identification of the pollutant responsible. Where two or more pollutants exceeded the level of 100, although the PSI value released was the one pertaining to the pollutant with the highest level, information on the other pollutants was also released. Levels above 100 could be associated with progressive preventive action by state or local officials involving issuance of health advisories for citizens or susceptible groups to limit their activities and for industries to cut back on emissions. At a PSI level of 400, the EPA deemed that "emergency" conditions would exist and that this would require cessation of most industrial and commercial activity. In July 1999, EPA issued its new "air quality index" (AQI) replacing the PSI. The principal differences between the two indices are that the new AQI does the following:

1. Incorporates revisions to the primary health-based national ambient air quality standards for ground-level ozone and particulate matter, issued by the EPA in 1977, incorporating separate values for particulate matter of 2.5 and 10.0 μg (PM2.5 and PM10), respectively.
2. Includes a new category in the index described as "unhealthy for sensitive groups" (index value of 101–150) and the addition of an optional cautionary statement, which can be used at the upper bounds of the "moderate" range of the 8-h ozone standard.
3. Incorporates colour symbols to represent different ranges of AQI values ("scaled" in the manner of colour topographical maps from green to maroon) that must be used if the index is reported in a colour format.
4. Includes mandatory requirements for the authorities to supply information to the public on the health effects that may be encountered at the various levels, including a requirement to report a pollutant-specific sensitive group statement when the index is above 100.
5. Mandates that the AQI shall be routinely collected and that state and local authorities shall be required to report it, for all metropolitan areas with more than 350,000 people (previously the threshold was urban areas with populations of more than 200,000).

6. Incorporates a new matrix of index values and cautionary statements for each pollutant.
7. Calculates the AQI using a method similar to that of the PSI—using concentration data obtained daily from "population-oriented State/Local Air Monitoring Stations (SLAMS)" for all pollutants except particulate matter (PM) (Ott and Thorn 1976).

The Mitre Air Quality Index (MAQI)

The Mitre air quality index (MAQI) was based on the 1970 Secondary Federal National Ambient Air Quality Standards. The index is the root sum square (RSS) value of individual pollutant indices, each based on one of the secondary air quality standard (Ott and Thorn 1976). This index is computed as follows:

$$\text{MAQI} = \left[I_S^2 + I_C^2 + I_P^2 + I_N^2 + I^2o\right]^{0.5} \quad (1)$$

where I_S is an index of pollution for sulphur dioxide, I_c is an index of pollution for carbon monoxide, I_P is an index of pollution for total suspended particulates, In is an index of pollution for nitrogen dioxide and I_O is an index of pollution for photochemical oxidants.

Sulphur Dioxide Index (***I_S***): The sulphur dioxide index is the RSS value of individual terms corresponding to each of the secondary standards. The RSS value is used to ensure that the index value will be greater than 1 if one of the standard values is exceeded. The index is defined as

$$I_s = \left[(C_{\text{sa}}/S_{\text{sa}})^2 + K_1(C_{s24}/S_{s24}) + K^2(C_{s3}/S_{s3})^2\right] \quad (2)$$

where C_{sa} is the annual arithmetic mean observed concentration of sulphur dioxide, S_{sa} is the annual secondary standard value (i.e., 0.02 ppm or 60 µg/m^3) consistent with the unit of measure of C_{sa}, C_{s24} is the maximum observed 24-h concentration of sulphur dioxide, S_{s24} is the 24-h secondary standard value (i.e., 0.1 ppm or 260 µg/m^3) consistent with the unit of measure of C_{s24}, C_{s3} is the maximum observed 3-h concentration of sulphur dioxide, S_{s3} is the 3-h secondary standard value (i.e., 0.5 ppm or 1300 µg/m^3) consistent with the unit of measure of C_{s3}, K_1 is 1 if $C_{s24} \geq S_{s24}$ and is 0 otherwise and K_2 is 1 if $C_{s3} \geq S_{s3}$ and is 0 otherwise.

Carbon Monoxide Index (***I_c***): The carbon monoxide index component of the MAQI is computed in a fashion similar to the sulphur dioxide index:

$$I_c = \left[(C_{c8}/S_{c8})^2 + K(C_{c1}/S_{c1})^2\right]^{0.5} \quad (3)$$

where C_{c8} is the maximum observed 8-h concentration of carbon monoxide, S_{c8} is the 8-h secondary standard value (i.e. 9 ppm or 10,000 μg/m^3) consistent with the unit of measure of C_{c8}, C_{c1} is the maximum observed 1-h concentration of carbon monoxide, S_{c1} is the 1-h secondary standard value (i.e. 35 ppm or 40,000 μg/m^3) consistent with the unit of measure of C_{c1}, and K is 1 if $C_{c1} \geq S_{c1}$ and is 0 otherwise.

Total Suspended Particulates Index (***I_P***): Total suspended particulate concentrations are always measured in micrograms per cubic metre. The index of total suspended particulates is computed as

$$I_p = \left[\left(C_{\text{pa}}/S_{\text{pa}}\right)^2 + K\left(C_{p24}/S_{p24}\right)^2\right]^{0.5} \tag{4}$$

where C_{pa} is the annual geometric mean observed concentration of total suspended particulate matter. The geometric mean is defined as

$$g = \left[\prod_{i=1}^{n} X_i\right]^{1/n} \tag{4a}$$

Because of the nature of a geometric mean, a single 24-h reading of 0 would result in an annual geometric mean of 0. The EPA recommends that one-half of the measurement method's minimum detectable value be substituted (in this case, 0.5 μg/m^3) when a "zero" value occurs. The S_{pa} is the annual secondary standard value (i.e., 60 μg/m^3), C_{p24} is the maximum observed 24-h concentration of total suspended particulate matter, S_{p24} is the 24-h secondary standard value (i.e., 150 μg/m^3) and K is 1 if $C_{p24} \geq S_{p24}$ and is 0 otherwise. Nitrogen Dioxide Index (In): The index of nitrogen dioxide does not require the RSS technique because only a single annual federal standard has been promulgated. The index is

$$I_n = C_{na}/S_{na} \tag{5}$$

where C_{na} is the annual arithmetic mean observed in the concentration of nitrogen dioxide and S_{na} is the annual secondary standard value (i.e., 0.05 ppm or 100 μg/m^3) consistent with the unit of measure of C_{na}.

Photochemical Oxidants Index (***I_o***): The index is computed in a manner similar to the nitrogen dioxide index. A single standard value is used as the basis of the index, which is

$$I_o = [C_{01}/S_{01}] \tag{6}$$

where C_{01} is the maximum observed the 1-h concentration of photochemical oxidants and S_{01} is the 1-h secondary standard value (i.e., 0.08 ppm or 160 μg/m^3) consistent with the unit of measure of C_{01}.

Application of the MAQI

An MAQI value of less than 1 indicates that all standards are being met for those pollutants in the MAQI computations. Because nine standards for five pollutants are involved in computing MAQI, any MAQI value greater than 3 guarantees that at least one standard value has been exceeded. If the MAQI values to be estimated by Eq. (1) are based on only five standards for three pollutants, then, for these figures, any MAQI value greater than 2.24 guarantees that at least one standard has been exceeded (Wang et al. 2005).

Extreme Value Index (EVI)

The extreme value index (EVI) was developed by Mitre Corporation for use in conjunction with the MAQI values. It is an accumulation of the ratio of the extreme values for each pollutant. The EVIs for individual pollutants are combined using the RSS method. Only those pollutants are included for which secondary "maximum values not to be exceeded more than once per year" are defined. The EVI is given by

$$EVI = [E_c^2 + E_s^2 + E_p^2 + E_o^2]^{0.5} \tag{7}$$

where E_c is an extreme value index for carbon monoxide, E_s is an extreme value index for sulphur dioxide, E_p is an extreme value index for total suspended particulates and E_o is an extreme value index for photochemical oxidants.

Carbon Monoxide Extreme Value Index (***E_c***): The carbon monoxide extreme value is the RSS of the accumulated extreme values divided by the secondary standard values. The index is defined as

$$E_c = [(A_{c8}/S_{c8})^2 + (A_{c1}/S_{c1})^2]^{0.5} \tag{8}$$

where A_{c8} is the accumulation of values of those observed 8-h concentrations that exceed the secondary standard and is expressed mathematically as

$$A_{c8} = \sum_i K_i (C_{c8})_i \tag{8a}$$

where K_i is 1 if $(C_{c8})\ i \geq S_{c8}$ and is 0 otherwise, S_{c8} is the 8-h secondary standard value (i.e., 9 ppm or 10,000 μg/m^3) consistent with the unit of measure of the $(C_{c8})_i$ values, A_{c1} is the accumulation of values of those observed 1-h concentrations that exceed the secondary standard and is expressed mathematically as

$$A_{c1} = \sum_i K_i (C_{c1})_i \tag{8b}$$

where K_i is 1 if $(C_{c1})_i \geq S_{c1}$ and is 0 otherwise, and S_{c1} is 1-h secondary standard value (i.e. 35 ppm or 40,000 μg/m^3) consistent with the unit of measure of the $(C_{c1})_\mathrm{i}$ values.

Sulphur Dioxide Extreme Value Index (***E_s***): The sulphur dioxide extreme value is computed in the same manner as the carbon monoxide EVI. This index also includes two terms, one for each of the secondary standards, which are maximum values, and to be expected more than once per year. It should be noted that no term is included for the annual standard. The index is computed as

$$\mathrm{E_s} = \left[(\mathrm{A_{s24}} / \ \mathrm{S_{s24}})^2 \ + \ \mathrm{A_{s3}} / \ \mathrm{S_{s3}})^2 \right]^{0.5} \tag{9}$$

where A_{s24} is the accumulation of those observed 24-h concentrations that exceed the secondary standard and is expressed mathematically as

$$A_{s24} = \sum_i K_i (C_{s24})_i \tag{9a}$$

where K_i is 1 if $(C_{s24})_i \geq S_{s24}$ and is 0 otherwise, S_{s24} is the 24-h secondary standard value (i.e., 0.1 ppm or 260 mg/m^3) consistent with the unit of measure of the $(C_{s24})_i$ values, A_{s3} is the accumulation of values of those observed 3-h concentration that exceed the secondary standard and is expressed mathematically as

$$A_{s3} = \sum\nolimits_i K_i (C_s)_i \tag{9b}$$

where K_i is 1 if $(C_{s3})_i \geq S_{s3}$ and is 0 otherwise, and S_{s3} is the 3-h secondary standard value (i.e., 0.1 ppm or 260 μg/m^3) consistent with the unit of measure of the $(C_{s3})I$ values.

Total Suspended Particulates Extreme Value Index (***E_p***): A secondary standard single maximum value not to be exceeded more than once per year is defined for total suspended particulates. The total suspended particulates EVI has only one term; no annual term is included. This index is computed as

$$E_p = A_{p24} / S_{p24} \tag{10}$$

where A_{p24} is the accumulation of those observed 24-h concentrations that exceed the secondary standard and is expressed mathematically as

$$A_{p24} = \sum_i K_i (C_{p24})_i \tag{10b}$$

where K_i is 1 if $(C_{p24}) \geq S_{p24}$ and is 0 otherwise, and S_{p24} is the 24-h secondary standard value (i.e., 150 μg/m^3).

Photochemical Oxidants Extreme Value Index (E_o): The index, like the total suspended particulates index, consists of a single term. The index is calculated as

$$E_o = A_{o1}/S_{o1} \quad (11)$$

where A_{o1} is the accumulation of those observed 1-h concentrations that exceed the secondary standard and is expressed mathematically as

$$A_{o1} = \sum_i K_i (C_{o1})_i \quad (11a)$$

where K_i is 1 if $(C_{o1})_i \geq S_{o1}$ and is 0 otherwise, and So 1 is the 1-h secondary standard value (i.e., 0.08 ppm or 160 μg/m^3) consistent with the unit of measure of the $(C_{o1})_i$ values.

Application of the EVI

The number or percentage of extreme values provides a meaningful measure of the ambient air quality because extreme high air pollution values are mostly related to personal comfort and well-being and affect plants, animals and property. The EVI and its component indices always indicate that all standards are not being attained if the index values are greater than 0. The index value will always be at least 1 if any standards based on a "maximum value not to be exceeded more than once per year" is surpassed. It should be noted that the index truly depicts the ambient air quality only if observations are made for all periods of interest (i.e. 1-h, 3-h, 8-h, and 24-h) during the year for which secondary standards are defined. Trend analyses using EVI values based on differing numbers of observations may be inadequate and even misleading.

Oak Ridge Air Quality Index (ORAQI)

The Oak Ridge Air Quality Index (ORAQI), which was designed for use with all major pollutants recognized by the EPA, was based on the following formula:

$$ORAQI = \left[COEF \sum_{i=1}^{3} ((Concentration\ of\ Pollutanti)/(EPA\ Standard\ for\ pollutanti))\right]^{0.967} \quad (12)$$

COEF equals 39.02 when $n = 3$, and equals 23.4 when $n = 5$. The concentration of the pollutants was based on the annual mean as measured by the EPA National Air Sampling Network (NASN). These are the same data on which the MAQI was based. The EPA standards used in the calculation were the EPA secondary standards normalized to a 24-h average basis. For SO_2, the standard used was 0.10 ppm; for NO_2, it was 0.20 ppm; and for particulates, it was 150–160 μg/m^3.

Application of the ORAQI

The coefficient and exponent values in the ORAQI formula mathematically adjust the ORAQI value so that a value of 10 describes the condition of naturally occurring unpolluted air. A value of 100 is the equivalent of all pollutant concentrations reaching the federally established standards.

Air Quality Depreciation Index

The air quality depreciation index, as proposed here, attempts to measure deterioration in air quality on an arbitrary scale that ranges between 0 and −10. An index value of '0' represents most desirable air quality having no depreciation from the best possible air quality with respect to the pollutants under consideration, while an index value of −10 represents maximum depreciation or worst air quality. Index value differing from 0 towards 10 represents successive depreciation in air quality from the most desirable.

The air quality depreciation index is defined as:

$$AQ_{dep} = \sum_{i=1}^{n} (AQ_i \times CW_i) - \sum_{i=1}^{n} CW_i \tag{13}$$

where AQ_i = Air Quality Index value for ith parameter, CW_i = Composite weight for ith parameter, n = Total no. of pollutants considered.

The values of the AQ_i were obtained from the value function curves. In the value function curves, the value of 0 signifies worst air quality and value of 1 represents the best air quality for corresponding pollutant concentration.

Value of CW_i in Eq. (13) is computed using the following expression:

$$CW_i = \frac{TW_i}{\sum_{i=1}^{n} TW_i} \times 10 \tag{14}$$

where

TW_i Total weight of ith parameter	AWi + $BPIW_i$ + HW_i
AW_i	Aesthetic weight for ith parameter
$BPIW_i$	Bio-physical impact weight for ith parameter
HW_i	Health weight for ith parameter

Air Quality Index Worldwide

Air Quality Index China

China has been monitoring the ambient atmosphere since the 1980s. Beginning in 1998, the Chinese government began to report the weekly air pollution index (API) by considering the total suspended particle (TSP), nitrogen oxide and sulphur dioxide concentration. Beginning in June 2000, major cities in China began to report daily API with daily measurements of PM10, nitrogen dioxide, and sulphur dioxide under the request of former State Environmental Protection Agency of China (now the Ministry of Environmental Protection of China) (Wang et al. 2013). A national ambient air quality standard of China was released in 1996 (NAAQS-1996) to define API calculation. The API (Air Pollution Index) is an index that indicates the pollution level of the atmosphere, ranging from 0 to 500. The higher the API value, the heavier the atmospheric pollution. According to NAAQS-1996, PM10, sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) were included in the calculation of the API. The first step in calculating the API is to calculate the IAPI (Individual Air Pollution Index) for each pollutant. The IAPI of each pollutant mentioned above is calculated as follows:

$$\mathrm{IAPI}_p = \frac{\mathrm{IAPI_{Hi}} - \mathrm{IAPI_{Lo}}}{\mathrm{BP_{Hi}} - \mathrm{BP_{Lo}}}(C_P - \mathrm{B}P_{Lo}) + \mathrm{IAPI}_{Lo} \tag{15}$$

where IAPI_P is the individual air pollution index for pollutant P (PM10, sulphur dioxide, and nitrogen dioxide) and C_P is daily mean concentration of pollutant P. $\mathrm{BP_{Hi}}$ and $\mathrm{BP_{Lo}}$ are the nearby high and low values of CP. $\mathrm{IAPI_{Hi}}$ and $\mathrm{IAPI_{Lo}}$ are the individual air pollution indexes in terms of $\mathrm{BP_{Hi}}$ and $\mathrm{BP_{Lo}}$. After the calculation of each IAPI_P, the API is then calculated by choosing the max IAPI_P as follows:

$$\mathrm{API} = \max(\mathrm{IAPI}_1; \ldots; \mathrm{IAPI}_n) \tag{16}$$

This equation suggests that the API is not the sum contribution of all of the air pollutants but rather the maximum value of the IAPI. The air pollutant with a maximum IAPI when the API is larger than 50 is designated as the primary pollutant. according to NAAQS-2012, 6 pollutants (PM2.5, PM10, Ozone, SO_2, NO_2 and CO) with 7 indexes (daily average PM2.5 concentration, daily average PM10 concentration, daily maximum 1-h Ozone concentration, maximum 8-h Ozone concentration, daily average SO_2 concentration, daily average NO_2 concentration and daily average CO concentration) are included in the new standard. The calculation of AQI replacing API is similar to that of API except that there are 7 individual AQI for each pollutant as follows:

$$IAQI = \frac{IAQI_{Hi} - IAQI_{Lo}}{BP_{Hi} - BP_{Lo}}(C_P - BP_{Lo}) + IAQI_{Lo} \quad (17)$$

where $IAQI_{Hi}$ and IAQ I_{Lo} are the individual air pollution indices in terms of BP_{Hi} and BP_{Lo}, respectively.

The daily API or AQI not exceeding 100 is considered to represent an attainment day. The number of attainment days in a year or the attainment rate is a key index to evaluate the air quality of a city. The attainment rate is the rate during the monitoring days when the API or AQI does not exceed 100 as follows (Tables 2, 3, 4 and 5).

Table 2 Concentration limits for AQI calculation

IAQI	PM 10 (μg/m^3)	SO_2 (μg/m^3)	PM 2.5 (μg/m^3)	NO_2 (μg/m^3)	1 h peak O_3 (μg/m^3)	8 h peak O_3 (μg/m^3)	CO (mg/m^3)
50	50	50	35	40	160	100	2
100	150	150	75	80	200	160	4
150	250	475	115	180	300	215	14
200	350	800	150	280	400	265	24
300	420	1600	250	565	800	800	36
400	500	2100	350	750	1000	–	48
500	600	620	500	940	1200	–	60

Source Chen et al. (2016)
*When 1 h average concentration of O_3 is higher than 800 μg/m^3, the 1 h average concentration of O_3 is used to calculate individual AQI or O_3 here
Attainment Rate = Sum of Attainment Days/Sum of Total Monitoring Day

Table 3 Each pollutants rate as the primary pollutant for all 190 cities with AQI data

Area	PM 2.5	PM 10	O_3	SO_2	NO_2	CO
National average	59.16	38.86	0.49	0	1.48	0.01
North China	60.36	37.27	0.20	0	0.28	0.01
South China	63.81	35.15	0.74	0	0.28	0.01
North-east China	52.64	41.26	0.03	0	6.04	0.03
North-west China	36.64	60.36	0.23	0	2.77	0

Source Chen et al. (2016); On the basis of above data

Table 4 10 cities with worst air quality

S. No.	City	Average AQI	Part of China
1	Xingtai	245	Hebei Province, North China
2	Shijiazhuang	229	Hebei Province, North China
3	Baoding	206	Hebei Province, North China
4	Korla	191	Xingjiang Province, North-west China
5	Handan	189	Hebei Province, North China
6	Hengshui	181	Hebei Province, North China
7	Yichang	172	Hubei Province, South China
8	Heze	167	Shandong Province, North China
9	Dezhou	165	Shandong Province, North China
10	Langfang	163	Hebei Province, North China

Source Chen et al. (2016)

Table 5 10 cities with best air quality

S. No.	City	Average AQI	Location
1	Sanya	41	Hainan Province, South China
2	Zhanjiang	50	Guangdong Province, South China
3	Zhoushan	52	Zhejing Province, South China
4	Shenzhen	59	Guangdong Province, South China
5	Lasa	60	Tibet, North-west China
6	Xiamen	61	Fujian Province, South China
7	Zhuhai	61	Guangdong Province, South China
8	Shanwei	63	Guangdong Province, South China
9	Yunfu	63	Guangdong Province, South China
10	Fuzhou	64	Fujian Province, South China

Source Chen et al. (2016)

Air Quality Index United States

Air quality index (AQI) is built adapting the Pollutants Standard Index developed by the United States Environmental Protection Agency, 1994. AQI is calculated for each pollutant as:

$$I_i = \frac{C_i}{S_i} \times 100 \quad (18)$$

where *i*, is the pollutant; C_i is the hourly concentration for nitrogen dioxide, carbon monoxide and ozone, while it is the 24-h carried mobile average for sulphur dioxide and particulate matter; S_i is the value for the attention state. The index '*I*' is equal to 100 when the concentration measured or the mobile mean over 24 h is equal to the attention state; an index lower than 100 means that the pollutant has a value lower than the attention state. After the different indexes, I_i have been calculated for every pollutant, we select the maximum index *I* between different indexes:

$$I \; max_i \; I_i$$

In this way, a characterization of the pollution level apart from the pollutant taken into account is obtained (Wang et al. 2005).

Air Quality Index India

NAAQS Dependent Air Quality Index

In this method, equal importance was given to all the pollutants. Using observed and standards value, the quality rating for each pollutant was calculated. The geometric mean of these quality ratings gives the Air Quality Index. Based on this assumption, the Air Quality Index was derived in the manner outlined as under. The existing concentrations of pollutants were compared with ambient air quality standards (with the standard being assumed as reference baseline for each pollutant) and accordingly the quality rating for a particular pollutant was derived as shown below:

$$Q_i = 10(C_i/S_i) \tag{19}$$

where

Q_i Quality rating for a *i*th pollutant
C_i Concentration of ith pollutant
S_i Air quality standard for *i*th pollutant

$$\text{Air Quality Index (AQI)} = (Q_1 \times Q_2 \times \cdots \times Q_n)^{1/n} \tag{20}$$

where

n Number of pollutants considered.

Following the above criteria, air quality index (AQI) is calculated for all the monitoring stations. Given below (Table 6) is the Air Quality Index of some Indian cities as recorded by World Health Organization.

Table 6 Indian cities and their AQI

S. No.	City	PM 10 (annual mean, μg/m^3)	PM 2.5 (annual mean, μg/m^3)	AQI
1	Agra	196	105	Extremely high
2	Ahmedabad	83	100	High
3	Allahabad	317	170	Extremely high
4	Amritsar	202	108	Extremely high
5	Bangalore	118	63	Very high
6	Bhopal	173	93	Extremely high
7	Bhubaneswar	81	43	High
8	Chennai	57	44	High
9	Dehradun	188	100	Extremely high
10	Delhi	29	122	Extremely high
11	Dhanbad	178	95	Extremely high
12	Guwahati	92	49	High
13	Gwalior	329	176	Extremely high
14	Hyderabad	79	59	High
15	Indore	143	76	Very high
16	Jaipur	187	100	Extremely high
17	Jalandhar	140	75	Very high
18	Jammu	119	64	Very high
19	Jodhpur	189	101	Extremely high
20	Kanpur	215	115	Extremely high
21	Kolkata	135	61	Extremely high
22	Lucknow	211	113	Extremely high
23	Mumbai	117	63	Very high
24	Nagpur	103	55	Very high
25	Noida	136	73	Very High
26	Patna	167	149	Extremely high
27	Pune	92	49	High

Source WHO

Conclusion

The concept of AQI in India is examined and found easy to understand. An AQI system based on maximum operator function (selecting the maximum of sub-indices of various pollutants as overall AQI) is adopted. Ideally, eight parameters (PM10, PM2.5, NO_x, SO_2, CO, O_3, NH_3, and Pb) having short-term standards should be considered for near real-time dissemination of AQI. It is recognized that air concentrations of Pb are not known in real time and cannot contribute to AQI. However, its consideration in AQI calculation of past days will help in examining the status of this important toxic. The proposed index has six categories and the colour schemes as shown below.

Good	Satisfactory	Moderately polluted	Poor	Very poor	Severe
(0-50)	(51-100)	(101-200)	(201-300)	(301-400)	(> 401)

A scientific basis, for severe >401, in terms of attainment of air quality standards and dose–response relationships of various parameters have been derived and used in arriving at breakpoint concentrations for each AQI category. It is proposed that for continuous air quality stations, AQI is reported in near real time for as many parameters as possible.

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Aquatic Insects as Pollution Indicator—A Study in Cachar, Assam, Northeast India

Arpita Dalal and Susmita Gupta

Abstract A seasonal study on water and aquatic insects of one oxbow lake (Satkorakandi *anua*) and one floodplain lake (Magura *haor*) of Cachar, Assam was conducted. Environmental variables of water, diversity, and density of aquatic insects were estimated by standard methods. In the oxbow lake, dissolved oxygen values were found to be lower than that of the floodplain lake. The pH of water was found below the acceptable limit of BIS in post-monsoon in oxbow lake, and in most of the seasons in floodplain lake. Other variables were within the permissible limit. The Biological Monitoring Working Party (BMWP) and $BMWP^{THAI}$ scores computed on the basis of tolerance level of the aquatic insects to organic pollution revealed poor water condition in all the sites and seasons in *anua* while in *haor* water condition was found moderate in some seasons of the year. Different biotic indices, correlation coefficients, canonical correspondence analysis were computed and the role of aquatic insects as pollution indicator has been discussed in the paper.

Keywords Aquatic insects · *Anua* · *Haor* · Biotic score · CCA

Introduction

Freshwater ecosystems are most endangered ecosystems of the world (Dudgeon 1999) and declines in biodiversity are far greater in freshwater than any other ecosystem of the world (Sala et al. 2000). Aquatic insects are important in freshwater systems as they support the terrestrial lives through aquatic maintenance of food chains and also serve as indicators of water quality due to their varying tolerance limits to organic and inorganic substances (Bass 1994; Mason 2002). Use of insects and/or their differential responses to stimuli in their aquatic habitat to determine the quality of that environment is known as Biomonitoring (Arimoro and Ikomi 2008; Merritt et al. 2008).

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The district Cachar is rich in wetlands particularly in floodplain lakes and oxbow lakes formed by River Barak, the major river of south Assam. Floodplain lakes are floodplains of river which help in drainage and flood control. Oxbow lakes are river formed perennial U-shaped wetlands which are generally formed due to change in river course. In spite of the presence of diverse types of wetlands in south Assam, only a few studies on aquatic insect diversity of oxbow and floodplain lakes were carried out (Purkayastha and Gupta 2012; Gupta and Narzary 2013). Present study focused on the comparison of the health of two different ecosystems using aquatic insects, popularly used in biomonitoring. The study also aimed to confirm the role of aquatic insects as bioindicator.

Materials and Methods

Study Area

Figure 1 shows the study sites. For this study, one oxbow lake (Satkorakandi *anua*—591,012.65 m^2) locally termed as '*anua*' and one floodplain lake (Magura *haor*—187,146 m^2) locally termed as '*haor*' were selected. Both the lakes are located in Cachar district of Assam, India. This *anua* is a meander of the River Barak whereas the *haor* is the floodplain lake of the River Rukni, one of the tributaries of the River Barak (Dalal and Gupta 2015). Both *anua* and *haor* are surrounded by human habitation and agricultural fields. The selected sites were Sat1 (N 24°45.292′ E 092°52.474′) and Sat2 (N 24°45.170′ E 092°52.695′) from Satkorakandi *anua*. The *anua* is located near a mosque. Sites selected from Magura *haor* were Haor1 (N 24°36.836′ E 092°51.887′) and Haor2 (N 24°36.910′ E 092°51.924′). These sites are mainly used for fishing. Seasonal collections (post-monsoon, winter, pre-monsoon, and monsoon) of water and aquatic insects were done from all these sites during 2013–14.

Methods of Collection and Analyses

The samples were collected in thoroughly cleaned PVC bottles and BOD bottles (for estimating DO) to the brim, without leaving any space in order to prevent the premature release of dissolved gases during the transit period. Environmental variables like air temperature (AT), water temperature (WT), rainfall (RF), transparency (TR), depth, pH, electrical conductivity (EC), total dissolved solid (TDS), dissolved oxygen (DO), free carbon dioxide (FCO_2), total alkalinity (TA), sodium (Na), potassium (K), nitrate (NO_3^-), and phosphate (PO_4^{3-}) were estimated. Air and water temperature were measured with the help of a mercury bulb thermometer (0–110 °C). RF data were collected from Meteorological Observatory, Cachar

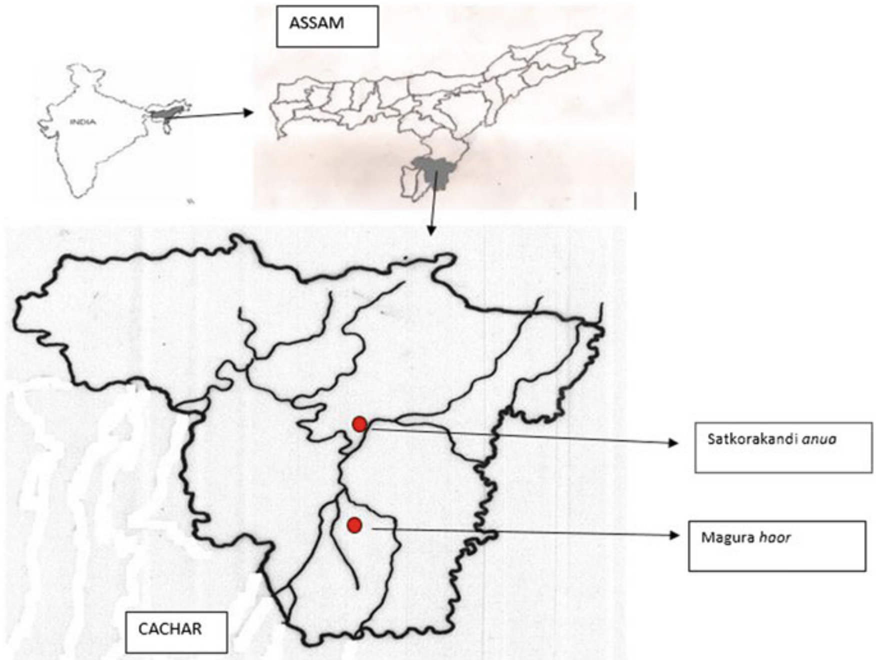

Fig. 1 Map of Cachar district, Assam (India) showing the location of Magura *haor* and Satkorakandi *anua*

College, Silchar, Assam. The pH and EC were measured by pH meter (Systronics μ pH System 361) and conductivity meter (Systronics TDS Meter 308), respectively. TR was estimated by taking the measurement of appearance and disappearance of Secchi's disk (Michael 1984). DO was estimated by Winkler method while TA and FCO_2 contents were analyzed by titrating with strong acid and alkali, respectively (Ramesh and Anbu 1996; APHA 2005). NO_3^- was estimated by using UV spectrophotometer and PO_4^{3-} was estimated using light spectrophotometer (APHA 2005). Sodium and potassium were estimated using flame photometer and depth was measured following standard literature (APHA 2005).

Aquatic insects were collected from different sites by kick method whereby the vegetation is disturbed and a circular net (mesh size 60 µm) is dragged around the vegetation for a unit of time (Macan and Maudsley 1968; Brittain 1974). Three such drags constituted a sample. Collected insects were immediately sorted and preserved in 70% ethyl alcohol. They were identified using Motic and Magnus stereozoom microscopes and with the help of standard keys (Kumar 1973a, b; Bal and Basu 1994a, b; Westfall and Tennessen 1996; Cheng et al. 2001; Bal and Basu 2004; Epler 2006, 2010; Madden 2010). Statistical analyses of data were done using different softwares like Past, IBM SPSS STATISTICS version 21, CANOCO for windows 4.5. Biomonitoring scores used were SIGNAL 2 (Chessman 2003), BMWP and ASPT (Mandaville 2002), $BMWP^{THAI}$, and $ASPT^{THAI}$ (Mustow 2002).

Results and Discussion

Physicochemical Parameters

Tables 1 and 2 show the seasonal variations of physicochemical properties of water for both the lakes. In the oxbow lake, DO values in Sat1 (post-monsoon, winter and monsoon) and Sat2 (post- and pre-monsoon) were recorded below 5 which is the acceptable limit of DO (Stiff et al. 1992). In contrast in both the sites of *haor* (floodplain lake) in all the seasons, DO values were above 4 except in Haor2 in monsoon. FCO_2 of all the sites in all the seasons except Haor1 in post-monsoon were recorded beyond 6 (acceptable limit as per BIS 2012). Low photosynthesis and high respiration rate of the aquatic biota might be one of the reasons for low DO and high FCO_2 in the oxbow lake. Das and Chakrabarty (2008) also recorded DO below 4 in Hansadanga beel (oxbow lake), West Bengal. A classical negative correlation between FCO_2 and DO (Wetzel 1984) was found in *haor* where RF was found significantly negatively correlated with DO and positively correlated with FCO_2 indicating organic pollution induced by anthropogenic input by surface runoff (Table 3). Previous study at one oxbow lake in Cachar district also recorded positive correlation of RF with FCO_2 (Gupta and Devi 2014). TA values, NO_3^- and PO_4^{3-} concentration in water were within the permissible limit in all the sites in all the seasons (WHO 2006; BIS 2012). This agreed with the findings of previous studies in lentic systems of Cachar district, Assam (Purkayastha and Gupta 2012; Gupta and Narzary 2013; Barman et al. 2014; Dalal and Gupta 2014). pH of Haor1, Haor2, and Sat2 (post-monsoon, pre-monsoon, and monsoon) and Sat1 (post-monsoon and monsoon) were recorded below the acceptable limit (6.5), i.e., they were slightly acidic in nature while rest of the physicochemical variables of water in all the sites and in all the seasons were within the permissible limit (WHO 2006; BIS 2012).

Aquatic Insects

A total of 6 orders, 22 families, 43 genera, and 53 species were recorded from the floodplain lake, Magura *haor* whereas from the oxbow lake, Satkorakandi *anua* 5 orders, 15 families, 27 genera, and 32 species were recorded. Highest number of orders was recorded from Haor1, Haor2 during post-monsoon and pre-monsoon, respectively, and Sat2 during post-monsoon and winter whereas lowest number of orders was recorded from Sat1 (monsoon). Highest number of families was recorded from Haor1 (pre-monsoon) and lowest from Sat1 (winter and monsoon). Haor2 (pre-monsoon) had the highest number of genera and species whereas Sat1 (monsoon) had the lowest number (Fig. 2). In both the systems, 14 species were

Table 1 Physicochemical properties of water of two different sites of Magura *haor* (floodplain lake) of Cachar, Assam during Post-monsoon–Monsoon (2013–14) (Mean ± SD)

Seasons	Post-monsoon		Winter		Pre-monsoon		Monsoon	
Sites	Haor1	Haor2	Haor1	Haor2	Haor1	Haor2	Haor1	Haor2
AT (°C)	25 ± 0	27 ± 0	24 ± 0	24 ± 0	28 ± 0	28 ± 0	34.5 ± 0	34.5 ± 0
WT (°C)	21 ± 0	21 ± 0	22 ± 0	22 ± 0	25.5 ± 0	26 ± 0	31 ± 0	28 ± 0
RF (mm)	93 ± 84.94	93 ± 84.94	6.67 ± 11.54	6.67 ± 11.54	142.83 ± 116.7	142.83 ± 116.7	442.16 ± 17.41	442.16 ± 17.41
TR (cm)	33.9 ± 0	14.5 ± 0	14.5 ± 0	21.65 ± 0	14.5 ± 0	13.1 ± 0	19.75 ± 0	24.5 ± 0
Depth (cm)	33.9 ± 0	20 ± 0	17 ± 0	34.5 ± 0	27.5 ± 0	23.5 ± 0	28.5 ± 0	31.8 ± 0
DO (mg l^{-1})	8.01 ± 1.97	8.66 ± 1.88	8.22 ± 0.43	10.73 ± 1.45	6.61 ± 0.55	7.88 ± 0.85	6.33 ± 0.25	4.99 ± 0.07
FCO_2 (mg l^{-1})	5.99 ± 2	9.32 ± 1.15	7.06 ± 1.01	7.98 ± 0	10.98 ± 1.71	11.24 ± 3.59	10.85 ± 1.02	19.70 ± 4.40
TA (mg l^{-1})	39.27 ± 0.70	22.2 ± 2.03	27.07 ± 1.01	30.66 ± 2.31	11.93 ± 1.15	11 ± 1.71	28.8 ± 2.03	28.2 ± 2.03
NO_3^- (mg l^{-1})	0.18 ± 0.11	BDL	1.35 ± 1.01	0.29 ± 0.18	0.16 ± 0.16	0.23 ± 0.08	0.005 ± 0.04	0.009 ± 0.02
PO_4^{3-} (mg l^{-1})	0.05 ± 0.06	0.22 ± 0.03	0.42 ± 0.25	0.15 ± 0.03	0.02 ± 0.01	0.02 ± 0.01	0.067 ± 0.03	0.186 ± 0.06
pH	6.27 ± 0.07	5.68 ± 0.15	6.91 ± 0.05	6.8 ± 0.06	6.24 ± 0.10	5.98 ± 0.07	6.35 ± 0.03	6.07 ± 0.07
EC (µS cm^{-1})	55.55 ± 4.36	19.14 ± 3.01	44.56 ± 1.91	50.44 ± 4.56	40.2 ± 9.14	51.5 ± 11.02	38 ± 2.38	28.28 ± 3.29
TDS (ppm)	36.1 ± 2.85	12.49 ± 1.99	29.02 ± 1.22	32.81 ± 3	26.09 ± 5.94	33.46 ± 7.17	24.66 ± 1.45	18.35 ± 2.13
Na (mg l^{-1})	2.31 ± 0.86	2.97 ± 2.11	1.76 ± 0.24	4.14 ± 1.40	2.11 ± 0.23	1.80 ± 0.07	1.02 ± 0.01	1.43 ± 0.30
K (mg l^{-1})	3.73 ± 0.31	1.24 ± 0.23	2.56 ± 0.12	2.54 ± 0.31	3.76 ± 1.24	3.35 ± 0.004	3.05 ± 0.38	3.33 ± 0.23

Table 2 Physicochemical properties of water of two different sites of Satkorakandi *anua* (Oxbow lake) of Cachar, Assam during Post-monsoon–Monsoon (2013–14) (Mean ± SD)

Seasons	Post-monsoon		Winter		Pre-monsoon		Monsoon	
Sites	Sat1	Sat2	Sat1	Sat2	Sat1	Sat2	Sat1	Sat2
AT (°C)	29 ± 0	22 ± 0	25 ± 0	26 ± 0	26 ± 0	26 ± 0	29 ± 0	30 ± 0
WT(°C)	24 ± 0	23 ± 0	23 ± 0	20.1 ± 0	25 ± 0	25.2 ± 0	27 ± 0	28 ± 0
RF (mm)	93 ± 84.94	93 ± 84.94	6.67 ± 11.54	6.67 ± 11.54	142.83 ± 116.7	142.83 ± 116.7	442.16 ± 17.41	442.16 ± 17.41
Depth (cm)	115 ± 0	120 ± 0	76 ± 0	47.5 ± 0	79 ± 0	78 ± 0	121.6 ± 0	120.1 ± 0
DO (mg l^{-1})	2.33 ± 0.12	3.6 ± 0.20	3.94 ± 0.28	4.66 ± 0.12	5.99 ± 0.53	3.48 ± 0.23	2.33 ± 0.24	4.04 ± 0.28
FCO_2 (mg l^{-1})	10.65 ± 3.05	9.99 ± 0	15.71 ± 1.96	16.57 ± 0.60	8.98 ± 2.03	10.18 ± 2.03	15.71 ± 0.46	14.84 ± 1.96
TA (mg l^{-1})	32.4 ± 1.44	31.67 ± 1.36	48.6 ± 2	51.93 ± 1.30	28.13 ± 1.01	25.06 ± 1.01	28.8 ± 0.35	30.4 ± 2.03
NO_3^- (mg l^{-1})	0.07 ± 0.07	0.01 ± 0.07	1.28 ± 0.76	0.31 ± 0.19	0.06 ± 0.04	0.06 ± 0.02	0.085 ± 0.03	0.072 ± 0.10
PO_4^{3-} (mg l^{-1})	0.02 ± 0.02	0.03 ± 0.02	0.24 ± 0.02	0.22 ± 0.01	0.02 ± 0.01	0.04 ± 0.04	0.146 ± 0.09	0.367 ± 0.14
pH	6.2 ± 0.06	6.25 ± 0.01	7.18 ± 0.05	7.03 ± 0.03	6.62 ± 0.02	6.35 ± 0.04	6.49 ± 0.14	6.45 ± 0.03
EC (µS cm^{-1})	36.83 ± 0.59	34.1 ± 0.82	76.29 ± 2.03	93.76 ± 2.07	36.55 ± 0.71	37.03 ± 2.02	42.91 ± 2.63	37.18 ± 4.72
TDS (ppm)	24.03 ± 0.42	22.3 ± 0.61	49.62 ± 1.37	61.04 ± 1.41	23.71 ± 0.45	24.06 ± 1.34	27.83 ± 1.69	24.03 ± 2.87
Na (mg l^{-1})	4.09 ± 0.86	5.1 ± 1.75	7.73 ± 0.60	5.01 ± 0.46	1.34 ± 0.01	2.21 ± 0.006	2.01 ± 0.32	1.48 ± 0.01
K (mg l^{-1})	1.83 ± 0.36	1.55 ± 0.16	2.21 ± 0.34	3.55 ± 0.17	1.80 ± 0.19	1.75 ± 0.03	1.90 ± 0.91	1.72 ± 0.18

Table 3 Pearson's 2-tailed correlation among the physicochemical variables of water, aquatic insect species richness and species density of both Magura *haor* and Satkorakandi *anua* of Cachar, Assam

Magura *haor*	Satkorakandi *anua*
DO versus FCO2 (−**)	Insect density versus WT (−*)
RF versus FCO2 (+**)	RF versus depth (+**)
RF versus DO (−**)	
Insect density versus species richness (+**)	Insect density versus TA (+*)
	Insect density versus K (+*)
	Insect density versus species richness (+**)

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

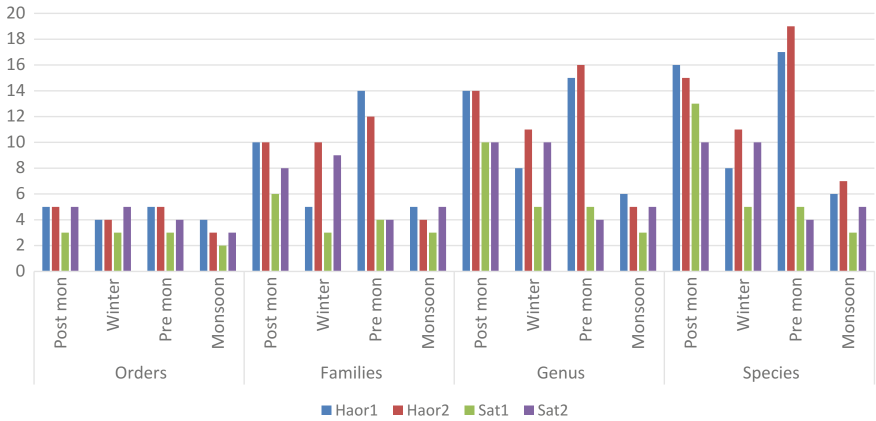

Fig. 2 Spatial and seasonal variations in total number of orders, families, genera, and species of aquatic insects in two different sites of Magura *haor* and Satkorakandi *anua* in Cachar district, Assam during post-monsoon to monsoon season (2013–14)

found common. Compared to the *haor, anua* had a record of less number of species although oxbow lakes are recognized for their importance in the maintenance and integrity of regional biodiversity and as natural nurseries of commercially important species (Agostinho et al. 2000). The reason might be less human intervention in the *haor* compared to the *anua*. Again between the two sites of *anua*, Sat2 had prominently lower number of insect taxa. This may be explained by the prevalence of macrophytes in Sat1 and absence in Sat2 as insects have close association with macrophytes (Wilcox and Meeker 1992; Moretti and Callisto 2005).

Tables 4 and 5 show the list of species, and dominance status (Engelmann 1978) of aquatic insects in different sites of the two lakes in different seasons. Plate 1 shows images of a few aquatic insect species recorded in the systems. *Octhebius* sp. (Hydraenidae) was the eudominant species in Haor2 in post-monsoon while *Cloeon* sp. was eudominant in post-monsoon in Haor1 and in both the sites of *haor* in monsoon. In Satkorakandi *anua* the eudominant taxa were *Paraplea* sp. (Pleidae) in Sat1 in monsoon, *Galerucella* sp. (Chrysomelidae) in Sat2 in pre-monsoon, *Cloeon* sp. (Baetidae) in Sat2 in winter, and Sat1 and 2 in pre-monsoon and *Culex* sp. (Culicidae) in Sat1 in winter. *Cloeon* sp. (order- Ephemeroptera, family- Baetidae) was found eudominant in both the systems. *Haor* had lower number of eudominant species in comparison to the *anua* which again proved higher diversity in *haor* than that of *anua*. This was also shown by Shannon_H′ values in *haor* where all the values were within the proper range of 1.5–3.5 (Turkmen and Kazanci 2010) except one season. Again most of the Margalef water quality index values of both the systems indicated moderate pollution. According to Lenat et al. (1980), Margalef water quality index values greater than 3 indicate clean condition; values less than 1 indicate severe pollution and intermediate value indicate moderate pollution (Table 6).

In this study, the families of importance were Hydraenidae, Baetidae, Chrysomelidae, and Culicidae because of their eudominance status (relative abundance > 31.7%). Baetidae, Hydraenidae, and Chrysomelidae are semi-tolerant families with tolerance value 4 and 5 while Culicidae is the most tolerant family having tolerance value 1 (Chessman 2003). Eudominant status of family Culicidae in *anua* indicated high level of pollution. Apart from the eudominant families tolerance levels of most of the families recorded in both the systems are 4 and 5, i.e., semi-tolerant (Mandaville 2002; Chessman 2003) indicating degrading nature of both the systems. The family Baetidae of order Ephemeroptera although belong to the sensitive group EPT (Ephemeroptera, Plecoptera, Trichoptera) (Rosenberg and Resh 1993) its tolerance value for both BMWP and SIGNAL is 4. Because of its high significance level of association with moderately polluted water, it is poorly prospected in biomonitoring (Alba- Tercedor et al. 1991; Menetrey et al. 2008). Previous studies in Cachar district also had records of *Cloeon* sp., family Baetidae from the moderately polluted ecosystems (Gupta and Narzary 2013; Dalal and Gupta 2014). Aquatic insect diversity and occurrence of mostly semi-tolerant taxa in both the systems showed human influence. The Biological Monitoring Working Party (BMWP) and $BMWP^{THAI}$ scores computed on the basis of tolerance level of the aquatic insects to organic pollution revealed poor water condition in all the sites and seasons in *anua* while in *haor* water condition was found moderate in some seasons of the year. Average Score Per Taxon (ASPT) and $ASPT^{THAI}$ scores of both the lakes also showed similar water condition ranging from probable moderate pollution (PMP) to doubtful quality (DQ). Stream Invertebrate Grade Number-Average Level (SIGNAL 2) scores of all the sites were below 4 indicating severe pollution status. Although SIGNAL 2 score is basically developed for stream studies it is also in use for wetland studies. Wetlands are likely to have naturally lower scores than streams in the same region (Chessman 2003). Hence, severe

Table 4 Dominance status of the aquatic insect species of the two different sites of Magura *haor* (floodplain lake) of Cachar, Assam during post-monsoon–monsoon, 2013–14 using Engelmann Scale (1978)

Orders	Seasons	Post-monsoon		Winter		Pre-monsoon		Monsoon	
	Taxa	Haor1	Haor2	Haor1	Haor2	Haor1	Haor2	Haor1	Haor2
Hemiptera	**Family**: **Gerridae**								
	Neogerris parvula	12.07	3.64	28.61	–	5.62	2.13	–	–
	Gerris sp.	–	0.91	–	–	–	–	–	–
	Gerris lepcha	6.9	0.91	–	8.33	–	2.13	–	–
	Trepobates sp.	–	–	7.15	–	–	–	–	–
	Limnogonus fossarum	–	–	–	–	–	2.13	–	–
	Family: **Notonectidae**								
	Anisops breddini	–	6.36	–	–	1.12	4.26	–	–
	Nychia sappho	–	0.91	–	–	–	–	–	–
	Aphelonecta sp.	1.72	1.82	–	–	–	21.29	–	–
	Anisops bouvieri	–	–	–	–	–	10.64	–	–
	Anispos exiguus	–	–	–	–	–	2.13	–	–
	Family: **Micronectidae**								
	Micronecta haliploides	3.45	–	–	–	–	–	–	10.35
	Micronecta siva	3.45	–	–	–	–	–	–	6.9
	Micronecta scutellaris	–	–	–	8.33	–	–	–	–
	Micronecta ludibunda	–	–	–	–	–	–	–	6.9
	Micronecta sp.	–	–	–	–	5.62	–	–	–
	Family: **Veliidae**								
	Baptista collaris	–	–	–	4.17		–	–	–
	Family: **Pleidae**								
	Paraplea sp.	–	0.91	–	–	1.12	–	–	–
	Family: **Nepidae**								
	Ranatra elongata	–	0.91	–	–		–	–	–
	Ranatra gracilis	–	–	–	4.17		–	–	–
	Ranatra sordidula	–	–	–	–	–	–	2.78	–
	Laccotrephes ruber	–	–	–	–	–	2.13	–	–
	Family: **Hydrometridae**								
	Hydrometra greeni	–	–	–	–	1.12	4.26	–	–
	Family: **Belostomatidae**								
	Diplonychus sp.	–	–	–	–	–	–	2.78	–

(continued)

Table 4 (continued)

Orders	Seasons	Post-monsoon		Winter		Pre-monsoon		Monsoon	
	Taxa	Haor1	Haor2	Haor1	Haor2	Haor1	Haor2	Haor1	Haor2
Coleoptera	**Family**: **Noteridae**								
	Suphisellus sp.	1.72	–	–	–	3.37	8.51	8.33	–
	Family: **Hydrophilidae**								
	Laccobius sp.	1.72	0.91	–	4.17	–	–	–	–
	Cercyon sp.	–	0.91	–	–	–	–	–	–
	Berosus sp.	–	–	7.15	–	1.12	2.13	–	–
	Helochares sp.	–	–	7.15	8.33			–	–
	Berosus indicum	–	–	–	–	1.12	–	–	–
	Hydrobius sp.	–	–	–	–	1.12	–	–	–
	Family: **Hydraenidae**								
	Octhebius sp.	–	58.19 (**E**)	–	–	–	–	–	–
	Family: **Dytiscidae**								
	Laccophilus sp.	–	–	–	8.33	1.12	2.13	–	–
	Cybister sp.	–	–	–	–	1.12	8.51	–	–
	Cybister lateralimarginalis	–	–	–	–	–	2.13	–	–
	Family: **Chrysomelidae**								
	Donacia sp.	–	–	–	20.83	–	–	–	–
	Galerucella sp.	–	–	–	–	1.12	2.13	–	–
	Family: **Hydrochidae**								
	Hydrochus sp.	–	–	–	8.33	–	–	–	–

(continued)

Table 4 (continued)

Orders	Seasons	Post-monsoon		Winter		Pre-monsoon		Monsoon	
	Taxa	Haor1	Haor2	Haor1	Haor2	Haor1	Haor2	Haor1	Haor2
Odonata	**Family**: **Libellulidae**								
	Hydrobasileus brevistylus	–	0.91	–	–	–	–	–	6.9
	Potamarcha sp.	–	–	7.15	–	–	–	–	–
	Leucorrhinia intacta	–	–	–	–	–	–	–	6.9
	Crocothemis servilia servilia	1.72	–	–	–	–	–	–	–
	Family: **Coenagrionidae**								
	Ischnura senegalensis	1.72	0.91	–	–	–	–	–	–
	Agriocnemis femina	3.45	–	14.31	–	–	–	8.33	–
	Ceriagrion cerinorubellum	–	–	7.15	–	1.12	–	–	–
	Pseudagrion australasiae	–	–	–	–	–	–	2.78	–
	Pseudagrion prunisom	–	–	–	–	–	–	–	3.45
	Family: **Aeshnidae**								
	Aeshna sp.	–	–	–	–	1.12	–	–	–
Ephemeroptera	**Family**: **Baetidae**								
	Cloeon sp.	48.28 (**E**)	17.28	21.46	16.67	4.5	10.64	75 (**E**)	58.66 (**E**)
Diptera	**Family**: **Culicidae**								
	Culex sp.	–	4.55	–	–	65.18	8.51	–	–
	Aedes sp.	1.72	–	–	–	–	–	–	–
	Family: **Chironomidae**								
	Ablabmesyia sp.	6.9		–	8.33	3.37	–	–	–
	Family: **Tabanidae**								
	Tabanus sp.	–	–	–	–	–	2.13	–	–
Orthoptera	**Family**: **Gryllidae**								
	Eunemobius sp.	–	–	–	–	–	2.13	–	–

RA < *1* Subrecedent; *1.1–3.1* Recedent; *3.2–10* Subdominant; *0.1–31.6* Dominant; >*31.7%* Eudominant (E)

Table 5 Dominance status of the aquatic insect species of the two different sites of Satkorakandi *anua* (Oxbow lake) of Cachar, Assam during post-monsoon–monsoon 2013–14 using Engelmann Scale (1978)

Orders	Seasons	Post-monsoon		Winter		Pre-monsoon		Monsoon	
	Taxa	Sat1	Sat2	Sat1	Sat2	Sat1	Sat2	Sat1	Sat2
Hemiptera	**Family**: **Gerridae**								
	Limnogonus nitidus	–	6.67	–	–	–	–	–	–
	Family: **Notonectidae**								
	Anisops niveus	–	6.67	–	–	–	–	–	–
	Anisops breddini	–	–	11.11	–	–	–	–	–
	Family: **Mesoveliidae**								
	Mesovelia vittigera	–	6.67	–	–	–	–	–	–
	Mesovelia mulsanti	–	–	–	2.22	–	–	–	–
	Family: **Micronectidae**								
	Micronecta haliploides	–	–	–	8.89	7.41	22.22	11.11	5
	Synaptonecta issa	–	–	–	–	7.41	–	–	–
	Family: **Pleidae**								
	Paraplea sp.	25.81	–	–	–	14.81	–	66.67 (**E**)	22.22
	Family: **Nepidae**								
	Ranatra varipes	3.23	–	–	4.44	–	–	–	–
Coleoptera	**Family**: **Noteridae**								
	Suphisellus sp.	9.68	–	–	–	–	–	–	–
	Family: **Hydrophilidae**								
	Berosus sp.	–	6.67	–	–	–	–	–	–
	Laccobius sp.	–	6.67	–	–	–	–	–	–
	Family: **Chrysomelidae**								
	Galerucella sp.	–	–	–	–	–	33.33 (**E**)	–	–

(continued)

Table 5 (continued)

Orders	Seasons	Post-monsoon		Winter		Pre-monsoon		Monsoon	
	Taxa	Sat1	Sat2	Sat1	Sat2	Sat1	Sat2	Sat1	Sat2
Odonata	**Family**: **Libellulidae**								
	Rhodothemis rufa	3.23	–	–	–	–	–	–	–
	Hydrobasileus brevistylus	6.45	–	–	–	–	–	–	–
	Potamarcha obscura	3.23	–	11.11	–	–	–	–	–
	Sympetrum sp.	3.23	–	–	–	–	–	–	–
	Sympetrum illotum	–	–	11.11	2.22	–	–	–	–
	Hydrocanthus sp.	–	–	–	2.22	–	–	–	–
	Leucorrhinia frigida	–	–	11.11	–	–	–	–	5.56
	Orthetrum sabina	–	13.33	–	–	–	–	–	–
	Neurothemis fluctuans	–	6.67	–	–	–	–	–	–
	Family: **Coenagrionidae**								
	Ceriagrion cerinorubellum	3.23	–	–	–	–	–	–	–
	Ischnura senegalensis	3.23	–	–	4.44	–	–	–	–
	Agriocnemis pygmaea	–	13.33	–	2.22	–	–	–	–
Ephemeroptera	**Family**: **Baetidae**								
	Cloeon sp.	–	13.33	–	68.89 (**E**)	66.67 (**E**)	33.33 (**E**)	22.22	–
Diptera	**Family**: **Culicidae**								
	Culex sp.	–	–	55.56 (**E**)	–	–	–	–	–
	Anopheles sp.	–	–	–	2.22	–	–	–	5.56
	Aedes sp.	–	–	–	–	3.7	–	–	–
	Family: **Simuliidae**								
	Gymnopais sp.	–	–	–	–	–	11.11	–	–
	Family: **Chironomidae**								
	Ablabmesyia sp.	–	2	–	2.22	–	–	–	–
	Paramerina sp.	–			–	–	–	–	16.67

RA < 1 Subrecedent; *1.1–3.1* Recedent; *3.2–10* Subdominant; *0.1–31.6* Dominant; *>31.7%* Eudominant (E)

Laccotrephes ruber *Limnogonus nitidus* *Culex* sp. *Cybister* sp.

Leucorrhinia frigid *Sympetrum illotum* *Ranatra varipes*

Ranatra gracilis *Cloeon* sp. *Potamarcha obscura*

Plate 1 Images of a few aquatic insect species

pollution interpreted from SIGNAL value could be considered as moderate pollution (Table 7). In both the ecosystems, insect density showed very high significant positive correlation with species richness. Such correlation was also found in previous studies in Cachar district in one oxbow lake and two different ponds (Gupta and Narzary 2013; Dalal and Gupta 2014) (Table 3).

Table 6 Diversity indices of aquatic insects of two different sites of Magura *haor* and Satkorakandi *anua* of Cachar, Assam during Post-monsoon–monsoon, 2013–14

		Haor1	Haor2	Sat1	Sat2
Post-monsoon	Shannon_H′	1.95	1.51	1.89	2.21
	Evenness_e^H/S	0.44	0.30	0.61	0.91
	Margalef	3.69	2.97	2.91	3.32
	Berger–Parker	0.48	0.58	0.35	0.2
Winter	Shannon_H′	1.91	2.26	1.30	1.25
	Evenness_e^H/S	0.84	0.87	0.73	0.35
	Margalef	2.65	3.14	1.82	2.36
	Berger–Parker	0.28	0.21	0.55	0.68
Pre-monsoon	Shannon_H′	1.53	2.61	1.061	1.31
	Evenness_e^H/S	0.27	0.71	0.57	0.92
	Margalef	3.56	4.67	1.21	1.36
	Berger–Parker	0.65	0.21	0.66	0.33
Monsoon	Shannon_H′	0.93	1.40	0.84	1.30
	Evenness_e^H/S	0.42	0.58	0.77	0.73
	Margalef	1.39	1.78	0.91	1.38
	Berger–Parker	0.75	0.58	0.66	0.5

Table 7 SIGNAL 2, BMWP, ASPT, $BMWP^{THAI}$ and $ASPT^{THAI}$ scores used at two different sites of Magura *haor* and Satkorakandi *anua* of Cachar district, Assam during post-monsoon–monsoon, 2013–14

		Haor1	Haor2	Sat1	Sat2
Post-monsoon	SIGNAL 2	3.38 (SP)	2.95 (SP)	2.69 (SP)	3 (SP)
	BMWP	37 (P)	38 (P)	21 (P)	32 (P)
	ASPT	4.62 (PMP)	5.42 (DQ)	5.25 (DQ)	4.57 (PMP)
	$BMWP^{THAI}$	42 (M)	31 (P)	16 (P)	32 (P)
	$ASPT^{THAI}$	4.66 (PMP)	5.16 (DQ)	5.33 (DQ)	4.57 (PMP)
Winter	SIGNAL 2	3.5 (SP)	3 (SP)	2.2 (SP)	3.33 (SP)
	BMWP	28 (P)	41 (M)	13 (P)	40 (P)
	ASPT	5.6 (DQ)	4.55 (PMP)	6.5 (DQ)	5 (PMP)
	$BMWP^{THAI}$	26 (P)	41 (M)	11 (P)	38 (P)
	$ASPT^{THAI}$	5.2 (DQ)	4.55 (PMP)	5.5(DQ)	4.75 (PMP)
Pre-monsoon	SIGNAL 2	2.54 (SP)	2.45 (SP)	3.22 (SP)	3.5 (SP)
	BMWP	65 (M)	49 (M)	14 (P)	19 (P)
	ASPT	5(DQ)	4.9 (PMP)	4.67 (PMP)	4.75 (PMP)
	$BMWP^{THAI}$	63 (M)	49 (P)	14 (P)	19 (P)
	$ASPT^{THAI}$	4.86 (PMP)	4.9 (PMP)	4.67 (PMP)	4.75 (PMP)

(continued)

Table 7 (continued)

		Haor1	Haor2	Sat1	Sat2
Monsoon	SIGNAL 2	3.72 (SP)	3.6 (SP)	2.6 (SP)	2.33 (SP)
	BMWP	25 (P)	23 (P)	14 (P)	20 (P)
	ASPT	5 (PMP)	5.75 (DQ)	4.7 (PMP)	5 (PMP)
	$BMWP^{THAI}$	25 (P)	21 (P)	14 (P)	18 (P)
	$ASPT^{THAI}$	5 (DQ)	5.25 (DQ)	4.7 (PMP)	4.5 (PMP)

Note SIGNAL 2 score: *<4* severe pollution (SP); *4–5* moderate pollution (MP); *5–6* mild pollution (MiP); *>6* healthy habitat (HH). BMWP score: *−10* very poor (VP); *11–40* poor (P); *41–70* moderate (M); *71–100* good (G); *>100* very good (VG). ASPT score: *<4* probable severe pollution (PSP); *4–5* probable moderate pollution (PMP); *5–6* doubtful quality (DQ); *>6* clean water (CW)

Table 8 Summary statistics of canonical correspondence analysis (CCA) for Magura *haor* and Satkorakandi *anua*

Systems	Magura *haor*		Satkorakandi *anua*	
Axes	1	2	1	2
Eigenvalues	0.655	0.621	0.845	0.754
Species environment correlations	1.000	1.000	1.000	1.000
Cumulative percentage variance of species data	20.4	39.8	23.8	45.1
Cumulative percentage variance of species-environment relation	20.4	39.8	23.8	45.1
Sum of all eigenvalues	3.206		3.549	
Sum of all canonical eigenvalues	3.206		3.549	

Canonical Correspondence Analysis (CCA)

Aquatic insect species data was subjected to canonical correspondence analysis (CCA), a direct gradient analysis method, which summarizes relationships between response variables and environmental variables (Leps and Smilauer 2003). Plots of ordinations are generated by CanoDraw (Ter Braak and Smilauer 2002). Table 8 shows the summary statistics of the CCA for Magura *haor* and Satkorakandi *anua*. The eigenvalues for axis 1 and 2 were 0.655 and 0.621 for *haor,* and 0.845 and 0.754 for *anua*, respectively. Species environment correlations were 1 for both the systems.

Table 9 shows the species and its code name used in the ordination graph of CCA for both the systems. CCA biplot ordination graph for species environmental variables of Magura *haor* revealed that AT, RF, DO, depth, FCO_2, TA, Na, and pH were the important variables. The strong negative correlation of DO with FCO_2 and RF confirmed the significant correlations shown by Pearson's correlation coefficient analysis. Species close to axis 1 were *Cloeon* sp., *Agriocnemis femina, Micronecta siva*, and *Ceriagrion cerinorubellum.* Species close to axis 2 were *Neogerris parvula*, *Octhebius* sp., *Ranatra elongate*, *Gerris lepcha*. A large number of species

Table 9 List of species and its code name used in CCA biplot ordination graph of Magura *haor* and Satkorakandi *anua*

S. No.	Magura *haor*	Species code name	S. No.	Satkorakandi *anua*	Species code name
1	*Neogerris parvula*	Neo	1	*Limnogonus nitidus*	LimnNi
2	*Gerris* sp.	Gerr1	2	*Anisops niveus*	AniNi
3	*Gerris lepcha*	Gerr2	3	*Anisops breddini*	AniBre
4	*Trepobates* sp.	Trepo	4	*Mesovelia vittigera*	MesoV
5	*Limnogonus fossarum*	Limno	5	*Mesovelia mulsanti*	MesMu
6	*Anisops breddini*	AniB	6	*Micronecta haliploides*	MicrHal
7	*Nychia sappho*	Nychia	7	*Synaptonecta issa*	SynoIss
8	*Aphelonecta* sp.	Aphelo	8	*Paraplea* sp.	ParaS
9	*Anisops bouvieri*	AniBo	9	*Ranatra varipes*	RanaVar
10	*Anispos exiguus*	AniEx	10	*Suphisellus* sp.	SuphiS
11	*Micronecta haliploides*	MicrHali	11	*Berosus* sp.	BersSp
12	*Micronecta siva*	MicrSi	12	*Laccobius* sp.	LaccoSP
13	*Micronecta scutellaris*	MicrScu	13	*Galerucella* sp.	GaleSP
14	*Micronecta ludibunda*	MicrLudi	14	*Rhodothemis rufa*	RhoRu
15	*Micronecta* sp.	Micrsp	15	*Hydrobasileus brevistylus*	HydBrevi
16	*Baptista collaris*	BaptCol	16	*Potamarcha obscura*	PotaObs
17	*Paraplea* sp.	Para1	17	*Sympetrum* sp.	SympS
18	*Ranatra elongata*	RanaElon	18	*Sympetrum illotum*	SympIllo
19	*Ranatra gracilis*	RanaGra	19	*Hydrocanthus* sp.	Hydroca
20	*Ranatra sordidula*	RanaSor	20	*Leucorrhinia frigida*	LeucorFRIGI
21	*Laccotrephes ruber*	LaccoR	21	*Orthetrum sabina*	OrtheSa
22	*Hydrometra greeni*	HydR	22	*Neurothemis fluctuans*	NeurotFlu
23	*Diplonychus* sp.	DiploSP	23	*Ceriagrion cerinorubellum*	CeriaCer
24	*Suphisellus* sp.	SupL	24	*Ischnura senegalensis*	IschSene
25	*Laccobius* sp.	LaccoSP	25	*Agriocnemis pygmaea*	AgrioPyg
26	*Cercyon* sp.	Cerc	26	*Cloeon* sp.	CloeoDi
27	*Berosus* sp.	BeR	27	*Culex* sp.	CulexS
28	*Helochares* sp.	Heloc	28	*Anopheles* sp.	AnopSP
29	*Berosus indicum*	BeroIn	29	*Aedes* sp.	Aedes

(continued)

Table 9 (continued)

S. No.	Magura *haor*	Species code name	S. No.	Satkorakandi *anua*	Species code name
30	*Hydrobius* sp.	HydBi	30	*Gymnopais* sp.	Gymno
31	*Octhebius* sp.	Octh	31	*Ablabmesyia* sp.	Ablab
32	*Laccophilus* sp.	LaccoS	32	*Paramerina* sp.	ParameS
33	*Cybister* sp.	CybS			
34	*Cybister lateralimarginalis*	CybLater			
35	*Donacia* sp.	Dona			
36	*Galerucella* sp.	GalL			
37	*Hydrochus* sp.	Hydroc			
38	*Hydrobasileus brevistylus*	HydBre			
39	*Potamarcha* sp.	Potamsp			
40	*Leucorrhinia intacta*	LeuIn			
41	*Crocothemis servilia servilia*	CroSer			
42	*Ischnura senegalensis*	IscSen			
43	*Agriocnemis femina*	AgriF			
44	*Ceriagrion cerinorubellum*	CeriC			
45	*Pseudagrion australasiae*	PseAus			
46	*Pseudagrion prunisom*	PsePru			
47	*Aeshna* sp.	Aesh			
48	*Cloeon* sp.	Cloe10			
49	*Culex* sp.	CulSP.			
50	*Aedes* sp.	Aedes			
51	*Ablabmesyia* sp.	Ablab			
52	*Tabanus* sp.	Taba			
53	*Eunemobius* sp.	Eunem			

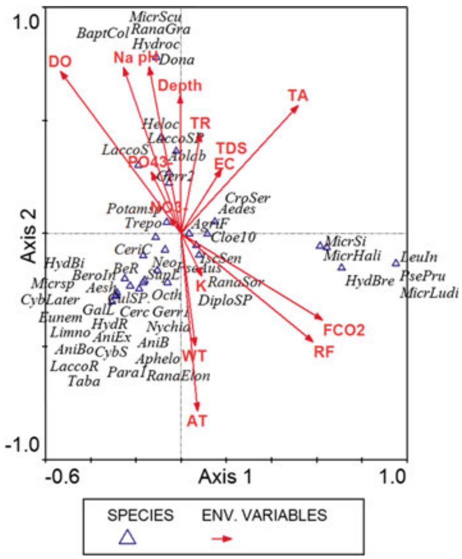

Fig. 3 Canonical correspondence analysis (CCA) biplot ordination graph of species and environment of Magura *haor*

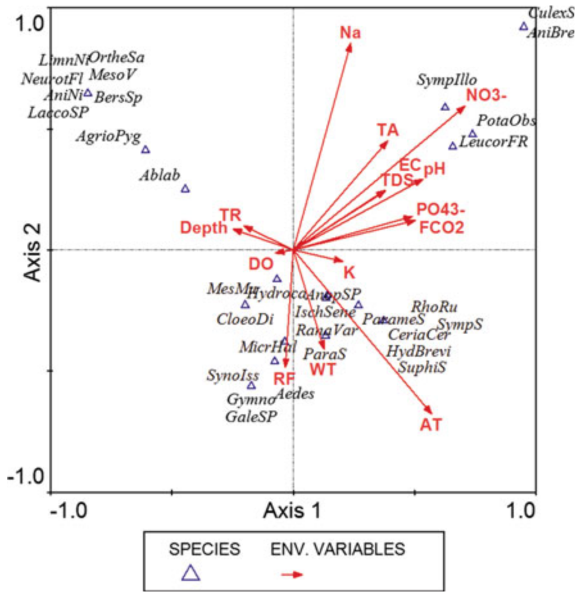

Fig. 4 Canonical correspondence analysis (CCA) biplot ordination graph of species and environment of Satkorakandi *anua*

were found clubbed in the negative side of both axis 1 and 2, not associated with any of the water variables (Fig. 3). In the case of *anua*, NO_3^-, AT, RF, and Na were the important variables. No species was found associated with axis 1. Species found associated with axis 2 were *Ischnura senegalensis, Cloeon* sp.*, Ranatra varipes, Anopheles* sp., *Aedes* sp. and *Hydrocanthus* sp. (Fig. 4).

Conclusion

This study found occurrence of mostly semi-tolerant species in both the systems indicating disturbance in the systems. Values of different diversity indices and biotic scores based on the diversity and density of aquatic insects indicated moderate pollution of water in both the systems. All the above facts confirmed the role of aquatic insects as a potential pollution indicator of freshwater systems.

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Monitoring of Air Pollution in Different Regions Along Road Network, Jharia Coalfield, Dhanbad, India

Shiv Kumar Yadav, Manish Kumar Jain and Dinesh Kumar Patel

Abstract Air pollution levels were measured during October, 2014 along the road network at Jharia Coalfield, Dhanbad, Jharkhand, India. The monitored PM concentrations were designated as PM_{10} and $PM_{2.5}$ for aerodynamic diameter smaller than 10 and 2.5 µm, respectively. Concentration of PM_{10} and $PM_{2.5}$ in mining area such as BMO, GDR, and KMO were about two times higher than ISM (non-mining area). Variation in the peaks of PM_{10} and $PM_{2.5}$ concentrations were well correlated with the traffic volume count (TVC) at all monitoring locations except GDR due to the transportation of coal using Hyva truck and associated activities due to the mining industry. Concentrations of PM_{10} and $PM_{2.5}$ exceed 24-hour standards as per Indian national ambient air quality standards (NAAQS 2009) as well as World Health Organization (WHO 2005) at all locations in the mining area. Based on the air quality index, air qualities were falling under very highly polluted category mainly at BMO, GDR, KDH, KMO, and DHR.

Keywords Particulate matter · Open cast coal mining · Exposure
Traffic volume count · Air quality index

Introduction

Air quality monitoring and pollution control have been a major environmental concern for the last three decades. Health of the people residing along roadside is seriously affected due to the adverse impacts of air pollution causing terrible diseases such as human health such as acute and chronic respiratory malady and cardiopulmonary sickness (WHO 2006; Brugge et al. 2007; UN 2015). The problems of air pollution are due to heavy traffic, mining operations, and other industrial activities (Baldauf et al. 2001; Collins et al. 2001; Pandey et al. 2014).

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The problems of air pollution are more critical for every living being in Jharia Coalfield (JCF). JCF is facing a huge burden of traffic congestion, overpopulation and industrial/mining problems. In particular, such issues target severely public activities like children moving to school, roadside vendors, and employees of uncovered or frequently open commercial establishments in traffic dense and narrow locations and all users of public places such as bus stands, auto stands etc. JCF has been declared as critically polluted zone by the Central Pollution Control Board (CPCB). Increases in air pollution levels to an alarming rate along the roadside of Jharia areas have also been reported by several researchers (Ghose and Majee 2000, 2001; Jain and Saxena 2002; Chaulya 2004; Dubey et al. 2012; Pandey et al. 2014).

The present study was conducted to measure air pollutants (PM_{10}, $PM_{2.5}$, SO_2, NO_2, and CO) concentration variations along roadside in mining and non-mining areas, JCF, Dhanbad, Jharkhand, India and their comparison of observed values with NAAQS 2009 and WHO 2005 standards. Apart from the observed concentration of pollutants, air quality index (AQI) values were also estimated for better understanding and interpretation of the pollution levels.

Materials and Methods

Study Area

Jharia Coalfield (JCF) is one of the most important coalfields in eastern India, located in Dhanbad, Jharkhand, India between latitude 23° 45′ 0″ North; longitude 86° 24′ 0″ East and 222 m above mean sea level (Fig. 1). JCF is the most exploited coalfield because of available metallurgical grade coal reserves. The mining method here comprises of both opencast as well as underground. A study related to JCF is of high importance due to the presence of highly populated township in the vicinity and chances of its negative impacts on society. Non-mining location was selected at the main gate of Indian School of Mines (ISM), Dhanbad located at distance of 7 km in a northeast direction (NE) from JCF for comparing the air quality of the mining area. Nine monitoring locations were selected for particulate matter (PM) monitoring in the study area as per IS: 5182 Part-XIV (Fig. 1). The selected locations were places of maximum population, heavy traffic, commercial and industrial/mining areas. Brief descriptions of the locations along with their GPS coordinates are presented in Table 1.

Data Collection

The present study of air pollution levels (PM_{10}, $PM_{2.5}$, SO_2, NO_2, and CO) was carried out during October, 2014 at eight different locations in mining and one location in non-mining areas. Twenty-four-hour average sampling was done on

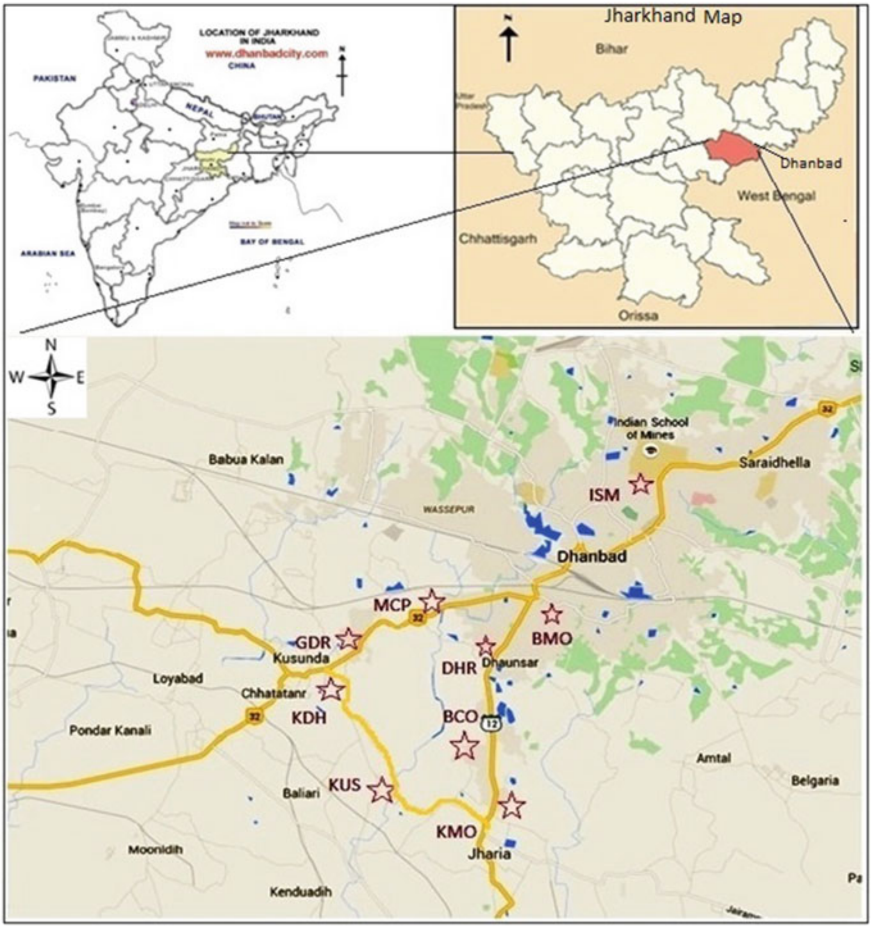


Fig. 1 Map of the monitoring locations in the study area

alternate days for 2 days in a week. Standard methods for monitoring and analysis of all parameters as prescribed by CPCB under NAAQS (2009) were followed. PM_{10} samples were collected by respirable dust sampler (Envirotech APM 460NL) at a flow rate of 1.1 m^3/min on Whatman glass fiber filters and $PM_{2.5}$ samples were collected by fine particulate sampler (Envirotech APM 550 MFC) at a flow rate 16.7 L/min on PTEF filter papers. The mass concentration of PM_{10} and $PM_{2.5}$ in $\mu g/m^3$ is computed by measuring the mass of particulates by gravimetric methods and volume of the air sampled. The samples of SO_2 and NO_2 in $\mu g/m^3$ were collected by thermoelectrically cooled gaseous samplers (Envirotech APM 411TE) as per improved West and Gaeke method and modified Jacob and Hochheiser method, respectively. Carbon monoxide (CO) was determined using a portable sampler KIMO (Model AQ200).

Table 1 Descriptions of monitoring locations along with GPS coordinates and their characteristics

Location	ID	Coordinate		Major activities
		N	E	
Bankmore	BMO	23° 47′ 18.4″	86° 25′ 11.6″	Busiest road and junction, commercial, residential, high traffic flow, mining and industrial activities within 1 km
Matkuria check post	MCP	23° 47′ 14.1″	86° 24′ 14.6″	Industrial, commercial and residential, medium traffic flow, mining activity nearby
Godhar	GDR	23° 47′ 2.9″	86° 23′ 43.6″	Transportation through the roads with Hyva truck, Open cast coal mining, Industrial, some residential, medium traffic flow
Kenduadeeh	KDH	23° 46′ 32.4″	86° 22′ 48.8″	Commercial, residential, high traffic flow, industrial/mining activity nearby
Kustaur	KUS	23° 45′ 40.5″	86° 23′ 26.1″	Commercial and residential, low traffic flow, mining activity nearby
Katras more	KMO	23° 44′ 54.5″	86° 24′ 36.0″	Transportation through the roads with Hyva truck, commercial and residential, high traffic flow, industrial/mining activity nearby
Bastacola	BCO	23° 45′ 29.1″	86° 24′ 42.0″	Commercial and residential, medium traffic flow, mining activity nearby
Dhansar	DHR	23° 46′ 43.0″	86° 24′ 45.6″	Commercial and residential, medium traffic flow, industrial/mining activity nearby
ISM Gate (non-mining)	ISM	23° 48′ 32.5″	86° 26′ 33.6″	Commercial and residential, medium traffic flow

In the determination of AQI, equal importance was given to all the pollutants. The quality for each pollutant was estimated by using observed and standard value. The geometric mean of these quality ratings gives the AQI.

The existing concentrations of pollutants were compared with ambient air quality standards (with the standard being assumed as a reference baseline for each pollutant) and accordingly the quality rating for a particular pollutant was derived in Eqs. 1 and 2 as shown below:

$$Q_i = 10(C_i/S_i), \tag{1}$$

where

Q_i Quality rating for an ith pollutant,
C_i Concentration of ith pollutant,
S_i Air quality standard for ith pollutant.

$$\text{Air Quality Index (AQI)} = (Q_1 \times Q_2 \times \cdots \times Q_n)^{1/n}, \tag{2}$$

where

n Number of pollutants considered.

The categorization of AQI values has been assigned as per guidelines provided by Environment Canada (Table 2). It measures the air quality in relation to the health on a scale from 1 to 10. The higher the number, the greater the health risk associated with the air quality.

The Air Quality Health Index (AQHI) is a scale designed to understand the air quality and its impact on health to make decisions related to health protection by limiting short-term exposure to air pollution and adjusting activity levels during high values (Table 3). This index is also helpful to people who are sensitive to air pollution and provides them with advice on how to protect their health during air quality levels associated with low, moderate, high and very high health risks (Ott and Thom 1976).

Table 2 Air quality rating scale index

Index value	Status of air pollution
1–3	Least polluted
4–6	Moderately polluted
7–10	Highly polluted
10+	Very highly polluted

Table 3 Air quality health index categories and health messages

Health risk	Air quality health index	Health messages	
		At risk population	General population
Low	1–3	Enjoy your usual outdoor activities	Ideal air quality for outdoor activities
Moderate	4–6	Consider reducing or rescheduling strenuous activities outdoors if you are experiencing symptoms	No need to modify your usual outdoor activities unless you experience symptoms such as coughing and throat irritation
High	7–10	Reduce or reschedule strenuous activities outdoors. Children and the elderly should also take it easy	Consider reducing or rescheduling strenuous activities outdoors if you experience symptoms such as coughing and throat irritation
Very high	Above 10	Avoid strenuous activities outdoors. Children and the elderly should also avoid outdoor physical exertion	Reduce or reschedule strenuous activities outdoors, especially if you experience symptoms such as coughing and throat irritation

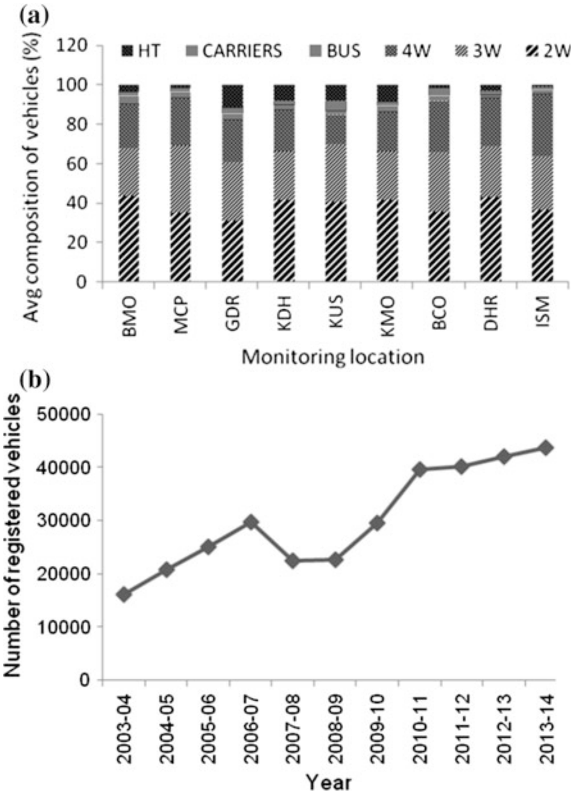
Source www.ec.gc.ca

Results and Discussion

Variations of Traffic Composition

Variation of Traffic Volume Count (TVC) and growth in the number of motor vehicles trend in Dhanbad, Jharkhand, India are presented in Fig. 2a–b. Daily average traffic flow analyses were done to show the greater percentage contribution of each type's vehicle for most of the sampling point at BMO, KDH, KMO, and DHR. The highest traffic flow was observed at BMO. A larger number of Hyva trucks were also noticed at GDR and KMO; which is the most important reason for particulate pollution on these locations. The number of two wheelers and three wheelers was more than 50% of total traffic at all monitoring locations. The growth rate of vehicles was seen higher in years 2003–2007. It was also observed that larger vehicles (10 years old) are one of the important reasons that contribute in air pollution along the roadside surroundings (Fig. 3b).

Fig. 2 **a** Average composition of vehicle variation at each location, **b** number of registered vehicles in Dhanbad. *Source* District Transport Office, Dhanbad Jharkhand, India



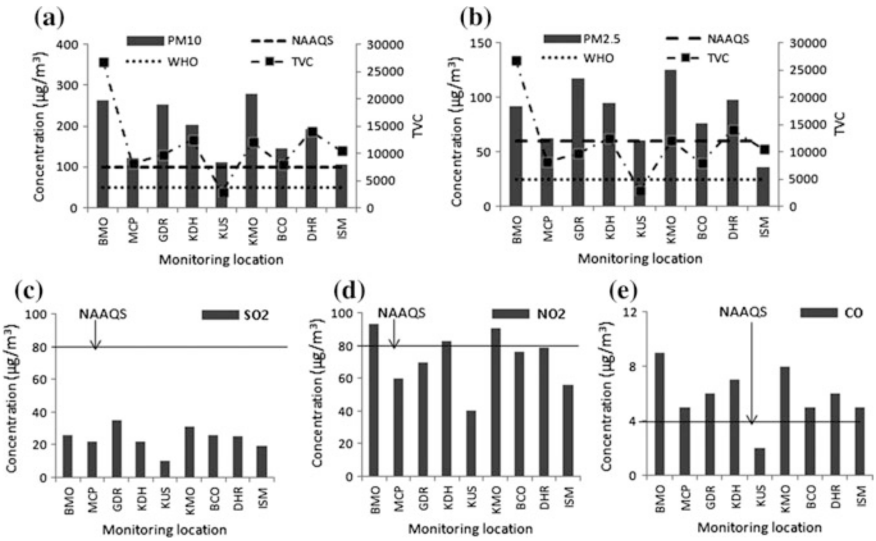


Fig. 3 Variations in average concentrations of **a** PM_{10}, **b** $PM_{2.5}$, **C** SO_2, **d** NO_2, and **e** CO during the monitoring period and compares to standards

Variations of Air Pollutant Concentration

Air pollutant (PM_{10}, $PM_{2.5}$, SO_2, NO_2, and CO) concentrations of various locations are presented in Fig. 3. Twenty-four-hour average PM_{10} and $PM_{2.5}$ concentrations with respect to TVC variation and standards are shown at all locations (Figs. 3a–b). The concentrations of PM_{10} and $PM_{2.5}$ at BMO, GDR, and KMO during monitoring were two times higher than ISM and exceeded the prescribed limit of NAAQS (100 and 60 μg m^{-3}) and WHO (50 and 25 μg m^{-3}) for PM_{10} and $PM_{2.5}$, respectively (Fig. 3a–b). The formation of particles (PM_{10} and $PM_{2.5}$) may be due to mining operations, heavy traffic, and re-suspension of dusts (Cole and Zapert 1995; Pandey et al. 2014; Sastry et al. 2015) near coal mining areas hence, proportions of these particles were high in the coal mining region. Variation of PM_{10} and $PM_{2.5}$ concentrations were also directly correlated with traffic volume count (TVC) at all monitoring locations except GDR.

The concentrations of SO_2 at all locations during monitoring were below the prescribed limit of NAAQS (80 μg m^{-3}) and exceeded the prescribed limit of WHO (20 μg m^{-3}) at all except ISM and KUS (Fig. 3c). SO_2 is directly emitted from fossil fuel combustion, industrial processes and then lost from the atmosphere through dry deposition at the surfaces or oxidation to sulfate (Pio and Feliciano 1996). The concentrations of NO_2 at BMO, KDH and KMO during monitoring were found exceeding the prescribed limit of NAAQS (80 μg m^{-3}) and WHO (40 μg m^{-3}) at all locations (Fig. 3d). Anthropogenic emissions of NO_2 in the area may be mainly due to coal, oil, and natural gas, with some emissions during

Table 4 Location-wise AQI of the study area

Location	Sub-index of various pollutants					AQI value	Category
	QPM_{10}	$QPM_{2.5}$	QSO_2	QNO_2	QCO		
BMO	24.7	14.3	3.3	11.9	22.5	12.5	Very highly polluted
MCP	11.4	9.7	2.8	7.5	12.5	7.8	Highly polluted
GDR	23.8	18.4	4.4	8.8	15.0	12.0	Very highly polluted
KDH	19.5	15.3	2.8	10.6	17.5	10.9	Very highly polluted
KUS	10.5	9.5	1.3	5.0	5.0	5.0	Moderately polluted
KMO	26.2	19.6	3.9	11.6	20.0	13.6	Very highly polluted
BCO	13.8	12.0	3.3	9.8	12.5	9.2	Highly polluted
DHR	18.2	15.3	3.1	10.6	15.0	10.7	Very highly polluted
ISM	9.8	5.5	2.4	7.0	12.5	6.5	Moderately polluted

blasting, combustion processes, including vehicle exhaust. NO_2 has a longer lifetime in the atmosphere in the absence of sunlight (Li et al. 2008).

The hourly average CO concentrations during monitoring also exceeded the prescribed limit of NAAQS (4 mg m^{-3}) except KUS (Fig. 3e). CO is directly emitted from vehicle exhaust, power generators, and also from incomplete combustion of various other fuels (including wood, coal, charcoal, oil, paraffin, propane, natural gas, and trash).

AQI for all locations were estimated based on NAAQS (2009) as per method described earlier. AQI showed significant spatial variations during the monitoring period (Table 4). The AQI values were falling under very highly polluted category at BMO, GDR, KDH, KMO, and DHR locations due to their proximity to coal mining areas. Heavy traffic flow at slow speed and poor road conditions may also be attributed to these high index values. The air quality of MCP and BCO was falling under highly polluted category due to medium traffic flow. On the other hand, the air quality of KUS and ISM fell under moderately polluted category. At KUS vehicle movement was less while at ISM movement of commercial vehicles were high.

Conclusion

The present study was conducted to investigate the ambient air quality of Jharia Coalfield, Dhanbad, India with respect to PM_{10}, $PM_{2.5}$, SO_2, NO_2, and CO at nine representative locations. The spatial variations in pollutant concentrations were quite significant, which may be caused by diversity among emissions. The concentrations of PM_{10} and $PM_{2.5}$ at BMO, GDR, and KMO during monitoring were about two times higher than ISM and exceeded the prescribed limit of NAAQS and WHO. The concentrations of SO_2 at all locations during monitoring were below the prescribed limit of NAAQS and exceeded the WHO at all locations except ISM and KUS. The concentrations of NO_2 at BMO, KDH, and KMO during monitoring exceeded the prescribed limit of NAAQS and WHO standards at all locations. The hourly average CO concentrations during monitoring also exceeded the prescribed limit of NAAQS except KUS.

Finally, through this study it can be inferred that the air quality is under very highly polluted category at BMO, GDR, KDH, KMO, and DHR locations based on AQI values.

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Spatial Distribution and Baseline Concentration of Heavy Metals in Swell–Shrink Soils of Madhya Pradesh, India

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Abstract Defining and understanding the current abundance and spatial distribution of metals in soils are essential and reliable information on this aspect are needed for proper legislation. To estimate the baseline concentrations and spatial distribution of heavy metals (HMs) in Swell–shrink soils Sehore and Vidisha districts, 100 surface soil samples (0–20 cm) were randomly collected across the two districts and their physico-chemical properties and total HM contents were analysed. Spatial distribution maps of HMs were prepared and influence of soil parameters on HMs was studied. Most of the soils in the region had neutral to alkaline pH (6.58–8.60), non saline (EC 0.11–1.3 dS/m), medium organic carbon (0.6%), $CaCO_3$ 0.2–11.5% and clay >40%. The baseline concentrations of HMs (mg kg^{-1}) were Cu, 178.1; Cd, 0.7; Pb, 24.4; Cr, 116.9; Ni, 81.8; and Zn, 85.2; respectively. The concentrations of Cd, Pb and Zn in all the samples were within the safe range but the concentrations of Cr, Cu and Ni were a little high.

Introduction

India is bestowed with diverse soil groups due to variability in parent materials, land topography and climatic conditions in different regions (Bhattacharyya et al. 2009). Each soil group as well as subgroup has distinct physical and chemical properties. Heavy metals are generally defined based on their atomic number, i.e. those elements having atomic number more than 20 or specific gravity (density) of more than >4.7 g/cm^3. Among heavy metals, Ag, As, Hg, V, Cd, Co, Cr, Cu, Ni, Se

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and Ti have high to moderately high toxicity to plants and Ag, As, Cd, Cr(VI), Hg, Sb, Se, Ti and V exhibit high toxicity to mammals (McBride 1994). Mean heavy metal concentrations in natural soil varies widely from 0.06 to 1.1 μg/g for Cd, 1.6–21.5 μg/g Co, 7–221 μg/g for Cr, 6–80 μg/g for Cu, 0.02–0.41 μg/g for Hg, 4–55 μg/g for Ni, 10–84 μg/g for Pb, 17–125 μg/g for Zn in non-contaminated soil of the world (McBride 1994). However, huge quantity of heavy metals are being mined out from deeper layers of earth crust and pose threat to the environment by affecting crop productivity and soil microbial biodiversity and also pose threat to human and animal health by contaminating food chain with toxic metals. Various soil properties determine degree of mobility/availability of heavy metals as well as effectiveness and adoptability of some of the management options over others for polluted soils (Saha et al. 2013). Therefore defining and understanding the current abundance and spatial distribution of metals in soils are essential first steps in being able to recognize and quantify natural or human-induced changes in the future. Due to variation in natural factors like parent materials (from which soil has been developed), climate, physiography, etc. wide variation in heavy metals contents among soils from different uncontaminated regions of different countries have been reported. Reliable data on this aspect are also needed for proper legislation. In order to address this issue, several other countries have established background concentration (BG) and upper baseline concentration (UBL) of heavy metals in soils of different regions. However, such information is scanty in our country which has diversified types of soils and agroclimatic conditions. Realizing the importance in control of pollution and management of polluted soil, many investigations on background concentrations of soil trace metals had been performed in various areas such as, Belgium (De Temmerman et al. 1984), China (Chen et al. 1991), Germany (Bachman et al. 1995), India (Kuhad et al. 1989), Italy (Bini et al. 1988), Poland (Andersen et al. 1994), Switzerland (Landry and Célardin 1988), The Netherlands (Denneman and Robbersen 1992), United Kingdom (Thornton 1982), United States of America (Holmgren et al. 1993; Bradford et al. 1996; Ma et al. 1997), Spain (Bech et al. 2005) and Western Europe (Angelone and Bini 1992). In these reports it has been shown that the primary factors influencing trace metal concentrations and spatial distribution in soils are parent materials and anthropogenic activities. Factors such as climate, the organic and inorganic components of soils, and redox potential status also affect the level of trace metals in soils. By keeping in view, the study is conceived and conducted with the following objectives:

1. To study the spatial distribution of heavy metals in the swell–shrink soils of Sehore and Vidisha districts of Madhya Pradesh.
2. To estimate the baseline concentrations of heavy metals in these soils.
3. To study the influence of soil properties on the concentration of heavy metals.

Materials and Methods

General Description of Study Area

Sehore and Vidisha districts are lying in the central part of Madhya Pradesh. These districts are part of the Malwa plateau with an undulating topography. They are primarily agricultural districts; Sehore occupies the Chambal and Narmada basin valley and Vidisha occupies Betwa Valley, having predominantly an agricultural economy. Agriculture is the main occupation of the people in these districts. Wheat, rice, sorghum, maize and soybean are the major crops sown in these districts and ground water has an important role to play for irrigation. The general information of these districts is given in Table 1.

Collection of Soil Samples

Geo-referenced (100 Nos.) surface soil samples from various locations (20 villages of Sehore district and from 22 villages of Vidisha district) across the two districts were collected. The names of the villages of two districts from where soil samples collected are listed in the Table 2.

Table 1 General information of Sehore and Vidisha district

Particulars	Sehore district	Vidisha district
Physiography	Deccan trap basalts underlined by Vindhyan sandstone and alluvium	Deccan trap basalts underlained by Vindhyan sandstone and overlain by river alluvium
Soil type	Vertic Ustochrept	Lithic Ustorthents
Area	6579 km^2	7371 km^2
Location	Latitude 22° 33′–23° 40′N Longitude 78° 26′–78° 02′E	Latitude 22° 20′–24° 22′N Longitude 77° 16′–78° 18′E
Industries	Jai Durga Steel Industries	Usha Agro Industries M.P. Iron Industries

Table 2 List of villages for soil sample collection

	Sehore district (20 villages)	Vidisha district (22 villages)
Selected villages	Janpur Bawadiya, Bairagarh Ganesh, Niwariya, Gudbela, Samardi, Arniya Gaji, Malipura (Ashta), Gwala, Chachmau, Bayan, Pangurariya, Semri Khanpura, Balagaon, Satrana, Chhapari, Bhada Khoi, Bhau Khadi, Bordi Kalan, Mogra, Dabla mata	Gamakar. Maholi, Sunari, Parasari, Banoh, Karmedi, Seu, Palalakpur, Mudra Pitamber, Khanpur, Lalatori, Muraria, Lateri, Sunkher, Emalia, Naarot, Mudra Abela, Bankhedi, Sojna, Atarikhejda, Kheriajagir, Olynza

Chemical Analysis of Soils

Soil pH

Soil pH was determined from soil–water suspension in the ratio of 1:2.5 with the help of Systronics Microprocessor based pH metre as described by Jackson (1973).

Electrical Conductivity

Electrical conductivity (EC) of soil–water suspension (1:2.5) was estimated with the help of a conductivity metre as outlined by (Jackson 1973). The electrical conductivity was measured at room temperature (25 °C) after the soil particles have been settled down.

Oxidizable Organic Carbon

Organic carbon of soil was estimated by oxidizing the soil with a mixture of 1*N* $K_2Cr_2O_7$ and concentrated H_2SO_4 and back-titrating the excess $K_2Cr_2O_7$ with standard ferrous ammonium sulfate solution using diphenylamine indicator following the wet digestion method of Walkley and Black (1934).

Calcium Carbonate

Percentage of $CaCO_3$ is estimated by acid neutralization method. For this 5 g soil (0.5 mm) is treated with 25 mL of 1*N* HCl for one hour by covering with a watch glass. Then it is transfered into a 100 mL volumetric flask and volume is made up and filtered. From the filtrate, 20 ml aliquot is taken in a conical flask (150 mL). Little distilled water is added, heated just to boil and cooled. The aliquot is titrated against 0.2*N* NaOH by adding 0.2 ml of phenolphthalein until the pink colour persists for 30 min.

Total Heavy Metal Concentration

For total heavy metal analysis, 1.0 g air dry soil (0.5 mm) was first pre-digested with 10 mL of concentrated HNO_3 for overnight. The pre-digested samples were digested in hot plate by adding 10 mL of di-acid (four parts of $HClO_4$ and nine parts of HNO_3) till the acid gets evaporated to near dryness. Process was repeated till the soil residue become whitish by adding di-acid mixture. One mL of $HClO_4$ was added and the sample was evaporated until the appearance of white fumes. The residue was dissolved by adding 4.0 mL of 12*N* HCl (kept for 1 min) and 50 mL of double distilled water and kept on sand bath for 4 h. Finally the volume of the digest was made to 100 mL and filtered by using Watman No. 42 filter paper. The filtrate was directly fed to ICP-OES for trace metals (Cu, Zn, Cd, Cr, Pb, Ni) determination. For cross checking the accuracy of the analytical procedure, the reference standard soil samples were also analysed along with the samples. The correlation between the observed values and the quoted values of reference sample came out to be 0.95–0.99.

Determination of Baseline Concentrations of Metals

Baseline concentrations can be determined both numerical and statistical ways, viz, range and mean ± standard deviation. In many naturally occurring processes, population follows a normal distribution where 99% of the population lies within $\mu \pm 3 * \sigma$ (μ = mean, and σ = standard deviation) (Feller 1971). Thus baseline concentration can be defined as range between $\mu + 3 * \sigma$ and $\mu - 3 * \sigma$. However, many investigators found that heavy metal concentrations in naturally occurring unpolluted soils follow a log-normal distribution (Chen et al. 1999a, b; Zhang et al. 2008). In that case, the geometric mean (GM) and geometric standard deviations (GSDs) are used to represent the central tendency and variation of the data. Baseline concentrations of the seven trace metals are defined as the range between GM/GSD^2 and GM $\times$ GSD^2 and taking the concentrations between the 5th and the 95th percentiles. This range included 95% of the samples (Dudka et al. 1995; Chen et al. 1999a, b; Zhang et al. 2008). This method was used to determine the baseline limit in this experiment.

$$\text{Lower baseline} = \frac{\text{GM}}{\text{GSD}^2} \tag{1}$$

$$\text{Upper baseline} = \text{GM} \times \text{GSD}^2 \tag{2}$$

where GM means for geometric mean and GSD means for geometric standard deviation.

Results and Discussion

Soil Characteristics

The important soil properties like soil reaction, electrical conductivity, oxidisable organic carbon, calcium carbonate and soil particle size were analysed in the laboratory. All the properties are presented in Table 3. The soil reaction of Sehore district ranged from 6.58 to 8.60 with mean value of 7.7 and for Vidisha district,

Table 3 Important soil properties of Sehore and Vidisha districts

Soil property	Sehore district (no. of samples = 50)		Vidisha district (no. of samples = 50)	
	Range	Mean	Range	Mean
pH	6.58–8.60	7.7	7.00–8.40	8.00
EC	0.11–0.62	0.3	0.11–1.3	0.30
OC (%)	0.21–1.24	0.6	0.17–1.09	0.60
$CaCO_3$ (%)	0.5–11.5	4.0	0.2–9.15	2.30
Sand (%)	27.58–66.96	38.7	29.6–41.9	34.3
Silt (%)	12.5–29.2	21.1	19.8–31.3	24.5
Clay (%)	15.3–59.0	40.2	32.7–47.5	41.2

it ranged from 7.0 to 8.4 with a mean value of 8.0. The electrical conductivity of the Sehore district ranged from 0.11 to 0.62 dS/m whereas, it ranged from 0.11 to 1.3 dS/m for Vidisha district with a mean value of 0.3 dS/m for both the districts. The organic carbon of Sehore district ranged from 0.21 to 1.24% with mean value of 0.6% and for Vidisha district, it ranged from 0.17 to 1.09% with a mean value of 0.6%. The percentage of $CaCO_3$ of Sehore district ranged from 0.5 to 11.5% with mean value of 4.0% and for Vidisha district, it ranged from 0.2 to 9.15% with a mean value of 2.3%. The sand, silt and clay of Sehore district ranged from 27.58 to 66.96%, 12.5 to 29.2% and 15.3–59.0%, respectively with mean value of 38.7, 21.1 and 40.2, respectively. The corresponding values for Vidisha district are 29.6–41.9, 19.8–31.3 and 32.7–47.5, respectively with a mean value of 34.3, 24.5 and 41.2%, respectively.

The soil reactions of Sehore and Vidisha districts ranged from neutral to (6.6) to alkaline range (8.4). Out of 50 samples of Sehore district, 15 (30%) samples are under neutral range, 14 (28%) are under mildly alkaline range, 19 (38%) are under moderately alkaline and only 2 (4%) are under highly alkaline range. For Vidisha district only 3 (6%) samples are under neutral range, 5 (10%) are under mildly alkaline range, 42 (84%) samples are under moderately alkaline range. So it is clear that, 70% of the samples in Sehore and 94% in Vidisha are under alkaline range. It is not strange to draw the reason for alkalinity as the parent material of these districts is predominantly basalt which yields black soil on weathering. The EC of the Sehore (0.11–0.62 dS/m) and Vidisha (0.11–1.3 dS/m) districts were under safer side as EC of all the samples in both the districts were below 2.0 dS/m, they are considered to be non-saline soils. The organic carbon content in the soils of Sehore district, out of 50 samples, 14 (28%) were below 0.5% (low), 24 samples (48%) were in between 0.5 and 0.75% (medium range) and 12 samples (24%) were above 0.75% (high). Whereas in the Vidisha district, 18 samples (36%) were at low category, 25 samples (50%) were in medium range and 7 samples (14%) were at high range. In the Sehore district 42 samples (84%) at or below 5% and 8 samples (16%) are above 5% $CaCO_3$. Whereas 48 samples (96%) at or below 5% and 2 samples (4%) are above 5% $CaCO_3$. The results indicated that mostly these soils are non-calcareous in nature. In case of textural classification, mostly they were clayey or clay loam soils due to high clay content.

Spatial Distribution of Heavy Metals

The concentrations (total) of six heavy metals in the soils of Sehore and Vidisha districts are presented in the Table 4. The heavy metal concentration range of Sehore district were 44.0–309.1 µg/g for Cu, 0.1–0.85 µg/g for Cd, 6.06–26.65 µg/g for Pb, 22.2–102.5 µg/g for Cr, 31–92.5 µg/g for Ni and 31.4–97.6 µg/g for Zn, with their corresponding geometric mean value of 91.89, 0.27, 16.26, 65.05, 57.34 and 61.97 µg/g, respectively. For Vidisha district, their concentrations were 39.55–141.9 µg/g for Cu, 0.20–0.65 µg/g for Cd, 11.33–23.18 µg/g for Pb, 57.95–62.30 µg/g for Cr, 42.85–69.73 µg/g for Ni and 44.85–73.70 µg/g for Zn, with their corresponding geometric mean value of 59.67, 0.35, 15.17, 77.27, 53.15 and 55.55 µg/g, respectively. The range of heavy metal concentrations in both the districts were 34.3–309.1 µg/g for Cu, 0.1–0.35 µg/g for Cd, 6.06–26.65 µg/g for Pb, 22.2–128.7 µg/g for Cr, 28.1–92.5 µg/g for Ni and 30.9–109.6 µg/g for Zn. The geometric mean values for concentrations of copper, cadmium, lead, chromium, nickel and zinc were 72.56, 0.30, 15.65, 70.68, 55.40 and 58.71 µg/g, respectively.

A comparison of this study and report generated by McBride (1994) is presented in Table 5. The higher concentration of copper in the Sehore district is mainly in the central parts of the district. The extremely high range of copper is much higher than the report generated by McBride (1994) need to be verified. But, out of 100 soil samples, 67 samples are less than 80 mg/kg and 33 soil samples are beyond the aforesaid limit. Regarding the concentrations of Cd and Pb, all the samples lie within the safe range. For Chromium, all the samples in these two districts lie much below the upper baseline given by McBride (1994) which is 221 mg/kg. With regard to the concentration of nickel, 39 samples are below 55 mg/kg and 61 samples are above the natural concentration limit. The concentration of the zinc is within the permissible limit. The higher concentration of Cu and Ni in these soils

Table 4 The concentration of various heavy metals in Sehore and Vidisha Districts

Heavy metals (µg/g)	Sehore district (*N* = 50)	Geometric mean	Vidisha district (*N* = 50)	Geometric mean	Total range	Geometric mean
Cu	44.0–309.1	91.89	39.55–141.9	59.67	34.3–309.1	72.56
Cd	0.1–0.85	0.27	0.20–0.65	0.35	0.1–0.35	0.30
Pb	6.06–26.65	16.26	11.33–23.18	15.17	6.06–26.65	15.65
Cr	22.2–102.5	65.05	57.95–62.30	77.27	22.2–128.7	70.68
Ni	31–92.5	57.34	42.85–69.73	53.15	28.1–92.5	55.40
Zn	31.4–97.6	61.97	44.85–73.70	55.55	30.9–109.6	58.71

Table 5 Comparison of heavy metals in the uncontaminated soils of world (McBride 1994) and the present study

References	Cu (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Cr (mg/kg)	Ni (mg/kg)	Zn (mg/kg)
McBride (1994)	6–80	0.06–1.1	10–84	7–221	4–55	17–125
This study	29.6–178.1	0.1–0.7	10–24.4	42.7–116.9	37.5–81.8	40.4–85.2

Table 6 Baseline concentration of heavy metals (mg/kg) for soils of Sehore and Vidisha

Heavy metals	Sehore district		Vidisha district		Study area	
	Lower	Upper	Lower	Upper	Lower	Upper
Cu	36.8	229.6	32.3	101.5	29.6	178.1
Cd	0.1	0.8	0.2	0.5	0.1	0.7
Pb	9.5	28.0	11.2	20.3	10.0	24.4
Cr	35.4	119.4	57.6	102.3	42.7	116.9
Ni	35.0	94.1	42.8	66.9	37.5	81.8
Zn	38.7	99.2	46.4	66.7	40.4	85.2

might be from parent material or anthropogenic activities. To confirm this, soil profile study is necessary which is beyond the scope of this article.

Baseline Concentrations of Heavy Metals

The baseline concentrations of six heavy metals in Sehore and Vidisha districts were estimated and presented in Table 6. The lower and upper baseline limits (range) of six heavy metals for Sehore district were 36.8 µg/g and 229.6 µg/g for Cu, 0.1 µg/g and 0.8 µg/g for Cd, 9.5 µg/g and 28.0 µg/g for Pb, 35.4 µg/g and 119.4 µg/g for Cr, 35.0 µg/g and 94.1 µg/g for Ni and 38.7 µg/g and 99.2 µg/g for Zn. The lower and upper baseline limits (range) of six heavy metals for Vidisha district were 32.3 µg/g and 101.5 µg/g for Cu, 0.2 µg/g and 0.5 µg/g for Cd, 11.2 µg/g and 20.3 µg/g for Pb, 57.6 µg/g and 102.3 µg/g for Cr, 42.8 µg/g and 66.9 µg/g for Ni and 38.7 µg/g and 99.2 µg/g for Zn. Upper and lower baseline concentrations of heavy metals for both the districts are 29.6 µg/g and 178.1 µg/g for Cu, 0.1 µg/g and 0.7 µg/g for Cd, 10.0 µg/g µg/g and 24.4 µg/g for Pb, 42.7 µg/g and 116.9 µg/g for Cr, 37.5 µg/g and 81.8 µg/g for Ni and 40.4 µg/g and 85.2 µg/g for Zn.

The upper baseline concentration for particular metal is considered as maximum concentration of metal in the soils of the region derived from natural phenomenon, i.e. weathering of parent material without any human-induced effect. This range is used for identification of the extent of soil pollution by HMs due to anthropogenic

Table 7 Correlation coefficients between soil properties and heavy metals

Metal	pH	EC	OC	Sand	Silt	Clay	$CaCO_3$
Cu	−0.322**	0.002	0.008	0.430**	−0.351**	−0.243*	0.318**
Cd	0.18	0.006	0.11	−0.058	0.304**	−0.116	0.058
Pb	−0.146	0.027	0.132	−0.282**	−0.034	0.312**	0.124
Cr	−0.019	−0.003	0.057	−0.557**	0.041	0.553**	−0.333**
Ni	−0.241*	0.032	−0.003	−0.202*	−0.201*	0.325**	−0.015
Zn	−0.102	0.185	0.013	0.218*	−0.187	−0.118	0.183

Note *significant at the 0.05 level; **significant at the 0.01 level

activities. However it is very difficult to derive actual baseline concentration for these soils, because they are under cultivation for longer period. Therefore to ensure these baseline concentrations, soil profile samples should be analysed to identify the contribution of parent materials.

Correlation Coefficient Between Heavy Metals and Soil Properties

The correlation coefficients between the soil properties and heavy metals were carried out in the soil samples of Sehore and Vidisha districts. The values of correlation coefficient are presented in Table 7. While studying the correlation it was found that the soil pH negatively influenced the total Cu and Ni; sand positively influenced the total Cu and Zn, negatively influenced the other metals; silt positively influenced the total Cd and negatively influenced the total Cu and Ni; clay positively influenced the total Pb, Cr and Ni, and negatively influenced the total Cu. The $CaCO_3$ content of the soil positively influenced the total concentration of Cu and negatively influenced total Cr. However this needs to be verified before establishing to any conclusion by increasing the number of samples.

Conclusions

The soils of both the districts are mostly at alkaline and non-saline range. As the samples are mostly from the agricultural fields, the organic carbon content is largely within the medium range. The concentrations of Cd, Cr, Pb and Zn, in all the samples lie within the safe range but the concentrations of Cu and Ni were little high, so need more attention as their higher concentrations are harmful to all the organisms. Identification and analysis of parent materials underlying the soil profile must be examined to know, if they are the main contributor for heavy metals. Correlation between the soil properties and heavy metals should also be carried not only for surface soils but also for the deeper layers. This kind of information contributes to identify the extent of soil pollution due to anthropogenic activities and also for more effective management of soil contaminated with heavy metals.

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Associative Study of Aerosol Pollution, Precipitation and Vegetation in Indian Region (2000–2013)

Manu Mehta, Shivali Dubey, Prabhishini and Vineet

Abstract The correlations between absorbing aerosol index (AAI), precipitation and Normalised Differential Vegetation Index (NDVI) have been shown in this study for the Indian region annually and seasonally (winter, pre-monsoon, monsoon and post-monsoon) from 2000 to 2013. Daily Aerosol Index has been obtained from OMAERov003 product provided by OMI-Aura sensor, daily precipitation used in this study is gridded IMD product, both at a spatial resolution of $0.25° \times 0.25°$. NDVI obtained from MISR Level 3 Component Global Land product at a spatial resolution of $0.5° \times 0.5°$ has been used as an indicator of vegetation cover. Annually and seasonally, the three parameters have been found to be highly, moderately or slightly correlated. The study has been reported at a confidence level of more than 95% (p-value <0.05).

Keywords Aerosol index · OMI · Precipitation · NDVI · Correlation

Introduction

Aerosols are colloidal particles of sub-micron dimension suspended in condensed form in air or other gasses in solid or liquid state. In the last few decades, aerosol pollution has altered hydrologic cycle at regional and global scales. This has been mainly due to the aerosol radiative forcing induced by absorbing or scattering solar

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radiation in the Earth's atmosphere. At the same time, aerosols provide Cloud Condensation Nuclei for the water evaporated from the Earth's surface. The aforementioned phenomena may either intensify or abate precipitation which may in-turn affect vegetative greenness and distribution. As a result, study of influence of aerosol–cloud interaction has gained momentum in the last decades. At the same time, anthropogenic absorbing aerosols cause direct radiative forcing which alters Earth's hydrological cycle and hence influences precipitation rates temporally and spatially (Wang et al. 2001). In Indian region, many studies have been performed to analyse the impact of aerosols (mainly absorbing) on precipitation during summer monsoon. The region where there has been increase in absorbing aerosols in the air due to anthropogenic activities is mainly Indo-Gangetic plain. In an attempt to study aerosol–cloud interaction along this region, Tripathi et al. (2007) found maximum correlation coefficient between aerosol optical depth (AOD) and cloud effective radii (CER) in winter season. However, spatially high values of correlation coefficients were found in monsoon season. Further, according to the review provided by Ramachandran et al. (2013), it was found that a weak positive correlation of 0.16 existed between absorbing aerosol index and precipitation and a weak negative correlation of −0.07 between absorbing aerosol index and Cloud Effective Radii during summer monsoon (2001–2010).

Also, studies have found that precipitation along with temperature, land use/land cover dynamics, soil moisture, rate of evapotranspiration, etc. have a direct influence on the vegetative growth and forest cover. From normalised differential vegetation index (NDVI), one can interpret plant health, growth and spatial distribution. The study on influence of pollutants on NDVI (Sarkar and Kafatos 2004) has found that aerosols (Aerosol Index) have local impact on NDVI and is mainly concentrated along the major industrial belts of the country. Findings by Prasad et al. (2007) have shown that negative correlation exists between NDVI and precipitation in the Indo-gangetic plain for 10 years (1990–1999), which is a highly polluted region. A similarity was found between the spatial distribution of NDVI and the advancement of monsoon over the country, with the two parameters (NDVI and precipitation) being highly correlated during monsoon and post-monsoon (Revadekar et al. 2012) for the period between 1981 and 2010. High correlation coefficient values between these parameters has been obtained during monsoon season (2000–2013) using both satellite and ground measurements (Mehta and Dubey 2015).

With the aim to understand association between the parameters viz., AAI, NDVI and precipitation, the study presents the seasonal (pre-monsoon, monsoon, post-monsoon and winter) and annual correlation coefficients between them. As the analysis is seasonal, the results would primarily pertain to rain-fed agriculture and forests.

Datasets Used

Multi-angle imaging spectro-radiometer (MISR) on-board Terra satellite measures intensity of solar radiation from the Earth's surface and atmosphere in different directions and spectral bands. Component global land surface (CGLS) product provides NDVI data at a spatial resolution of 0.5° × 0.5° (Diner et al. 2008).

Daily rainfall data, provided by National Data Center (NDC), IMD Pune, at a spatial resolution of 0.25° × 0.25° has been used for ground measurements. This data has been generated by IMD by interpolating (using method proposed by Shepherd 1968) the precipitation reported by around 6000 rain gauge stations into gridded format.

Level 3 global 0.25° × 0.25° gridded UV Aerosol Index from the Aura ozone monitoring instrument (OMI) from 2005 to 2013 is used in the study. Positive values of UVAI (>0.2) represent absorbing aerosols, negative values (<−0.2) represent small non-absorbing aerosols, (pure scattering), while near values (±0.2) represent the presence of clouds or larger non-absorbing or scattering particles (Torres et al. 2007).

Results

All correlations have been performed using analysis of variance (ANOVA) method in MATLAB. Before performing the correlations, the datasets were brought to similar resolutions by performing Nearest Neighbour Interpolation using Erdas. Overall, a negative correlation exists between annually and seasonally averaged absorbing aerosol index (AAI) and precipitation over the entire country (Fig. 1). A strong negative correlation has been found during pre-monsoon season (−0.55), on the other hand, the correlation is weak during monsoon season (−0.25). The

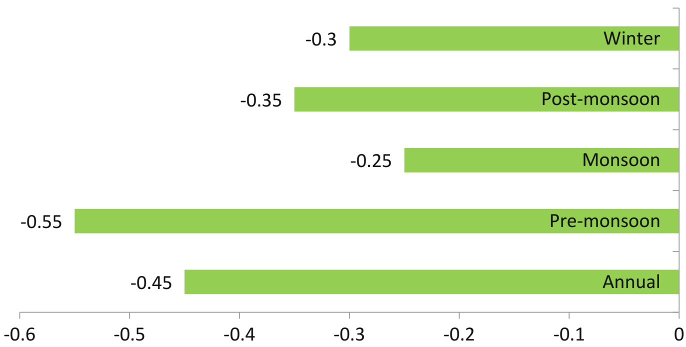

Fig. 1 Correlation coefficients between absorbing aerosol index (AAI) and precipitation

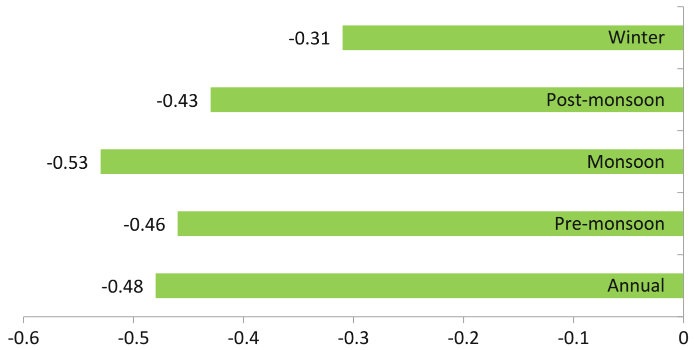

Fig. 2 Correlation coefficients between absorbing aerosol index (AAI) and NDVI

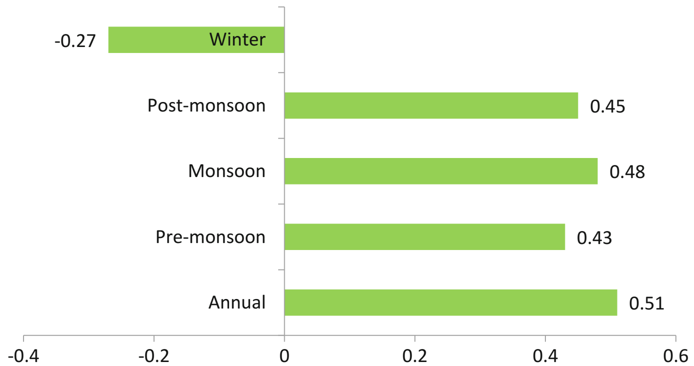

Fig. 3 Correlation coefficients between NDVI and precipitation

findings indicate that absorbing aerosols could have suppressed precipitation over the last decade but one cannot limit the implication here.

Again, a negative correlation exists between annually and seasonally averaged absorbing aerosol index (AAI) and NDVI over the entire country (Fig. 2). This is indicative of the fact that NDVI could be directly influenced by precipitation (Fig. 3). Findings show highest correlation coefficient between AAI and NDVI during monsoon season (−0.53) and least during winter season (−0.31).

Positive correlations exist between NDVI and precipitation annually as well as for all seasons except winter (Fig. 3). During winter, factors other than precipitation, such as temperature, soil moisture, land use–land cover dynamics influence vegetative cover significantly (Mehta and Dubey 2015; Revadekar et al. 2012; Nischitha et al. 2014; Mehta and Dubey 2015). Strong correlation has been observed annually (0.51) and during monsoon season (0.48).

Conclusion

Absorbing aerosol index is negatively correlated with both precipitation and NDVI, signifying that absorbing aerosol pollutants have suppressed the above two parameters in the last decade. Aerosol forcing has maximum influence on precipitation during pre-monsoon (Correlation Coefficient = −0.55) and on NDVI during monsoon season (CC = −0.53). Also, positive correlations exist between NDVI and precipitation except for winter season (−0.27), confirming to other NDVI-precipitation interaction studies mentioned in the paper. This signifies that in the major part of a year, precipitation directly influences NDVI. Since, not all correlations are strong, the study could be extended further by taking into consideration other important climatic as well as anthropogenic factors such as temperature, evapotranspiration rate, humidity, land use/land cover dynamics, etc.

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Fuzzy Logic Based Performance Evaluation of EIA Reports for Hydroelectric Projects

Purbashree Sarmah and Arvind K. Nema

Abstract The performance evaluation of Environmental Impact Assessment is a difficult multi-dimensional process because the decision-making not only considers the technical facts but also the subjective values. Decision-support method like Fuzzy Logic Toolbox helps decision makers to bring equilibrium between facts and values. In this paper, an effort to make a better framework for EIA reports of Hydroelectric Projects is undertaken. Attributes considered are identification of issues and scoping, baseline conditions, alternatives, impact identification and prediction, risk assessment, mitigation, documentation, public participation and monitoring plan. Quality is defined through five parameters viz. Excellent, Good, Moderate, Poor and Inadequate. With the help of Fuzzy Logic Toolbox in MATLAB, different expert rules are made. Attributes are taken as inputs and the parameters are taken as membership functions. Ranges are defined for different parameters. Five EIA reports for hydropower projects from different locations of Northeastern India are selected and compared. Scores are given to the EIA reports for different hydropower projects. Suggestions for future improvements are provided.

Introduction

Environmental impact assessment (EIA) is a planning and management tool that is used for the determination of consequences of developing projects. For avoiding or reducing the negative impacts of a project which is in planning phase, EIA is a very effective method (Ahammed and Nixon 2006). For a better and sustainable development of environment, EIA presents a systematic analysis and assessment process of planned activities (Glasson et al. 1999). Brilliant environmental decision-making

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can be made with the help of a good EIA. EIA review is the key procedure for quality control of EIA. The high quality EIA report can help in effective transformation of EIA strategy into practice. However, a good-quality EIA report is rare in reality. There are various drawbacks remained in the EIA system even after the project is started. EIA expert committee members, approval authorities, project proponents, NGOs and consulting professionals, reveals various drawbacks which include; inadequate capacity of EIA approval authorities, deficiencies in screening and scoping, inadequate public participation and feeble monitoring (Panigrahi and Amirapu 2012). Different frameworks for formation of a good EIA report are made by different scholars and institutions/agencies like European Union, World Bank, etc. In India, the first EIA comes under Environment Protection Act 1986. Although the Environmental Impact Assessment Notification, 2006 and its amendments by the Ministry of Environment and Forest set certain guidelines for EIA practice in India, these guidelines are not enough for preparing a Good EIA report. The contemporary EIA practice is facing several challenges (Rao and Ramana 2008). In Sarmah et al. (2015), nine attributes and their respective criteria are considered for EIA reports. On the basis of these criteria, general rules are made for EIA reports with five quality parameters viz. Excellent, Good, Moderate, Poor and Inadequate.

In this paper, particularly EIA reports on hydroelectric projects are selected from Northeastern part of India and expert rules are applied on them to find the quality of the report. Expert rules are made from expert knowledge to use and control of domain knowledge (Modak and Biswas 1999). These are prepared from general rules with specialized thinking. This is creation of the coherent human thought process. Expert rules make the decision-making easier. Fuzzy logic (Zadeh 1996) is a tool which is able to compute with words. It is used for modeling qualitative human thought processes in the study of complex methods and decisions. In Fuzzy logic, the 'IF-THEN' Fuzzy rules represent the qualitative sensitivity based reasoning.

Fuzzy inference is the process of creating the mapping from a given input to an output using Fuzzy logic. According to Fuzzy Logic Toolbox User's Guide (2015), Fuzzy inference process comprises of five parts

- Fuzzification of the input variables.
- Application of the Fuzzy operator (AND or OR) in the antecedent.
- Implication from the antecedent to the consequent.
- Aggregation of the consequents across the rules.
- Defuzzification.

Objectives and Scope

The objectives of the paper are

- To review EIA of hydroelectric projects considering different criteria for attribute.

- To generate expert rules using Fuzzy Logic toolbox.
- Case studies taking five hydroelectric projects of Northeastern states of India.
- To make conclusions and give some improvements suggestion for future.

The scope of the paper is limited to only five river valley projects of the Northeastern states of India. All these projects are developed to harness solitary the hydroelectric potential of the rivers. Five hydroelectric projects selected from Northeastern India are Demwe Lower Hydroelectric Project, Arunachal Pradesh, Dibbin Hydroelectric Project, Arunachal Pradesh, Pauk Hydroelectric Project, Arunachal Pradesh, Ting Ting Hydroelectric Project, Sikkim and Heo Hydroelectric Project, Arunachal Pradesh. There are lots of other hydroelectric projects in Northeastern India for which the EIA reports can be reviewed and compared.

Methodology

From the previous work of Sarmah et al. (2015), attributes for hydroelectric projects considered are identification of issues and scoping, baseline conditions, alternatives, impact identification and prediction, risk assessment, mitigation, documentation, public participation and monitoring plan. Quality is defined through five parameters viz. Excellent, Good, Moderate, Poor and Inadequate. Different criteria are identified which fall under the defined parameters. These criteria are specifically objective types which are derived from subjective criteria of various literature sources. These criteria are useful to make a new criteria list for a specific project work and also give scope to make expert rules.

Fuzzy Logic Based Expert Rule System

In this paper, an attempt to propose an integrated decision support framework that employs Fuzzy logic (FL) to manipulate the subjectivity as decision makers do in appraising the facts and values is done. Finally, the proposed approach is applied to

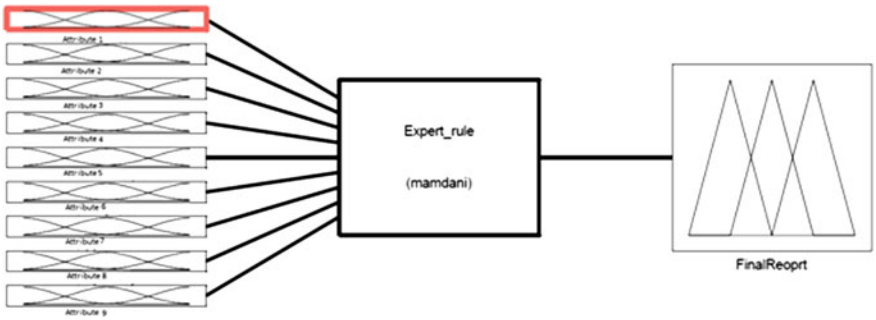


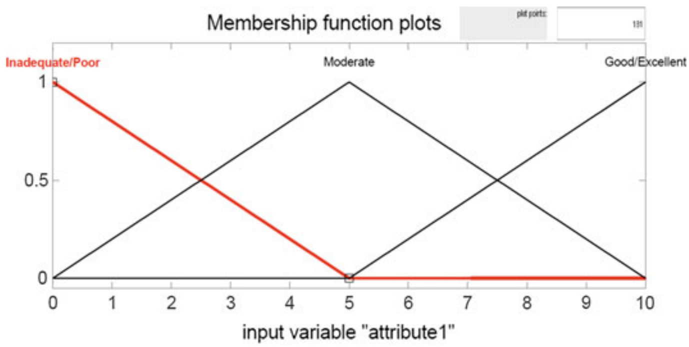
Fig. 1 Fuzzy logic based expert rule system for hydroelectric project

the EIA reports of hydroelectric projects, exemplified in five case studies of the Northeastern hydroelectric projects. An expert rule system for nine attributes of hydroelectric project is made by using Fuzzy logic. Mamdani is taken as Fuzzy inference system. Figure 1 shows the Fuzzy logic based expert rule system.

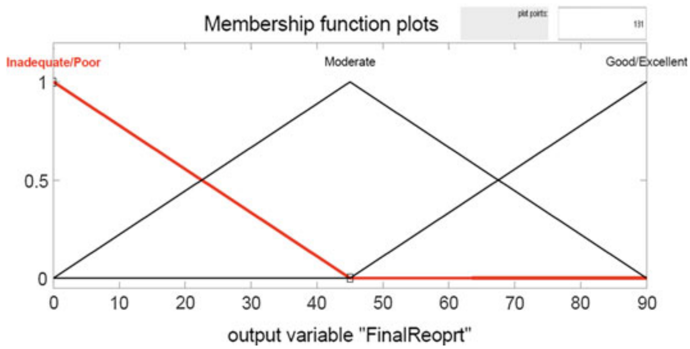
In the expert rule system, nine attributes are considered as inputs and final report is taken as output. Quality parameters are taken as membership functions. The membership functions are taken as Inadequate/Poor, Moderate and Good/Excellent to make the expert rule easier. Ranges are defined for different parameters. For attributes, range is taken as 0–10 as shown in Fig. 2a and for final report, range is taken as 0–90 as shown in Fig. 2b.

If-Then rules are made in Fuzzy Logic system, where the antecedent of the rule has nine parts from nine attributes. All parts of the antecedent are calculated simultaneously and resolved to a single output. For example, rule no. 1 is given below:

Rule 1: IF attribute 1 is Inadequate/Poor AND attribute 2 is Inadequate/Poor AND attribute 3 is Inadequate/Poor AND attribute 4 is Inadequate/Poor AND



(a) Range for quality of attributes



(b) Range for quality of final report

Fig. 2 **a** Range for quality of attributes. **b** Range for quality of final report attribute 5 is Inadequate/Poor AND attribute 6 is Inadequate/Poor AND attribute 7 is Inadequate/Poor AND attribute 8 is Inadequate/Poor AND attribute 9 is Inadequate/Poor THEN final report is Inadequate/Poor.

Result and Discussion

Five hydroelectric projects are selected from the Northeastern Part of India. These projects are

1. Demwe Lower Hydroelectric Project, Arunachal Pradesh (1750 MW).
2. Dibbin Hydroelectric Project, Arunachal Pradesh (120 MW).
3. Pauk Hydroelectric Project, Arunachal Pradesh (145 MW).
4. Ting Ting Hydroelectric Project, Sikkim (99 MW).
5. Heo Hydroelectric Project, Arunachal Pradesh (240 MW).

Quality of the EIA reports of these five hydroelectric projects is assessed. Expert rules are made by using Fuzzy Logic. Scores are given to different attributes and final score is obtained from Fuzzy Logic System for all the five EIA reports.

Demwe Lower Hydroelectric Project, Arunachal Pradesh

Project Description

Under this development, a concrete gravity dam is proposed to be constructed near village Mompani on Lohit river in Lohit District of Arunachal Pradesh. The EIA report has been prepared by CISMHE, University of Delhi in July, 2009.

Physical Features

The project is located at the foothill of Lohit basin. The project is located about 800 m upstream of Parasuram Kund bridge on NH 52 and falls in Lohit district with reservoir extending into Anjaw district of the State of Arunachal Pradesh. The project area can be accessed from Dibrugarh airport, which is about 550 km from Guwahati airport. The project site is about 215 km from Dibrugarh. A surface power house is proposed on the right bank of Lohit river to accommodate five numbers of vertical Francis turbines of 342 MW each.

Catchment area: 20,174 km^2.
Storage at maximum water level: 516.38 MCM.
Height of dam: A concrete gravity dam of 163.12 m height above deepest foundation level.

Table 1 Quality of nine attributes for DEMWE hydroelectric project EIA report

Attributes	1	2	3	4	5	6	7	8	9
Quality	G/E	G/E	I/P	G/E	I/P	M	G/E	I/P	M

where
G/E Good/excellent
M Moderate
I/P Inadequate/poor

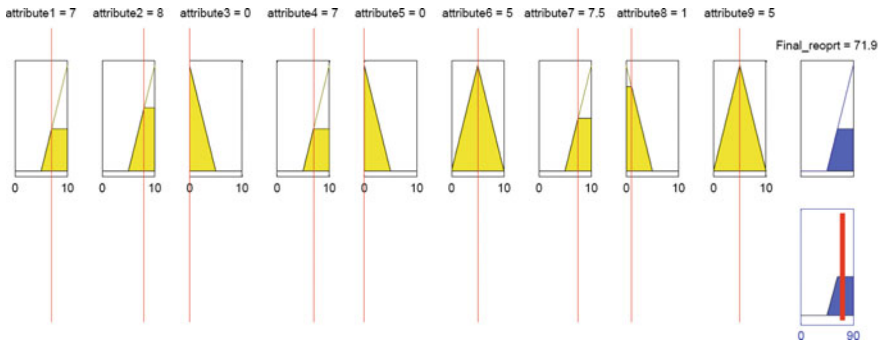


Fig. 3 Scoring for final EIA report of DEMWE hydroelectric project

Design discharge: 1729 cumecs.
Design head: 112 m.
Capacity: 1750 MW.

Performance Evaluation

Quality of nine attributes for Demwe hydroelectric project EIA report are marked as shown in Table 1. Putting these qualities in Fuzzy Logic system and giving score to nine attributes, the final score of the EIA report is evaluated. Figure 3 gives the scoring for final EIA report of Demwe hydroelectric project.

Dibbin Hydroelectric Project, Arunachal Pradesh

Project Description

The Dibbin Project is a run of river project with diurnal storage located on the Bichom River in the West Kameng district of Arunachal Pradesh. The EIA report has been prepared by WAPCOS Centre for Environment.

Physical Features

The dam site of the proposed Dibbin hydroelectric Project is located in the upper reach of river Bichom just downstream of confluence of Bichom Chu with Difya. The dam site is approachable through PWD road from Rupa up to Nafra and then a foot path of about 15 km up to Dibbin village. Power house site is located near Nachibin village. Nafra is connected to Rupa town by a PWD road. The nearest airport is at Tezpur.

Catchment area: 630 km^2.
Gross storage capacity: 7.085 MCM.
Height of dam: A concrete gravity dam of 92 m height above deepest foundation level.
Discharge capacity: 7380 cumecs.
Capacity: 120 MW.

Performance Evaluation

Quality of nine attributes for Dibbin hydroelectric project EIA report are marked as shown in Table 2. Putting these qualities in Fuzzy Logic system and giving score to nine attributes the final score of the EIA report is evaluated. Figure 4 gives the scoring for final EIA report of Dibbin hydroelectric project.

Table 2 Quality of nine attributes for DIBBIN hydroelectric project EIA report

Attributes	1	2	3	4	5	6	7	8	9
Quality	G/E	G/E	I/P	G/E	M	M	M	I/P	M

where
G/E Good/excellent
M Moderate
I/P Inadequate/poor

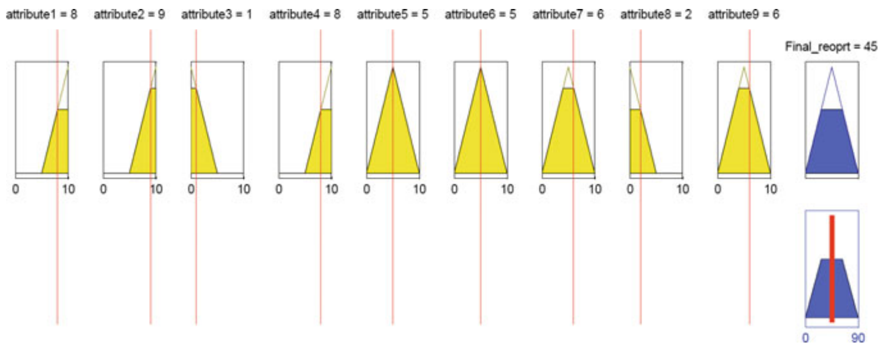


Fig. 4 Scoring for final EIA report of DIBBIN hydroelectric project

Pauk Hydroelectric Project, Arunachal Pradesh

Project Description

Pauk H.E. Project is the most upstream one of the cascade of three projects developed by Velcan Energy Group in the Mechuka subdivision of West Siang district of Arunachal Pradesh. The nearest township from the project is Mechuka, located 15 km upstream of the dam site. The EIA report has been prepared by CISMHE, University of Delhi in May 2014.

Physical Features

The Pauk HE project is proposed to harness the potential in Yarjep River which is a major tributary of river Siyom, forming a part of Brahmaputra river system. The project area is a steep mountainous area at an average elevation of 1000–1600 m. Geographically dam site is located between 94° 14′ 43″E longitude and 28° 32′ 46″ N latitude near Chengrung village. From the project site, the nearest operational airport is around 522 km, located at Likhabali in North Lakhimpur district of Assam.

Catchment area: 982 km^2.
Storage at maximum water level: 2820 cumecs.
Height of dam: A concrete gravity dam of 105 m height above deepest foundation level.
Design discharge: 121.65 cumecs.
Design head: 105 m.
Capacity: 145 MW.

Performance Evaluation

Quality of nine attributes for Pauk hydroelectric project EIA report are marked as shown in Table 3. Putting these qualities in Fuzzy Logic system and giving score to nine attributes the final score of the EIA report is evaluated. Figure 5 gives the scoring for final EIA report of Pauk hydroelectric project.

Table 3 Quality of nine attributes for PAUK hydroelectric project EIA report

Attributes	1	2	3	4	5	6	7	8	9
Quality	G/E	G/E	G/E	G/E	M	G/E	G/E	G/E	M

Where
G/E Good/excellent
M Moderate
I/P Inadequate/poor

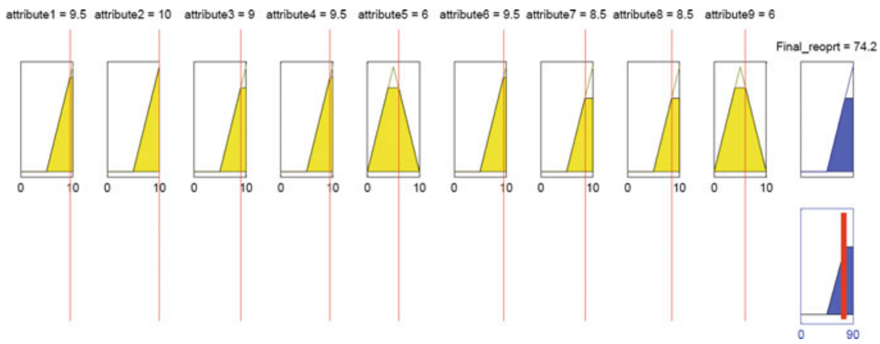


Fig. 5 Scoring for final EIA report of PAUK hydroelectric project

Ting Ting Hydroelectric Project, Sikkim

Project Description

The Ting Ting HEP located in West Sikkim envisages the utilization of the flow of Rathong Chhu a tributary of Rangit River for the generation of electric power. The EIA report has been prepared by RS Envirolink Pvt. Ltd. in August, 2010.

Physical Features

The project is located on the Rathong Chhu stream near the Yuksom village in West district of Sikkim. The project is proposed to have a 55 m high Dam across approximately 9 km upstream of Rathong Chhu's confluence with Rangit River; a 2.14 km head race tunnel and a surface power station with two Vertical Francis Turbine-driven generating units each of 49.5 MW (2 × 49.5 MW) aggregating to 99 MW.

Catchment area: 372 km^2.
Storage at maximum water level: 0.46 MCM.
Height of dam: A concrete gravity dam of 55 m height above deepest foundation level.
Design discharge: 46.13 cumecs.
Capacity: 99 MW.

Performance Evaluation

Quality of nine attributes for Ting Ting hydroelectric project EIA report are marked as shown in Table 4. Putting these qualities in Fuzzy Logic system and giving score

Table 4 Quality of nine attributes for TING TING hydroelectric project EIA report

Attributes	1	2	3	4	5	6	7	8	9
Quality	G/E	G/E	I/P	G/E	M	G/E	G/E	M	G/E

where
G/E Good/excellent
M Moderate
I/P Inadequate/poor

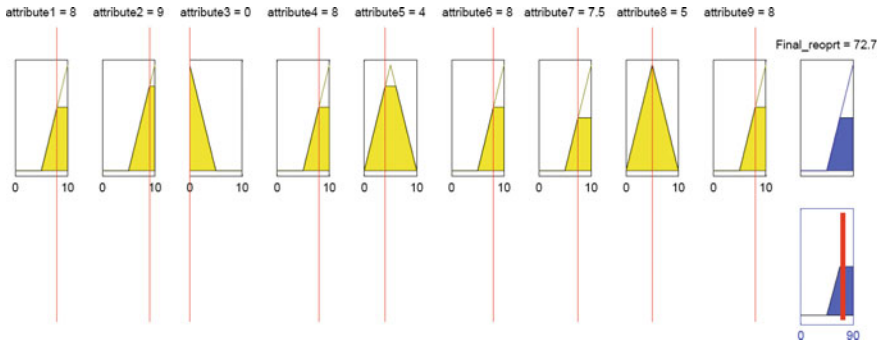


Fig. 6 Scoring for final EIA report of TING TING hydroelectric project

to nine attributes the final score of the EIA report is evaluated. Figure 6 gives the scoring for final EIA report of Ting Ting hydroelectric project.

Heo Hydroelectric Project, Arunachal Pradesh

Project Description

Heo H.E project is the middle project of the cascade of three projects developed by Velcan Energy in the Mechuka subdivision of the West Siang district of Arunachal Pradesh. The EIA **report has been prepared by CISMHE, University of Delhi in May, 2014**.

Physical Features

The Heo HE project is proposed to harness the power potential in Yarjep River (Shi Shito) which is a major tributary of river Siyom, forming a part of Brahmaputra river system. The nearest township from the project is Mechuka, located 19 km upstream of the barrage site. The project area can be approached through a motorable road up to barrage site, and then by foot tracks from the Tato-Mechuka road. The project falls in a mountainous area at an average elevation of 1000–1500 m.

Catchment area: 1065 km^2.
Active storage: 0.15 MCM.
Height of barrage: 16 m height above river bed level.
Design discharge: 130.23 cumecs.
Design net head: 201.8 m.
Capacity: 240 MW.

Performance Evaluation

Quality of nine attributes for Heo hydroelectric project EIA report are marked as shown in Table 5. Putting these qualities in Fuzzy Logic system and giving score to nine attributes the final score of the EIA report is evaluated. Figure 7 gives the scoring for final EIA report of Heo hydroelectric project.

Final scores for all the hydroelectric projects are obtained from Fuzzy logic toolbox. Demwe Lower Hydroelectric Project, Arunachal Pradesh gets a score of 71.9 out of 90, Dibbin Hydroelectric Project, Arunachal Pradesh gets a score of 45 out of 90, Pauk Hydroelectric Project, Arunachal Pradesh gets a score of 74.2 out of

Table 5 Quality of nine attributes for HEO hydroelectric project EIA report

Attributes	1	2	3	4	5	6	7	8	9
Quality	G/E	G/E	G/E	G/E	M	G/E	G/E	G/E	M

where
G/E Good/excellent
M Moderate
I/P Inadequate/poor

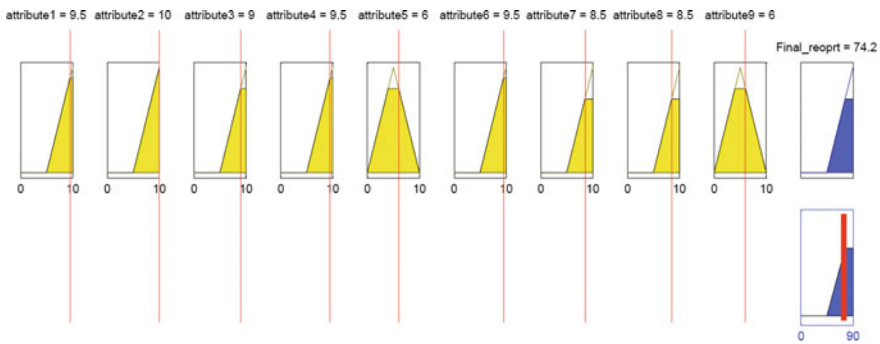


Fig. 7 Scoring for final EIA report of HEO hydroelectric project

90, Ting Ting Hydroelectric Project, Sikkim gets a score of 72.7 out of 90 and Heo Hydroelectric Project, Arunachal Pradesh gets a score of 74.2 out of 90. Among all the reports, Diibbin hydroelectric project gets the least score. So, changes should be made accordingly in order to make the EIA report better. The other reports are in the Good/Excellent quality range. Both Pauk and Heo hydroelectric project have the highest score.

Conclusion

The quality of an EIA should be such that it should make some change in a better way, i.e. it should improve the environmental sustainability and should help in better decision-making. The decision-making on sanction of environmental impact assessment (EIA) is basically a difficult multi-dimensional process because it considers both the scientific facts and qualitative analysis. Since, Fuzzy Logic based expert rule system is able to give final scores on the quality of the EIA report, therefore it can be taken as an assessor of the effectiveness of EIA reports not only for hydroelectric projects but also for other projects.

The framework is composed of the Fuzzy logic providing the following benefits:

- Enabled to handle dependence problems among attributes and
- It is empowered with subjective assessment modeled by Fuzzy logic to link the space between scientific facts and the fulfillment of social values and beliefs.

Although the proposed approach has been demonstrated by case studies of five northeastern states' hydroelectric project, further investigation is needed in the future, including the involvement of additional specialists to refine Fuzzy rules and the use of statistics instead of experts' judgments to define the dependence among attributes.

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Assessment and Prediction of Environmental Noise Generated by Road Traffic in Nagpur City, India

Sameer S. Pathak, Satish K. Lokhande, P.A. Kokate and Ghanshyam L. Bodhe

Abstract The main intention of research is to quantify and predict the noise level due to heterogeneous traffic conditions at critical junctions and highways. A study was carried out to assess the existing status of noise levels and its impacts on the environment with a possibility of further expansion of the city. Vehicular traffic noise levels measured during peak and non-peak hours at all selected locations were higher (71–76 dBA and 69.3–76.3 dBA) than the prescribed limits. The recognized amount of traffic and with the help of road geometry data, prediction of noise level is performed using modified Federal Highway Administration (FHWA) model, and the computed noise was compared with the measured one for assuring the relevance of this model for prediction of forthcoming noise. The outcome received from this model was nearer to the observed noise level, having a percentage error of ±3%, the best fit lines generated between them gives R^2 of 0.457. In this study measured and computed noise exposure levels were depicted with the help of contour maps. Octave band spectral analysis reveals that the interrupted traffic flow is above the free flow traffic and realized that the contribution of two wheeler and cars/jeep are mainly responsible for a generation of noise level at both the lower and higher frequencies, it also signifies that the FHWA model is convenient to be used for Indian circumstances.

Introduction

India has emanated as a rapidly developing economy, ensuing swift industrialization and urbanization, the increment in vehicles can produce a life-threatening noise. (Tripathi et al. 2006), The vehicles reported in India enhanced from around

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0.3 million in 1951 to almost 142 million in 2011 (MoRTH GoI 2013) an increase of 7.7% annually as against a population growth of 3.8% during the same period. The annual growth was even faster at 10% during the period of 2001−2011 (CSTEP). The root age of environmental noise in our daily life is mainly concerned with the increasing urbanization and the development of transportation sector within metropolitan cities (Kaklauskas et al. 2009; Shukla et al. 2009; Akgungor et al. 2008; Daunoras et al. 2008; Jovic and Doric 2010). The significant factor for inflation of noise in the urban region is vehicular traffic contributing to almost 55% of the entire noise. (Omidvari and Nouri 2009; Banerjee and Chakraborty 2006; Goswami 2009). Several previous studies on traffic noise resolve the major source of noise existing in the urban areas. It is a dominant source of a nuisance both in the developed and developing nations. Tremendous noise can affect the health of the people living proximity to road junctions and busy highways. It disturbs the quality of life in urban areas; this is due to rapid growth in vehicular traffic (Patel et al. 2006; Alam et al. 2001; Calixto et al. 2003; Cowan 1994; Rylander et al. 1976). Therefore, an environmental assessment of traffic noise is more complex in Indian cities regarding the conglomeration in a traffic situation, having different vehicle category, congestion, road geometry and deficiency of traffic sense. (Kalaiselvi and Ramachandraiah 2010; Wani and Jaiswal 2010)

Background of Nagpur City

Nagpur, the orange city, is a tertiary largest city and the second capital of the Indian state of Maharashtra; and being virtually at the geographical centre of India. All large-scale highways and railways are going through this city, it is at the colligation of two National Highways, NH-6 and NH-7 and also associated to all Metropolitan of India by air routes. This has ensued the city being a major trade and transportation center. Accelerated urbanization specifies the level of expansion of any region affecting an enormous increase in motor vehicles, which affects the environment to a significant amount. The entire length of roads in the city is 1907 km having the major road is about 500 km, and other were interior roads (Indo-USAID 2006). In the Nagpur district, the population is heavily focused in the city, which prevails the urban scene, the trend of urbanization in Nagpur district is shown in Fig. 1, Nagpur nearly half of the total population of the district lives in Nagpur (Bhonsle 2010).

The vehicles in Nagpur city have sprung up at a degree of 8.00% per annum during 2009–2012 as depicted in Fig. 2. The contribution of scooter/motorcycle endured at 83.6% to 82.6 during that span. On the other hand, the share of cars and jeeps which were at 9.38% in 2009 goes to 10.08% in 2011. On an average, the share of two wheeler taking over a dominant role in the traffic of Nagpur city (Aparajit 2012; Deo 2014).

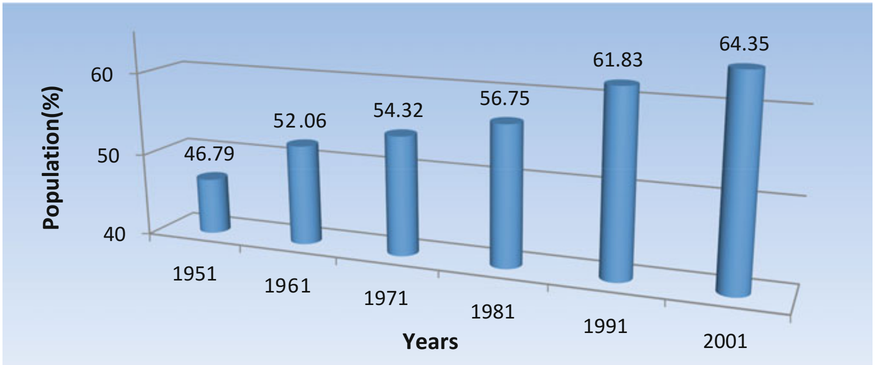

Fig. 1 Percentage of urban population in Nagpur region

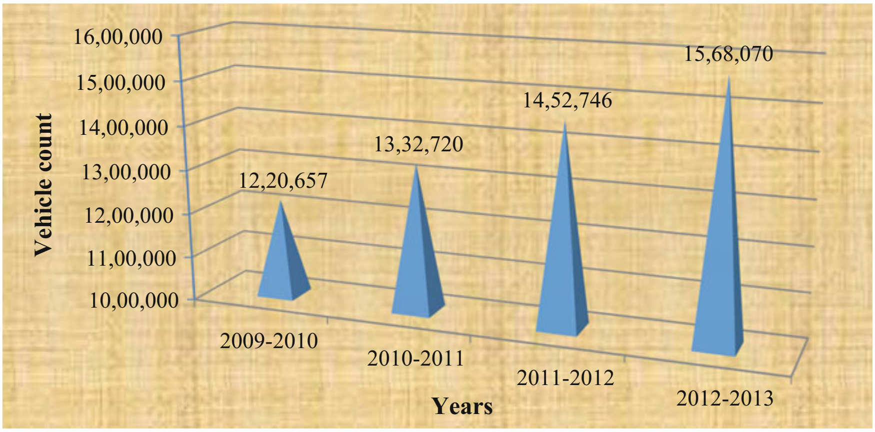

Fig. 2 Vehicle count during the period of 2009−2012

Noise Prediction

In order to meliorate the assessment of traffic noise for obstructed as well as free flow traffic, the prediction model is required to evaluate the interaction between characteristics of traffic and emission levels of noise for better projection of a future situation based on the study of present trends (Ugbebor et al. 2015). Most of the countries have developed their traffic noise prediction models according to their traffic and environmental conditions, such as Burgess model (1977) in Sydney (Australia), Griffith and Langdon Model (1968), CSTB (Centre Scientifique et Technique du Batiment) model was formulated by the French, CoRTN (Calculation of Road Traffic Noise) model (1975) has been developed by the Transport and Road Research Laboratory and the Department of Transport of the United Kingdom, the

RLS90 (Richtlinien für den Lärmschutz an Straben) traffic noise model in Germany, the Statens Planverk 48 model in Scandinavia, Nouvelle Methode de Prevision de Bruit or simply NMPB-Routes-96 model in French, ASJ model in Japan, The Italian Research Institute developed a TNM, the **"CNR"** model (Consiglio Nazionale delle Ricerche) and the GIS based road traffic noise prediction model was drawn up in China (2002) (Rajakumara et al. 2008).

Anti-noise legislations, major highway control ordinances and other governmental policies that pertain environmental noise control strategies, however, could not be diminished noise annoyance without a prior assessment and prediction. Hence, it's mandatory to control noise earlier; it crosses an alarming stage. In this paper, endeavor has been made to judge the traffic noise level in selected areas of Nagpur city and performed noise prediction using modified Federal Highway Administration Agency (FHWA) model and compare the estimated noise with the measured one for assuring the relevancy of the model.

Materials and Methods

Study Area

With a probability of further elaboration of the city, a comprehensive survey was carried out at numerous junctions and arterial roads in Nagpur city including heavy traffic jam as well as free flow traffic in the morning and evening hours. Subsequently, nine locations were selected including six junctions and three highways namely Medical square (J1), Ram Nagar square (J2), Indora square (J3), RBI square (J4), Jagnade square (J5), HB Town square (J6); Amravati road (H1), Wardha road (H2) and Chinwada road (H3) which lies between 21° 05′ and 21° 11′ N latitude and 79° 00′ to 79° 08′E longitude as illustrated in Fig. 3.

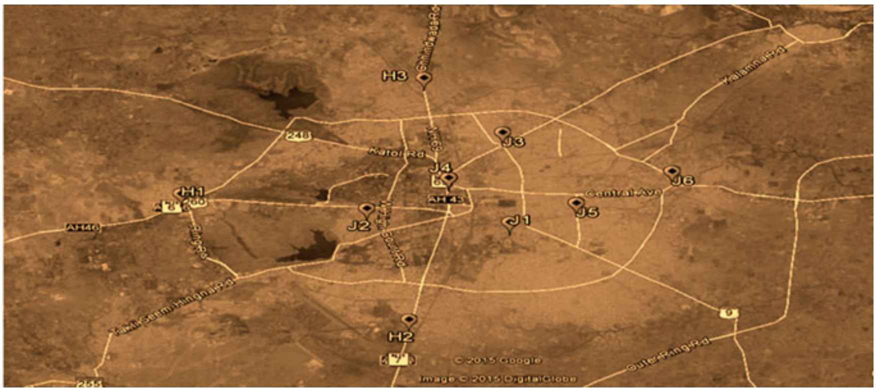

Fig. 3 Map showing study area of Nagpur city for noise monitoring

Evaluation of Traffic Noise

Measurement of traffic noise was accomplished at all the selected nine locations across the Nagpur city, in which six stations are the heavily populated junctions, while the remaining three are the highways passing towards outside of the city. Measurements of different parameters at each site and gathering of data were executed for one hour at two different peak time intervals in the morning (10:00–11:00 am) and evening (6:00–7:00 pm). Traffic noise was recorded using the sound level metre CK: 172B Optimus Green (Cirrus, UK) as per Indian standards with fast response mode having "A" frequency weighted and data logging of 1s time interval, the definitive range of the equipment is of 20–140 dBA. During noise assessments, the data collection in the field was accomplished in accordance with the recommendations of national and international agencies. The microphone of the device was located at a distance of 3.5 m from the road edge and placed at the height of 1.2–1.5 m from the land. In order to eradicate the consequence of interference due to building reflections, noise exposure levels are measured 1 m away from the structures.

Data Extraction

Noise metre was mounted on a stand and placed away from the road in order to receive a valuable estimation of noise. Investigation of traffic volume was achieved continuously for one hour manually at all chosen sites and are classified into six categories (scooter/motorcycle, car/jeep/van, auto rickshaw, light commercial vehicles, heavy truck, and buses) based on the necessity of our study. Average speed for each category of vehicles was calculated by specifying two points on the road at well-known distance, note down the entry and exit time for each category of vehicles at beginning and end marking points, by dividing the known distance with time difference between those points, speed in km/h for each vehicle classes were estimated. The structure of road consisting of geometrical parameter, category, traffic lanes, road situation was also considered in the study. The distance of noise equipment from the midpoint of road for locations Medical square, Ram Nagar square, Indora square, RBI square, Jagnade square, HB Town square; Amravati road, Wardha road and Chinwada road were around 24.5, 9, 10.5, 18, 14.5, 17, 10.5, 15 and 15.5 m respectively.

Traffic Noise Modelling

The prediction of noise is achieved by applying modified FHWA model in accordance with Indian contexts. Traffic noise can be forecasted based on single vehicle noise, volume and speed of vehicles, observer distance from the source and other correlation coefficients. FHWA model distributes noise level through a series of adjustments to the reference sound level assessed via sampling stations; the equation for traffic noise prediction algorithm is shown below. (Bhattacharya et al. 2001)

$$\mathrm{Leq} = L_0 + \Delta\mathrm{Li}, \tag{1}$$

where

L_0 reference noise level of a stream of vehicles;
$\Delta\mathrm{Li}$ adjustment applied.

The expression for well-defined FHWA model is given below.

$$L_{\mathrm{eqi}} = L_0 + A_{\mathrm{VS}} + A_D + A_S, \tag{2}$$

where

L_{eqi} hourly equivalent noise for each category of vehicle;
L_0 reference energy mean emission level;
A_{vs} volume and speed correction;
A_D distance correction;
A_S ground cover correction.

The FHWA model computes noise level through a series of adjustments which are discussed individually as shown (Nirjar et al. 2003).

Reference Energy Mean Emission Level

It is the noise level emitted by each of six classes of vehicles; the reference noise level was calculated using the individual noise emission equation for various categories of vehicle.

Volume and Speed Correction

$$A_{\mathrm{VS}} = 10\,\log_{10}(D_0 V/S) - 25, \tag{3}$$

where

D_0—reference distance; S—speed in km/h; V—volume of traffic in each class of vehicle (veh/h)

Distance Correction

$$A_D = 10\ \log_{10}(D_0/D)^{1+\alpha}, \tag{4}$$

where

D_0—reference distance considered as 15 m in FHWA model; D—distance from the centre of the line to the equipment position; α—ground cover coefficient.

Equivalent noise for each category of vehicle is estimated using Eq. (2) and then logarithmically compute the total hourly L_{eq}, the combined L_{eq} is the logarithmic summation of the emission value having each category of vehicles using below expression

$$L_{eq} = 10\ \log \sum 10^{Leqi/10} \tag{5}$$

Results and Discussions

Data Analysis

Traffic noise induced due to interrupted and uninterrupted flow registered at chosen junctions and highways is presented in Table 1. The perception of study area and data gathered during assessment are analytically scrutinized and discussed in this segment.

The sustainable noise parameters such as average equivalent noise, L_{10}, L_{50} and L_{90} (indicates that the noise levels exceeded 10, 50 and 90% of the measurement period) were recorded to resolve the degree of noise at selected regions.

During estimation of L_{eq}, prevailing parameters like degree of variation in noise level and traffic streams are considerably accountable; it is assessed with following terms:

Noise Pollution Level (NPL) = L_{eq} + a ($L_{10} - L_{90}$), where a = 1.0 (constant in the equation)

Traffic Noise Index (TNI) = 4 ($L_{10} - L_{90}$) + L_{90} − 30 dB

Noise Climate (NC) = $L_{10} - L_{90.}$

After analyzation of above noise descriptors, it was observed that during morning time interval the L_{10}, L_{50} and L_{90} were ranged from 72.6 to 77.5 dBA; 68.2 to 72.1 dBA and 63.1 to 68.8 dBA respectively and the noise level of 71.4–77.5 dBA; 65.6–70.8 dBA and 58.6–67.6 dBA are received in the evening time period.

Table 1 Noise level in dBA at all the selected locations

	Morning hours							Evening hours						
Locations	Leq	L10	L50	L90	NPL	TNI	NC	Leq	L10	L50	L90	NPL	TNI	NC
J1	71	72.6	68.2	65.9	77.7	62.7	6.7	71.5	74.2	69.7	66.8	78.9	66.4	7.4
J2	72.3	73.6	68.2	64.8	81.1	70	8.8	75.2	77.5	70.8	67.6	85.1	77.2	9.9
J3	75.3	77.1	72.1	68.8	83.6	72	8.3	71.6	74.0	69.5	66.0	79.6	68	8
J4	71.5	73.0	68.5	63.6	80.9	71.2	9.4	71.6	73.5	69.1	64.7	80.4	69.9	8.8
J5	76	76.6	69.9	66.7	85.9	76.3	9.9	76.3	77.2	70.7	67.4	86.1	76.6	9.8
J6	73.7	75.3	69.3	65.1	83.9	75.9	10.2	73.2	74.8	69.5	65.6	82.4	72.4	9.2
H1	73.7	76.8	69.9	63.1	87.4	87.9	13.7	69.3	71.4	66.4	62.3	78.4	68.7	9.1
H2	74.6	77.5	70.2	63.1	89	90.7	14.4	72.8	74.8	68.1	62.3	85.3	82.3	12.5
H3	73.1	76.3	65.9	58	91.4	101.2	18.3	71.5	74.6	65.6	58.6	87.5	92.6	16

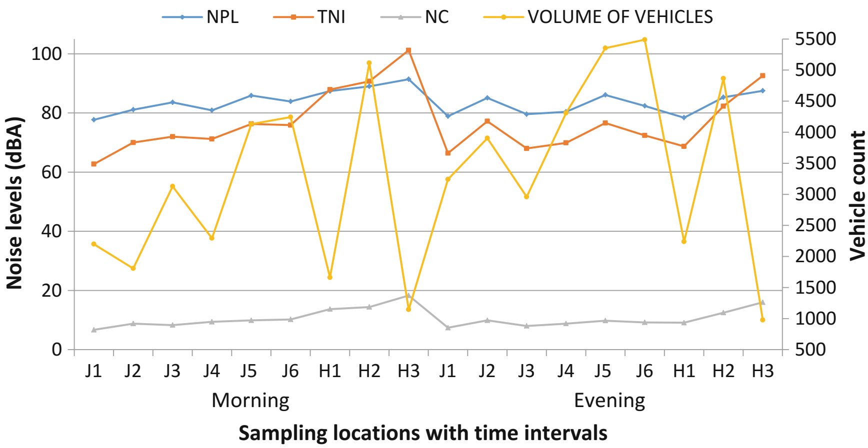

Fig. 4 Vehicle count versus level of noise descriptors (NPL, TNI and NC)

The maximal level of NPL, TNI and NC (during morning and evening time periods) was recorded (101.2 and 92.6 dBA); (91.4 and 87.5 dBA) and (18.3 and 16 dBA) at Chinwada road (H3). The observed vehicle counts and traffic congestion at this location are less which may allow different categories of vehicles to move speedily on the road this may be the reason having, higher values of NPL, TNI, and NC at this sampling point. However, minimum value was noted (62.7 and 66.4 dBA); (77.7 and 78.9 dBA) and (6.7 and 7.4 dBA) at medical square (J1) having greater traffic count and large road width as depicted in Fig. 4.

Data harvested throughout the analyzing period reveals that undesirable and annoying noise levels in Nagpur city exceeds over 70 dB at all the locations observed in this study as shown in Fig. 5. The identified Leq levels recorded during morning and evening periods ranged from 71.00 to 76.00 dBA and 69.3 to 76.3 dBA, highest measured equivalent sound was observed at junction J5 in the morning as well as in the evening hours equate with other stations because of having minimum road width and higher traffic count. Below sketch also represents the interconnection between noise and traffic flow. This significant traffic volume may be the prime factor resulted in average noise levels at all the locations exceed the prescribed limit by national standards. It is also concluded that the dominant factor for generation of noise in Nagpur city is the percentage of scooter/motor cycle and cars/jeep/vans comparison with other categories of vehicles.

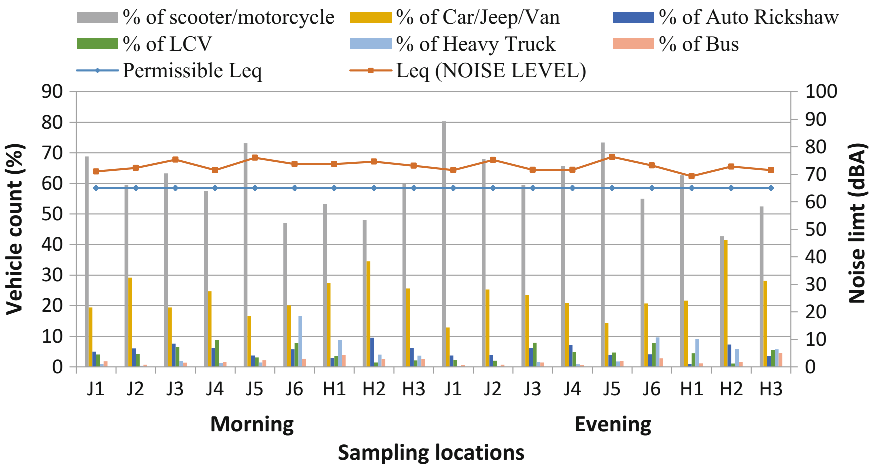

Fig. 5 Distribution of vehicles versus noise level at different measuring sites

Spectral Analysis of Junction and Highway Traffic

The implementation of frequency analysis is carried out for extracting the exhaustive data from a convoluted noise, and it serves the justification to fluctuate the noise level with respect to frequency, which is linked to variations in the situation of the noise creating sources. It can be acted by registered one-third octave band sampling data from all the selected cross sections and highways and measure the frequency allocation of sound level electronically through sound measuring device. Hunt et al. established that the low frequency noise is normally generated from vehicle engine while noise having greater frequencies is resulted from tyre/road interaction for entire speeds, that is the dominating noise originating from all speeds in a surplus of 30 km/h. This indicates that the uninterrupted traffic is controlled by road/tyre interaction, whereas interrupted traffic noise is dominated by engine noise (Hunt et al. 1991).

While considering the above fact, when our results were investigated, some contradictory outcomes are received in this study. During morning interval, the observed noise levels due to interrupted traffic flow was higher compared with uninterrupted traffic flow for lower frequency energy (up to 200 Hz) and for further frequencies (<200 Hz) higher noise levels were due to uninterrupted traffic flow. However, during the evening hours, the highest noise level at both the lower and higher frequency (below 250 Hz and above 2 kHz) is generated due to interrupted traffic, as a result of increased traffic percentage at most of the sampling stations during the evening intervals as shown in Fig. 6.

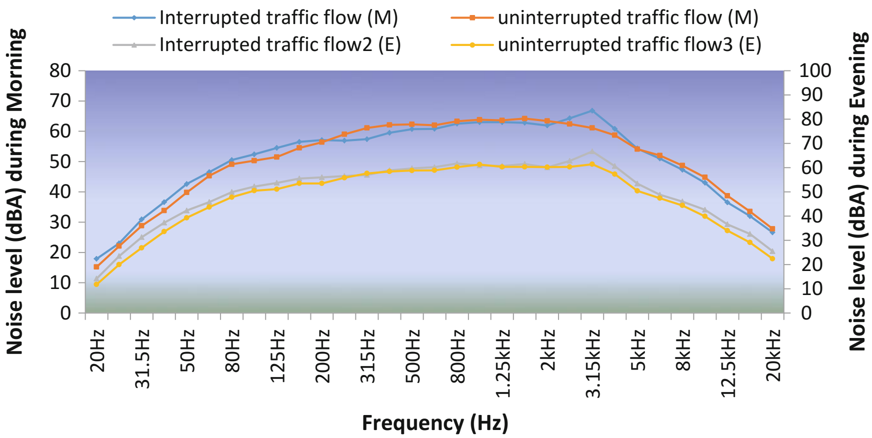

Fig. 6 Spectral analysis during measurement period

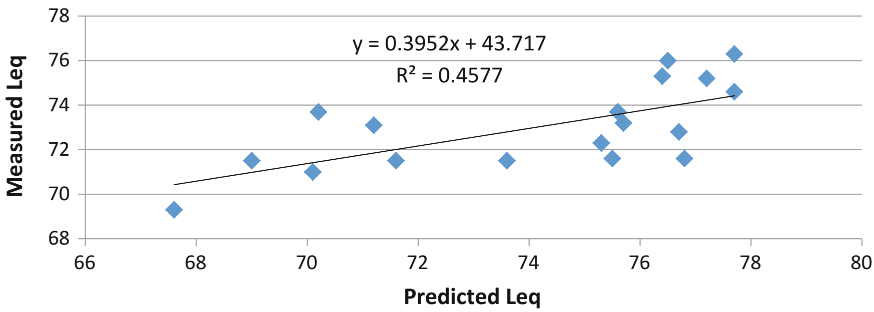

Fig. 7 Correlation plot for predicted and measured noise level

Model Illustration

To find out the relevancy of the customized FHWA model, evaluation of traffic stream for various categories of vehicles and their velocity has been scrutinized and resolved that the computed noise levels were overestimated than that of observed values at most of the selected locations. The correlation of predicted outcomes depicts that the evaluated noise is close to the measured values having a percentage error of ±3% between them and the best fit line was also generated which gave an R^2 value of 0.457 as shown in Fig. 7. Based on the findings, it can be observed that the modified FHWA model gives a strong correlation and best suitability for prediction of noise levels in Indian cities within an acceptable limit of accuracy.

In this research, the noise survey of Nagpur city was conducted at different sampling stations, including cross-sections traffic as well as free flow traffic during morning and evening peak hours, and attempt has been made to depict the present

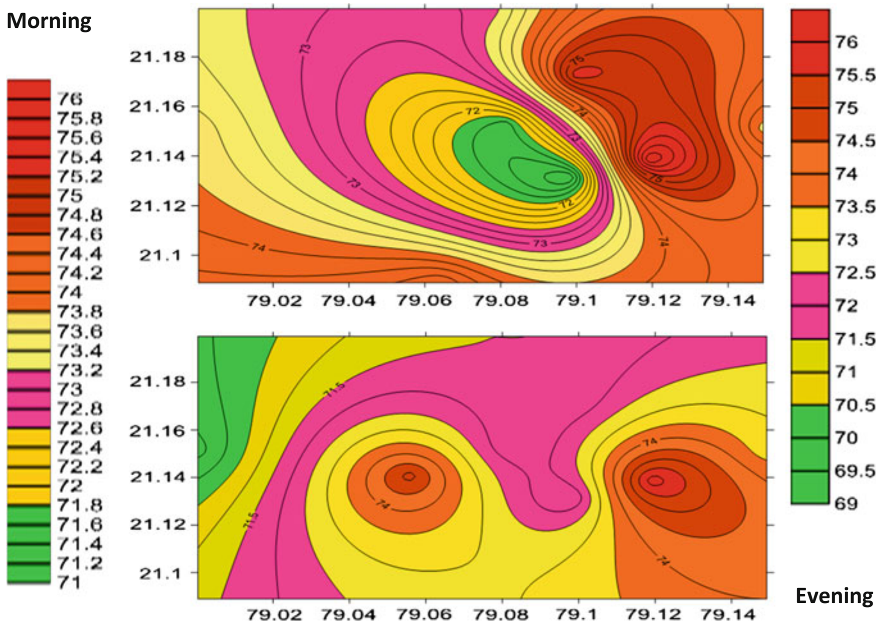

Fig. 8 Noise map of Nagpur city during morning and evening intervals

noise scenario with the help of contour map for better understanding of variation of noise during different times of the day. The contour map demonstrated that the average noise level at all the sampling stations was found in the exceeded range of 69.3–76.3 dBA as shown in Fig. 8.

Conclusion

This research distinctly revealed that the noise obtained from both heterogeneous and free flow traffic is higher than the recommended national standards for both morning and evening peak intervals and it concludes that road traffic noise directly depends on increased noise from the vehicular engine horn during interrupted traffic flow and poor road conditions. Heavy traffic had greater velocity vehicles on the selected highways, and the transportation sector was also one of the dominant sources of noise in this city.

The statistical analysis between forecasted and measured values was performed to find out the fitness of the model. It can reveal that the modified FHWA model gives a significantly higher correlation coefficient values and can be applied successfully for the prediction of road traffic noise under Indian traffic conditions within a tolerable boundary.

The reported noise spectrum shows the distribution of noise levels with respect to frequency, and it depicts that noise generated due to interrupted traffic flow is above the free flow traffic. The traffic noise can also be displayed in the form contour lines with various colour shades for different levels of noise contours and indicates the exceeded noise level at all selected locations in the Nagpur city.

Hence it is mandatory to generate the noise control policies to avoid harmful results of sound pollution and for restricting such unwanted noise, regulation of traffic volume, the speed of vehicles and unwanted horns at sensitive points might be helpful for reducing noise pollution, to avoid the adverse effect on the community and the environment. A comprehensive program for public awareness is urgently required to control the vehicular traffic and protect the public from its unwanted impacts.

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Time-Dependent Study of Electromagnetic Field and Indoor Meteorological Parameters in Individual Working Environment

A.K. Mishra, P.A. Kokate, S.K. Lokhande, A. Middey and G.L. Bodhe

Abstract Human beings in modern society are facing wide-range of electromagnetic (EMF) radiations from few hertz (Hz) to gigahertz (GHz) range. Its minor sources are power supply, personal computers, Wi-Fi routers, Zig-bee, cell phones and base trans-receiver stations (BTS) devices. We have extensively used them in microenvironments like offices, restaurants, buses, close auditorium, etc. In such indoor environments, the air quality incorporates various gaseous emissions, temperature, humidity, particulate matters, etc. Accordingly, the cumulative effect of EMF and air-quality parameters can change human health and quality of life. This paper described exposure assessment of EMF and indoor meteorological parameters in the individual microenvironment during working and non-working hours. The results were obtained via broadband methodology for assessment of EMR and point source methodology for temperature, relative humidity and particulate matter (PM). The kriging model in surfer software approved to be more suitable to show accurate gridding of EMF during working and non-working hours. No significant change observed in time-dependent analysis of EMF, temperature, humidity and PM count. However, telephony band was dominant during whole analysis. Hence, more investigations are required to identify the quantitative relation between these independent parameters.

Keywords EMF · Microenvironment · Electro-smog · Indoor meteorological parameters

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Introduction

In the recent years, human beings exposed to a different degree of air pollutants and electromagnetic radiation (EMR) due to increasing population density in the urban area. The artificial electromagnetic fields (EMF) created a similar situation like faradays cage in individual working environments. Air pollutants, EMF radiations, noise and improper lighting arrangement always affected the productivity of the staff in his working place. A good air quality in any microenvironment is necessary for workers. Hence, several types of studies have demonstrated that the poor indoor air quality can negatively affect the human beings and his productivity (Pejtersen et al. 1999; Wargocki et al. 2002a, b; Skyberg et al. 1997). The individuals exposed to indoors can often bear little resemblance to those experienced outdoors in nature, and that many individuals exposed to inappropriate levels and types of electric fields can reduce localized concentrations of biologically essential and microbiocidal small air ions (Jamieson et al. 2007).

Additionally, poorly designed electromagnetic environments are more prone to electronic hypersensitivity, stress level, oxygen uptake and performance. (Kamienska-Zyla and Prync-Skotniczny 1996; Clements-Croome and Jukes 2001; Bio-Initiative Report 2007; Genuis 2008). However, the mechanism of EMF effect on human health is still a debatable issue in bio-electromagnetic community but long-term exposure can be detrimental to human beings.

An EMF and Indoor Meteorological Parameters

There is a known fact that the EMF is invisible radiations that possess electric (E) and magnetic (H) components and flows in the direction of propagation of current. In an environment, the electric fields are produced by the local build-up of electric charges in the atmosphere associated with thunderstorms. The earth's magnetic field causes a compass needle to orient in a north–south direction and is used by birds and fish for navigation.

Besides these natural sources, the electromagnetic spectrum also includes fields generated by human-made sources. In our daily life, we exposed to a different level of EMF through electrical gadgets, Wi-Fi, mobile phones, security devices, etc. at 50 Hz to 3 GHz. The long-term biological effects of the electromagnetic field are tissue damage or body heat and stress result in 'work stoppage' by unnecessary heating. The considerable amount of research has been under progress to find out the exact relationship between EMF radiation and human health. Likewise, inadequate power, arrangement inside office also contributes accumulation of electric field density near electrical gadgets.

Similarly, many solid and liquid particles are harmful to the quality of air (Ebelt et al. 2000; Dons et al. 2011; Pope et al. 2006; Puett et al. 2009; Rojas et al. 1999). They can be distributed in the air as per circulation of the airflow, temperature and humidity. Its intensity and levels may vary based on the location of the office environments. However, peoples are spending 90% of their time in closed environment of residence, office, shopping mall, theater, etc. Hence, it is important to assess the possible air quality parameter in working environments (Janssen et al. 2000; Mihalis et al. 2015; Bako-Biro et al. 2004). Hence, there is a need to address this issue of monitoring and assessment in indoor working environment to improve the health and productivity of workers. This article attempts to explore most heterogeneous environmental parameter in individuals' working environments, i.e. EMF radiation, temperature, humidity and PM. Accordingly, to map the exposure difference during working and non-working hours were the secondary objective of this work.

Methodology

The International Communication for Non-Ionizing Radiation Protection (ICNIRP) guideline was followed for estimation of EMR (ICNIRP 2008). Likewise, IEEE protocol was used for choosing the location and monitoring methodology (IEEE 2010; ITU 2015). The total 11 different points from the office environment were identified for exposure monitoring. However, the common equipment at each place was personal computer, scanner, air conditioner, ceiling fan, uninterrupted power supply (UPS), cell phone and laptop. Each equipment was fixed according to its position and assessment point.

All the locations were selected in office environments in government office of Nagpur city. The periodic time interval data was collected during working and non-working hours in the month of July 2015. The continuous measurements of electric field were taken using an SMP2 portable electromagnetic field meter. The broadband measurement methodology enables to assess the EMF radiation from 100 kHz to 3 GHz. The 50 Hz operating equipment were neglected due to extremely low magnetic field at selected distance. The distance from the computers and other RF emitting equipment were 0.7−1.0 m. The temperature and relative humidity (RH) of working as well as non-working hours was measured using Equinox EQ-172 m. The dimensions of all the rooms were measured in feet using GLM professional VF250. The concentration of PM was measured using a portable mini las aerosol spectrometer (Mini–LAS) model 11-R version-1.178, programmed by GRIMM Aerosol, Germany. All the equipment was calibrated and measurements were taken at height of 1.5 m from floor of the room.

Result and Discussion

Working and Non-working Hours

To replicate this study in the future at different places, the common official working hours were considered during monitoring, i.e. 10:00 AM to 6:00 PM and 6:00 PM to 10:00 AM. During office hours, 90% of equipment were 'ON' while during non-working hours, 10% of them were under functioning state. The electric field was monitored at 11 different locations in an office environment with a sample count of 720 at each location as per ICNIRP guidelines. However, the indoor meteorological parameter such as temperature, RH and particulate matter were monitored thrice per day along with the EMF meter. After averaging of each sampling location, Table 1 depicts the exposure levels of all parameters. The highest value observed in E-filed was 49.86×10^{-2} V/m during working hours and the lowest was 30.09×10^{-2} V/m during non-working hours respectively. Particulate matter may occur due to regular foot movements, accumulation of dust from outer sources.

Table 1 Showing the average values of EMF, Temp and RH on different location during working and non-working hours

Location	Working hour (10:00 AM to 6:00 PM)				Non-working hour (6:00 PM to 10:00 AM)			
	EMF (V/m)	TEMP (°C)	RH (%)	PM_{10} (μg/m^3)	EMF (V/m)	TEMP (°C)	RH (%)	PM_{10} (μg/m^3)
1.	49.86×10^{-2}	27.85	57.32	50.3	31.86×10^{-2}	29.56	77.05	30.8
2.	44.02×10^{-2}	27.80	57.62	55.2	32.02×10^{-2}	29.60	74.23	35.5
3.	46.49×10^{-2}	27.50	56.25	49.4	30.09×10^{-2}	29.60	74.21	34.5
4.	35.51×10^{-2}	27.50	56.24	39.1	31.51×10^{-2}	29.60	74.17	35.5
5.	42.77×10^{-2}	27.42	60.32	46.5	36.77×10^{-2}	29.60	74.38	40.1
6.	45.19×10^{-2}	27.41	58.07	45.1	39.19×10^{-2}	29.60	74.18	41.8
7.	41.78×10^{-2}	26.92	55.85	35.3	36.18×10^{-2}	29.60	74.12	40.2
8.	39.43×10^{-2}	29.34	52.09	41.1	33.43×10^{-2}	29.60	74.96	34.6
9.	35.74×10^{-2}	28.01	56.13	40.5	30.74×10^{-2}	29.60	74.03	31.7
10.	31.31×10^{-2}	27.20	53.08	35.1	28.31×10^{-2}	29.50	74.27	30.2
11.	38.70×10^{-2}	26.80	59.88	43.1	33.17×10^{-2}	29.50	74.04	37.8

Contour

Contour was plotted by selecting the length of the room as *x*-axis and width of the room as *y*-axis whereas; value of E-field was plotted in the *Z*-axis. Generally, contour is used to in environmental monitoring and GIS data representation. However, the kriging model is generally used in field of environmental mapping, remote sensing, etc. First time, it has been applied to mimic the situation for electromagnetic field using different locations. This exposure map represents an exposure level of EMF during working and non-working environment. The plotted pattern in Fig. 1a, b shows no remarkable difference between working and non-working. Hence, the specific frequencies may be present during working and non-working hours.

Additional Measurements

The spectrum analysis of electromagnetic field was crucial for identification of the unwanted frequency band. Hence, the spectrum from 100 kHz to 3 GHz frequency was scanned using signal hound spectrum analyzer with broadband antenna during working and non-working hours. The common telephony bands of GSM900, 1800, 2100 kHz were observed during working and non-working hours. Figure 2a, b illustrates frequency spectrum available in indoor environments. The negligible interference of other frequency was observed that confirm the presence of telephony band.

Temperature and relative humidity (RH) were also measured separately during the E-field and particulate matter measurements. Temperature and RH values were recorded for 6 min, i.e. 360s similar to other parameters. Many scientific studies reveal direct proportionality relations between RH and temperature, i.e. as temperature increases the relative humidity decreases and vice versa. The same kind of pattern was found in our study also. The graph in Figs. 3a, b and 4a, b shows that the temperature and RH levels have not much difference. This may be occurring due to seasonal variation and climatic conditions. The results can differ in different season at the same location.

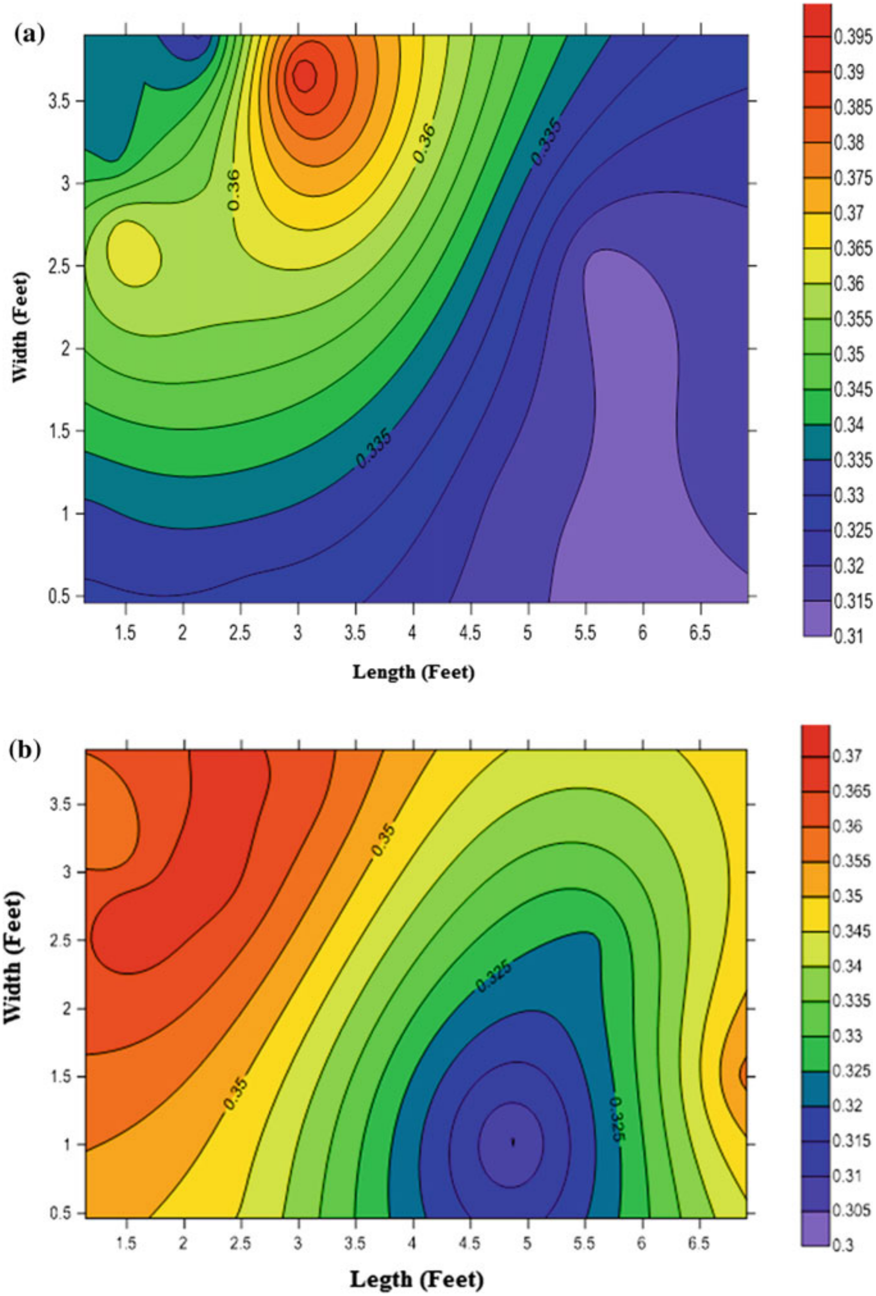

Fig. 1 **a** Contour of EMF during non-working hours, **b** contour of EMF during non-working hour

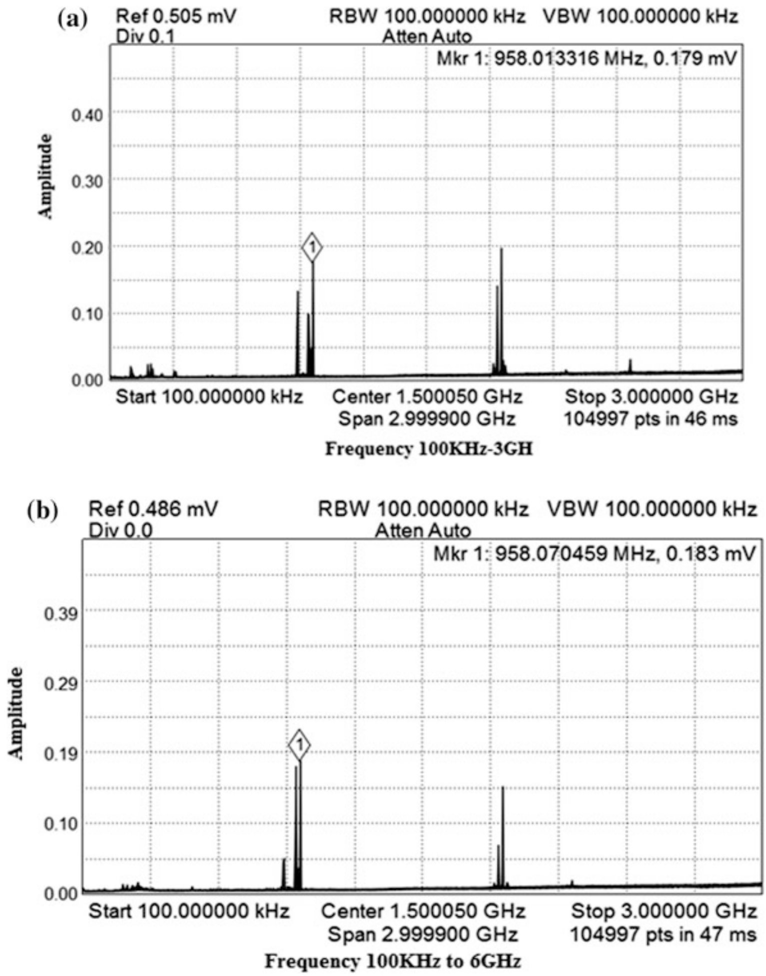

Fig. 2 **a** Spectrum analysis during working hours, **b** spectrum analysis during non-working hours

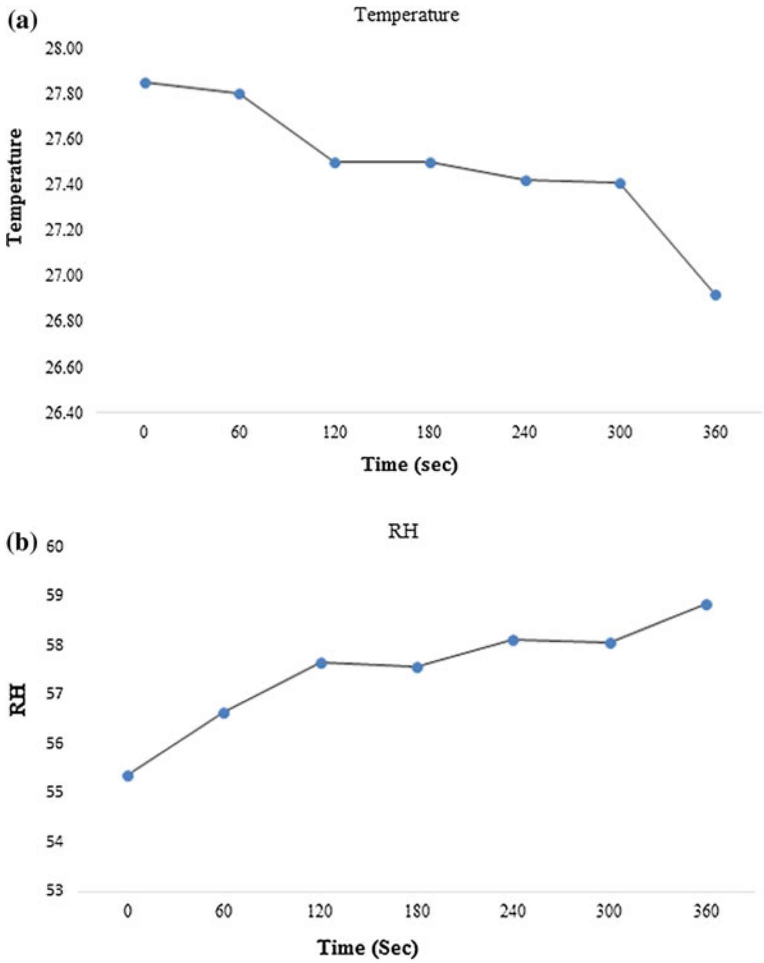

Fig. 3 **a** Average of temperature during working hours, **b** Average of humidity during working hours

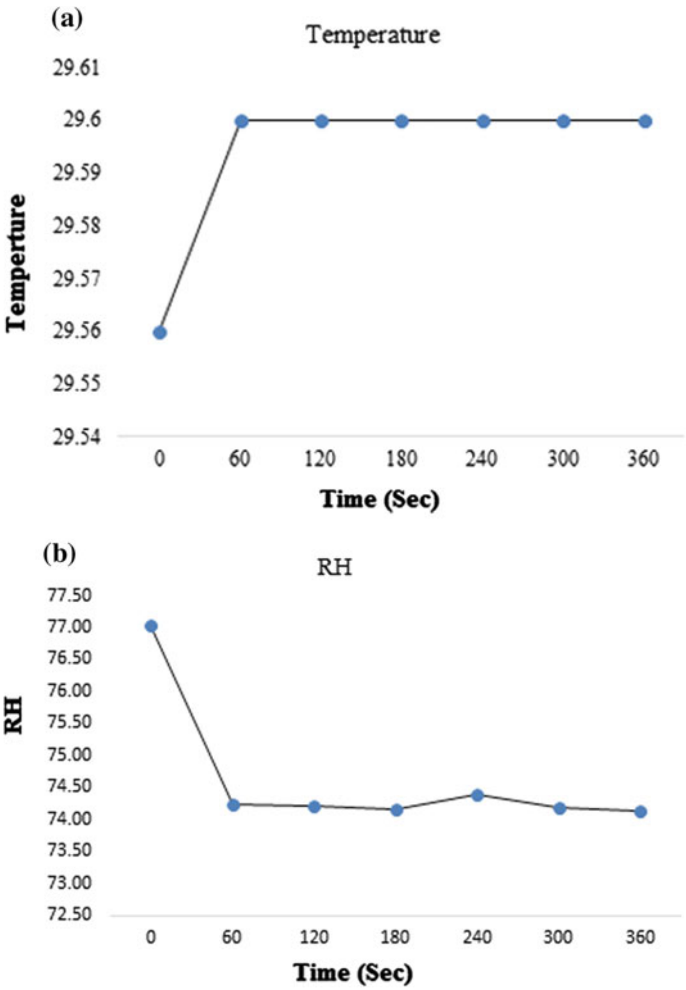

Fig. 4 **a** Average of temperature during non-working hours, **b** Average of humidity during non-working hours

Conclusion

The E-field and meteorological parameter's study carried out in the original office environments first time in India. An individual always spends more time in the indoor office environments and can sense mimic condition similar to faraday's cage and exposed more via telephony equipment operating in the range of 100 kHz to 3 GHz. The localized electric field effects on health are more dominant to access the exposure scenario in terms of E-field. The level of electropollution that individuals exposed can change according to the internal architecture of the room. After analysis of the EMF levels the results, it is concluded that poor variations is observed during working and non-working hours. The kriging model gives a better option to show EMF distribution in the working and non-working hours. Regular monitoring of frequency selective EMF in microenvironment is very difficult due to interference of other frequencies. However, further investigations are needed to identify the exact correlation between electromagnetic field and indoor meteorological parameters. Seasonal indoor studies of temperature, humidity and electromagnetic field are also essential to maintain the health of workers.

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Fish Biodiversity and Its Periodic Reduction: A Case Study of River Narmada in Central India

Muslim Ahmad Shah, Vipin Vyas and Shalini Yadav

Abstract Studies on fish biodiversity are important for planning remedial measures for conservation of our rich aquatic biodiversity resources. The variability in life is largely governed by the environment and genes they possess. Thus more than 99% of all species amounting to over five billion species that ever lived on earth are estimated to be extinct. Information from the available sources suggest that about 1.2 million have been documented and over 86% species are still not yet documented. Besides natural disaster, about 99% species are presently considered as threatened species and are at great risk from human activities, primarily those driving out by habitat loss, introduction of exotic species, global warming, construction of dams, over fishing activities, increasing demand for water, the damming of rivers throughout the world, the dumping and accumulation of various pollutants, and finally invasive species make aquatic ecosystems one of the most threatened part on the planet. Thus it is not surprising that there are many fish species that are endangered in both freshwater and marine habitats.

Keywords Diversity · Species · Aquatic · Exotic · Extinction · Ecosystem

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Introduction

Water generally collects in a river from precipitation through a drainage basin from surface runoff and other sources such as ground water recharge, springs, and the release of stored water in ice and glaciers. Rivers have always been the most important fresh water resources. Biodiversity is a contraction of biological diversity. It reflects the number, variety, and variability of living organisms and how these change from one location to another and over time. It includes diversity within species (genetic diversity) between species (species diversity) and between ecosystems (ecosystem diversity). It is frightening but true: Our planet is now in the midst of its sixth mass extinction of plants and animals, the sixth wave of extinctions in the past half-billion years. We are currently experiencing the worst spate of species die-offs. Although extinction is a natural phenomenon, it occurs at a natural "background" rate of about one to five species per year. Scientists estimate we are now losing species at 1,000–10,000 times the background rate, with literally dozens going extinct every day. It could be a scary future indeed, with as many as 30−50% of all species possibly heading toward extinction by mid-century. Biodiversity is essential to the health of natural systems. Thus conserving biological diversity is essential for protecting life on this planet. It becomes even more important to know about the fact that the current anthropogenic destruction of biodiversity is dangerous. Hence, conservation must be analyzed both scientifically and morally.

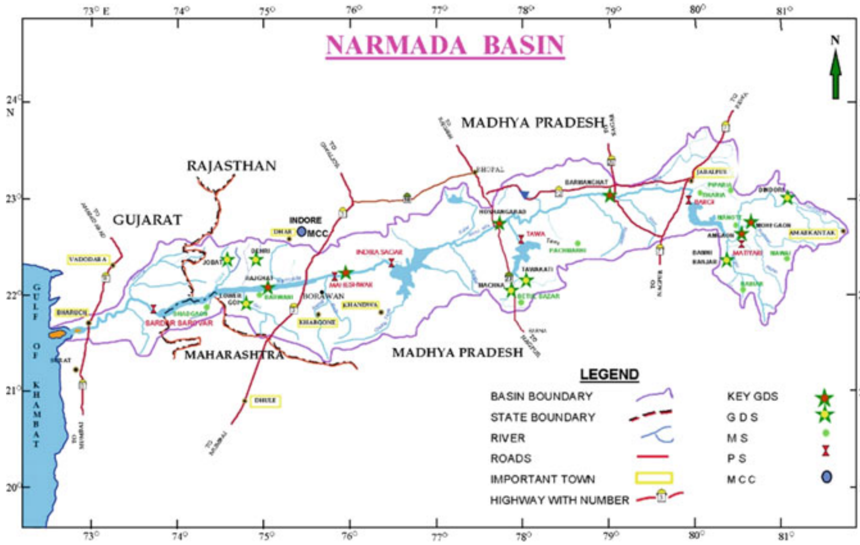
Keeping this in mind, a comparative study on Fish Biodiversity and its periodic reduction was done during 2013–2014. Diversity is commonly used to describe the number, variety, and variability of living organisms.

Materials and Methods

Study Area

Narmada is the largest west flowing river of India and one of the 13 prominent rivers of India, originates from a small tank called Narmada kund located at Amarkantak town in Maikal Hill ranges from eastern part of Madhya Pradesh forms a traditional boundary between North India and South India over a length of 1, 312 km before draining through the gulf of Cambey (Khambat) into the Arabian Sea. The tributaries of River Narmada are of great importance in Central India as they provide an important source of water, irrigation, and other resource-based activities. When river Narmada emerges from the Marble Rocks it enters into its first fertile basin. This basin extends about 320 km with an average width of 35 km in the south. The northern part of the valley is the Barna–Bareli plain, where the

Barna River flows. The pictorial map of the Narmada River Basin (Source: Narmada Control Authority, Madhya Pradesh) and its salient features are given below.



Salient features of Narmada basin	
Basin	*Extent*
Longitude	72° 38′–81° 43′E
Latitude	21° 27′–23° 37′N
Length of Narmada river (km)	1312
Catchment area (sq. km)	98796
Average water resource potential (MCM)	45639
Utilizable surface water resource (MCM)	34500
Live storage capacity of completed projects (MCM)	17806.0
Live storage capacity of projects under construction (MCM)	6835.00
Total live storage capacity of projects (MCM)	24641.0
No. of hydrological observation stations of CWC	26 (including 8 Gauge site)
No. of flood forecasting stations of CWC	4

The aim of this research was to determine the fish biodiversity loss of River Narmada in Central India. During this study five sampling stations were chosen for sampling in the central zone of MP which starts from Shahganj village to Holipur village.

Site S1: Shahganj

The stretch of the river at Shahganj station is of run condition. The depth of water is about 370 cm and an elevation of about 290 m above sea level. Bed substrates recorded at this site was soil, sand, and gravel type. It has a shallow region with weed infested banks and is located at 22° 14′N latitude and 77° 80′E longitude. It is a swift moving area characterized by predominantly smooth to slight turbulent flow of 49 cm. The site is inhabited with more than 100 fisher families which earn their lively hood from this site and its adjoining areas.

Site S2: Bandrabhan (Sangam)

The Bandrabhan station is riffle habitat and is bed substrates recorded at this site was sand, gravel, and boulder type. This region also has weed-infested banks and has flow of 52 cm. The water at this place is swift moving and bubbling type. At this site two main rivers namely Narmada and Tawa joins each other; so this site is famous as Sangam. In this spot, a holy mela is also organized on the occasion of Kartik Purnima. This section of river is followed by some religious practices also.

Site S3: Budhni Ghat

The station Budhni is a town and a Nagar Palika in Sehore district in the state of Madhya Pradesh, India. It is situated on Bhopal to Hoshangabad road at a distance of 10 km from Hoshangabad in north direction on the banks of Narmada River. This site is located at 22° 76′N latitude and 77° 69′E longitude. The depth of water is about 210 cm and an elevation of about 287 m above sea level. This region is highly infested with aquatic vegetation near the banks of the river. This stretch is in a pool condition with a maximum range between banks is 245.5 m. Bed substrates recorded at station was soil, sand, slit, and gravel type.

Site S4: Moukala

This station shows run habitat and is situated at 22° 73′N latitude and 77° 65′E longitude. The depth of water is about 290 cm and an elevation of about 282 m above sea level. There are only five fishermen families at Moukala but fishermen of other areas come for fishing at this site. This station has a shallow region with weed infested-bank and the river bed substrates are sand, soil, slit, and gravel type. Both the banks of the station have agriculture lands in the vicinity and agricultural practice are shown at this station. Majority of the population near this site are labors. The village near this site is will electrified and people use electric motors for irrigating the agricultural lands. Fish is the main food item for people at this site.

Site S5: Holipur

This site is 25 km far from Hoshangabad by road and it is connected with metalled road passing 5 km through forest and is located at 22° 74′N latitude and 77° 61′E longitude. There is a famous religious temple of Hanuman ji on the bank on this study station. A very few people living neat this site are named as Mooni Maharaj because they do not speak but express their views through writing and there is a Dharamshala under construction near this study station. The depth of water at this site is about 405 cm and is at an elevation of about 282 m above sea level. This site is highly infested with aquatic vegetation near the banks. This stretch is in a pool condition and the range between banks is 356 m. Bed substrates recorded at this site was soil, sand, slit, and gravel type. Both the banks of this station have agriculture lands in the vicinity and agricultural practice are also shown at this station. The flow of water at this site was recorded as 49 cm.

Fish Collection and Identification

In this study, fishes were collected from all sampling stations of the river stretch under study during winter, summer, monsoon, and post-monsoon seasons. Fishing was done at every sampling stations seasonally by using different types of nets having mesh size of 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 mm and area size of the nets (gill net, cast net) was 36 sq. ft. The strategy used for fishing was same as was used by the local fishermen of the area under study. Five stations were selected for fishing which ranged from Shahganj to Holipur a 30 km river stretch. The fish sampling sites, where fishing was done are Shahganj, Bandraband, Budhni ghat, Moukala and Holipur.

At least 10 fishing efforts were made at every station seasonally and the catch was then weighed by a balancer and was noted down at every station. Further the collected fishes catch was identified by using standard identifying keys of Jayaram (1999), Qureshi and Qureshi (1983) and Shrivastava (1998). The collected fishes were sorted species-wise and the numbers of individuals for each species were counted and then their percent composition was determined.

Result

Present Scenario of Fish Diversity of River Narmada at Hoshangabad

During this study, a total **37 specie**s of fishes belonging to **1 Kingdom**, **1 Phylum**, **3 Classes, 5 Orders, 11 Families,** and **24 Genera** were recorded from Shahganj to Holipur a 30 km river stretch in the Hoshagabad district of Madhya Pradesh. These fish species are recorded are summarized in Tables 1 and 2 respectively.

Once upon a time River Narmada was highly diversified pertaining to its fish resource but the mad rate race for fishing jeopardized the life depending on this resource. The fish diversity was on the peak with a total of 93 species were recorded prior to 1967 (Karamchandani et al. 1967; Vyas et al. 2006).

Discussion

This study was also carried out in river Narmada in the year 2015. It was observed in this piece of study that there is a periodic reduction of fish species in the river to a great extent and in this piece of study 56 fish species gets reduced and these reducing species are Hilsa ilisha, Gonialosa manmina, Notopterus notopterus, Barilius varga, Barilius evezardi, Barilius radiolatus, Catla catla, Crossocheilus latius latius, Cirrhinus latia, Cirrhinus reba, Danio aequipinnatus, Danio rerio, Exomus danricus, Parapsilorhynchus tentaculatus, Garra gotyla, Garra lamta, Garra mullya, Labeo rohita, Labeo boggut, Labeo pangusia, Labeo dyocheilus, Puntius goganio, Puntius ambassis, Puntius pinnauratus, Puntius dorsalis, Puntius stigma, Oreichthys cosuatis, Tor khudree, Tor putitora, Lepidocephalichthys guntea, Noemacheilus dayi, Noemacheilus evezardi, Noemacheilus heiheilus beavani, Ompok bimaculatus, Ompok pabda, Mystus cavasius, Mystus tengara, Mystus vittatus, Rita pavimentata, Amblycepsmangois, Gagata itchkeea, Glyptothorax lonah, Glyptothorax ribeiroi, Laguvia ribeiroi, Clupisoma garua, Silonia silondia, Heteropneustes fissilis, Channa gachua, Channa punctatus, Channa striatus, Badis badis, Glossogobius giaris, Mastacembilus armatus, Anguilla bengalensis, Hypopthalimichthys molitris and Cyprnus carpio. This decline in studies also found to be corelated with the investigations that are carried out by Karamchandani et al. and Vyas et al.

Table 1 Classification of fish species recorded during the study

Kingdom	Phyllum	Class	Order	Family	Zoological names
Animalia	Chordata	Actinopterigii	Cypriniformes	Cyprinidae	*Amblypharyngodon mola*
					Barilius bendelisis, B. barila, Labuca
					Chela labuca
					Cirrhinus mrigala
					Danio devario
					Labeo bata, L. calbasu, L fimbriatus
					Osteobrama cotio
					Oxygaster bacaila, O. clupeoids, O. gora
					Puntius amphibious, P. crysopoma, P. conchonius, P. sarana, P. sophore, P. titius
					Rasbora daniconius
					Tor tor
				Nemacheilidae	*Nemacheilus botra*
			Perciformis	Anabantidae	*Anabas testudineus*
					Chanda nama
					Parambassis chandaranga
				Channidae	*Channa marulius*
				Nandidae	*Nandus nandus*
			Siluriformis	Clarridae	*Clarias battrachus*
				Bagridae	*Mystus aor, M. bleekeri*
					Rita rita
				Siluridae	*Wallago attu*
			Synbrancheformis	Mastacembelidae	*Mastacembelus pancalus*
			Beloniformis	Belonidae	*Xenentodon cancila*
		Osteocthyes	*Perciformis	Anabantidae	*Colisa fasciata*
		Teleostomi	*Siluriformis	*Bagridae	**Mystus seenghala*

*Indicates repeated ones

Table 2 .

Recorded fish Species of river Narmada	Fish species recorded by Karamchandani et al. (1967)	Fish species missing as per Karamchandani et al. (1967)	Fish species recorded by Vyas et al. (2006)	Fish species Missing as per Vyas et al. (2006)	Fish species recorded in the present study	Fish species missing as per the Present Study
Hilsa ilisha	*Hilsa ilisha*	*	*	*Hilsa ilisha*	*	*Hilsa ilisha*
Gonialosa manmina	*Gonialosa manmina*	*	*	*Gonialosa manmina*	*	*Gonialosa manmina*
Notopterus notopterus	*Notopterus notopterus*	*	*Notopterus notopterus*	*	*	*Notopterus notopterus*
Amblypharyngodon	*Amblypharyngodon*	*	*Amblypharyngodon*	*	*Amblypharyngodan mola*	*
Barilius bendelisis	*Barilius bendelisis*	*	*Barilius bendelisis*	*	*Barilius bendelisis*	*
Barilius varga	*	*Barilius varga*	*	*Barilius varga*	*	*Barilius varga*
Barilius barila	*Barilius barila*	*	*Barilius barila*	*	*Barilius barila*	*
Barilius evezardi	*Barilius evezardi*	*	*	*Barilius evezardi*	*	*Barilius evezardi*
Barilius radiolatus	*Barilius radiolatus*	*	*	*Barilius radiolatus*	*	*Barilius radiolatus*
Catla catla	*Catla catla*	*	*	*Catla catla*	*	*Catla catla*
Crossocheilus latius latius	*Crossocheilus latius latius*	*	*	*Crossocheilus latius latius*	*	*Crossocheilus latius latius*
Cirrhinus mrigala	*Cirrhinus mrigala*	*	*Cirrhinus mrigala*	*	*Cirrhinus mrigala*	*
Cirrhinus latia	*	*Cirrhinus latia*	*	*Cirrhinus latia*	*	*Cirrhinus latia*
Cirrhinus reba	*Cirrhinus reba*	*	*	*Cirrhinus reba*	*	*Cirrhinus reba*
Danio devario	*Danio devario*	*	*Danio devario*	*	*Danio devario*	*
Danio aequipinnatus	*Danio aequipinnatus*	*	*	*Danio aequipinnatus*	*	*Danio aequipinnatus*
Danio rerio	*Danio rerio*	*	*	*Danio rerio*	*	*Danio rerio*
Exomus danricus	*Exomus danricus*	*	*	*Exomus danricus*	*	*Exomus danricus*
Parapsilorhynchus tentaculatus	*Parapsilorhynchus tentaculatus*	*	*	*Parapsilorhynchus tentaculatus*	*	*Parapsilorhynchus tentaculatus*
Garra gotyla	*Garra gotyla*	*	*	*Garra gotyla*	*	*Garra gotyla*
Garra lamta	*Garra lamta*	*	*	*Garra lamta*	*	*Garra lamta*

(continued)

Table 2 (continued)

Recorded fish Species of river Narmada	Fish species recorded by Karamchandani et al. (1967)	Fish species missing as per Karamchandani et al. (1967)	Fish species recorded by Vyas et al. (2006)	Fish species Missing as per Vyas et al. (2006)	Fish species recorded in the present study	Fish species missing as per the Present Study
Garra mullya	*Garra mullya*	*	*	*Garra mullya*	*	*Garra mullya*
Labeo rohita	*Labeo rohita*	*	*	*Labeo rohita*	*	*Labeo rohita*
Labeo bata	*Labeo bata*	*	*Labeo bata*	*	*Labeo bata*	*
Labeo boggut	*Labeo boggut*	*	*	*Labeo boggut*	*	*Labeo boggut*
Labeo calbasu	*	*Labeo calbasu*	*Labeo calbasu*	*	*Labeo calbasu*	*
Labeo pangusia	*	*Labeo pangusia*	*	*Labeo pangusia*	*	*Labeo pangusia*
Labeo dyocheilus	*Labeo dyocheilus*	*	*	*Labeo dyocheilus*	*	*Labeo dyocheilus*
Labeo fimbriatus	*Labeo fimbriatus*	*	*Labeo fimbriatus*	*	*Labeo fimbriatus*	*
Labeo gonius	*Labeo gonius*	*	*Labeo gonius*	*	*Labeo gonius*	*
Chela labuca	*Chela labuca*	*	*Chela labuca*	*	*Chela labuca*	*
Oxygaster bacaila	*	*Oxygaster bacaila*	*Oxygaster bacaila*	*	*Oxygaster bacaila*	*
Oxygaster chipeoides	*Oxygaster chipeoides*	*	*Oxygaster chipeoides*	*	*Oxygaster chipeoides*	*
Puntius conchonius	*Puntius conchonius*	*	*Puntius conchonius*	*	*Puntius conchonius*	*
Puntius goganio	*Puntius goganio*	*	*	*Puntius goganio*	*	*Puntius goganio*
Puntius sarana	*Puntius sarana*	*	*Puntius sarana*	*	*Puntius sarana*	*
Puntius ambassis	*Puntius ambassis*	*	*	*Puntius ambassis*	*	*Puntius ambassis*
Puntius amphibius	*Puntius amphibius*	*	*Puntius amphibius*	*	*Puntius amphibius*	*
Puntius chrysopoma	*Puntius chrysopoma*	*	*Puntius chrysopoma*	*	*Puntius chrysopoma*	*
Puntius pinnauratus	*Puntius pinnauratus*	*	*	*Puntius pinnauratus*	*	*Puntius pinnauratus*
Puntius dorsalis	*Puntius dorsalis*	*	*	*Puntius dorsalis*	*	*Puntius dorsalis*
Puntius stigma	*	*Puntius stigma*	*	*Puntius stigma*	*	*Puntius stigma*
Puntius titius	*Puntius titius*	*	*	*Puntius titius*	*Puntius titius*	*
Puntius sophore	*Puntius sophore*	*	*Puntius sophore*	*	*Puntius sophore*	*

(continued)

Table 2 (continued)

Recorded fish Species of river Narmada	Fish species recorded by Karamchandani et al. (1967)	Fish species missing as per Karamchandani et al. (1967)	Fish species recorded by Vyas et al. (2006)	Fish species Missing as per Vyas et al. (2006)	Fish species recorded in the present study	Fish species missing as per the Present Study
Oreichthys cosuatis	*Oreichthys cosuatis*	*	*	*Oreichthys cosuatis*	*	*Oreichthys cosuatis*
Rasbora daniconius	*Rasbora daniconius*	*	*Rasbora daniconius*	*	*Rasbora daniconius*	*
Tor tor	*Tor tor*	*	*Tor tor*	*	*Tor tor*	*
Tor khudree	*Tor khudree*	*	*	*Tor khudree*	*	*Tor khudree*
Tor putitora	*Tor putitora*	*	*	*Tor putitora*	*	*Tor putitora*
Lepidocephalichthys guntea	*Lepidocephalichthys guntea*	*	*Lepidocephalichthys guntea*	*	*	*Lepidocephalichthys guntea*
Nemacheilus botia	*Nemacheilus botia*	*	*Nemacheilus botia*	*	*Nemacheilus botia*	*
Noemacheilus dayi	*Noemacheilus dayi*	*	*	*Noemacheilus dayi*	*	*Noemacheilus dayi*
Noemacheilus evezardi	*Noemacheilus evezardi*	*	*	*Noemacheilus evezardi*	*	*Noemacheilus evezardi*
Noemacheilus heiheilus beavani	*	*Noemacheilus heiheilus beavani*	*	*Noemacheilus heiheilus beavani*	*	*Noemacheilus heiheilus beavani*
Ompok bimaculatus	*Ompok bimaculatus*	*	*Ompok bimaculatus*	*	*	*Ompok bimaculatus*
Ompok pabda	*	*Ompok pabda*	*	*Ompok pabda*	*	*Ompok pabda*
Mystus bleekeri	*Mystus bleekeri*	*	*Mystus bleekeri*	*	*Mystus bleekeri*	*
Mystus cavasius	*Mystus cavasius*	*	*	*Mystus cavasius*	*	*Mystus cavasius*
Mystus tengara	*	*Mystus tengara*	*Mystus tengara*	*	*	*Mystus tengara*
Mystus vittatus	*Mystus vittatus*	*	*	*Mystus vittatus*	*	*Mystus vittatus*
Mystus aor	*Mystus aor*	*	*Mystus aor*	*	*Mystus aor*	*
Mystus seenghala	*Mystus seenghala*	*	*Mystus seenghala*	*	*Mystus seenghala*	*
Wallago attu	*Wallago attu*	*	*Wallago attu*	*	*Wallago attu*	*
Rita rita	*	*Rita rita*	*Rita rita*	*	*Rita rita*	*
Rita pavimentata	*Rita pavimentata*	*	*	*Rita pavimentata*	*	*Rita pavimentata*
Amblycepsmangois	*Amblycepsmangois*	*	*	*Amblycepsmangois*	*	*Amblycepsmangois*

(continued)

Table 2 (continued)

Recorded fish Species of river Narmada	Fish species recorded by Karamchandani et al. (1967)	Fish species missing as per Karamchandani et al. (1967)	Fish species recorded by Vyas et al. (2006)	Fish species Missing as per Vyas et al. (2006)	Fish species recorded in the present study	Fish species missing as per the Present Study
Gagata itchkeea	*Gagata itchkeea*	*	*	*Gagata itchkeea*	*	*Gagata itchkeea*
Glyptothorax lonah	*Glyptothorax lonah*	*	*	*Glyptothorax lonah*	*	*Glyptothorax lonah*
Glyptothorax ribeiroi	*Glyptothorax ribeiroi*	*	*	*Glyptothorax ribeiroi*	*	*Glyptothorax ribeiroi*
Laguvia ribeiroi	*Laguvia ribeiroi*	*	*	*Laguvia ribeiroi*	*	*Laguvia ribeiroi*
Clupisoma garua	*Clupisoma garua*	*	*Clupisoma garua*	*	*	*Clupisoma garua*
Silonia silondia	*	*Silonia silondia*	*	*Silonia silondia*	*	*Silonia silondia*
Heteropneustes fissilis	*Heteropneustes fissilis*	*	*Heteropneustes fissilis*	*	*	*Heteropneustes fissilis*
Clarias batrachus	*Clarias batrachus*	*	*Clarias batrachus*	*	*Clarias batrachus*	*
Xenentodon cancila	*Xenentodon cancila*	*	*Xenentodon cancila*	*	*Xenentodon cancila*	*
Channa gachua	*Channa gachua*	*	*Channa gachua*	*	*	*Channa gachua*
Channa marulius	*Channa marulius*	*	*Channa marulius*	*	*Channa marulius*	*
Channa punctatus	*Channa punctatus*	*	*	*Channa punctatus*	*	*Channa punctatus*
Channa striatus	*	*Channa striatus*	*Channa striatus*	*	*	*Channa striatus*
Chanda nama	*Chanda nama*	*	*Chanda nama*	*	*Chanda nama*	*
Chanda ranga	*Chanda ranga*	*	*Chanda ranga*	*	*Chanda ranga*	*
Badis badis	*Badis badis*	*	*	*Badis badis*	*	*Badis badis*
Nandus nandus	*Nandus nandus*	*	*Nandus nandus*	*	*Nandus nandus*	*
Anabas testudineus	*	*Anabas testudineus*	*Anabas testudineus*	*	*Anabas testudineus*	*
Colisa fasciata	*	*Colisa fasciata*	*Colisa fasciata*	*	*Colisa fasciata*	*
Glossogobius giaris	*Glossogobius giaris*	*	*Glossogobius giaris*	*	*	*Glossogobius giaris*
Mastacembilus armatus	*Mastacembilus armatus*	*	*Mastacembilus armatus*	*	*	*Mastacembilus armatus*
Mastacembelus pancalus	*Mastacembelus pancalus*	*	*Mastacembelus pancalus*	*	*Mastacembelus pancalus*	*

(continued)

Table 2 (continued)

Recorded fish Species of river Narmada	Fish species recorded by Karamchandani et al. (1967)	Fish species missing as per Karamchandani et al. (1967)	Fish species recorded by Vyas et al. (2006)	Fish species Missing as per Vyas et al. (2006)	Fish species recorded in the present study	Fish species missing as per the Present Study
Osteobrama cotio	*Osteobrama cotio*	*	*Osteobrama cotio*	*	*Osteobrama cotio*	*
Anguilla bengalensis	*Anguilla bengalensis*	*	*	*Anguilla bengalensis*	*	*Anguilla bengalensis*
Oxygaster gora	*	Oxygaster gora	*Oxygaster gora*	*	*Oxygaster gora*	*
Hypopthalimichthys molitris	*	Hypopthalimichthys molitris	*	*Hypopthalimichthys molitris*	*	*Hypopthalimichthys molitris*
Cyprnus carpio	*	Cyprnus carpio	*	*Cyprnus carpio*	*	*Cyprnus carpio*

Conclusion

It is concluded from this investigation that the diversity of fish species is reducing at an alarming rate. In the past less than 50 years a total of 56 species of fishes gets reduced in the river Narmada in Central India. The aquatic ecosystems are subjected to a variety of stresses due to varied land use patterns and water resources development processes. The ecological changes following the construction of dams on the river or its tributaries may be determined since it may restrict the fish migration and impending their accessibility to breeding, nursery, and feeding grounds thus leads to the loss of fish diversity besides, fishing activity was found common in the river Narmada. Thus the most widespread approaches to management involve some control of fishing activities. This takes two main forms, the banning of certain types of fishing methods as poisoning of water body and the restriction on using small mesh size nets further commercial exploitation of river bed for extraction of stones/pebbles should not be allowed in order to preserve the breeding grounds and food web of the fishery. Catch control measures must be applied in the river so as to enhance species diversity and to promote fisheries sustainably.

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Effects of Anthropogenic Activities on the Fresh Water Ecosystem—A Case Study of Kappithodu in Kerala

Sherly P. Anand and D. Meera

Abstract A case study was conducted on the impact of anthropogenic activities on the water quality parameters of Kappithodu, a small tributary of Pamba River, in Alappuzha district of Kerala, from October 2013 to September 2014. The river is found to be heavily polluted with wastes and effluents from many Prawn peeling centers, Vandanam Medical college hospitals and outlets of the septic tanks of nearby houses. Water quality analysis and bacteriological studies were conducted based on standard hydrological and microbiological methods. Bacteriological studies revealed that water body is highly polluted with Coliform Bacteria, *Klebsiella* and *Pseudomonas.* Water quality analysis revealed the presence of phosphates, nitrates and chloride ions in high quantities.

Keywords Physicochemical parameters · Turbidity · Hardness
Chloride · Kappithodu

Introduction

India ranks second in human population and first in cattle population, and has got only 4% of the world's free water resources. This indicates the pressure on drinking water in India. 64% of the area in peninsular India is water starved, when compared to the other parts; 80% of India's total water usage is for irrigation. 60% of irrigation and 80% of drinking water comes from ground water. Water pollution is one of the major environmental issues and this causes scarcity of drinking water. Most of the industries are located on the banks of water bodies and they dispose their waste directly into water bodies. Dumping of industrial and sewage waste into any

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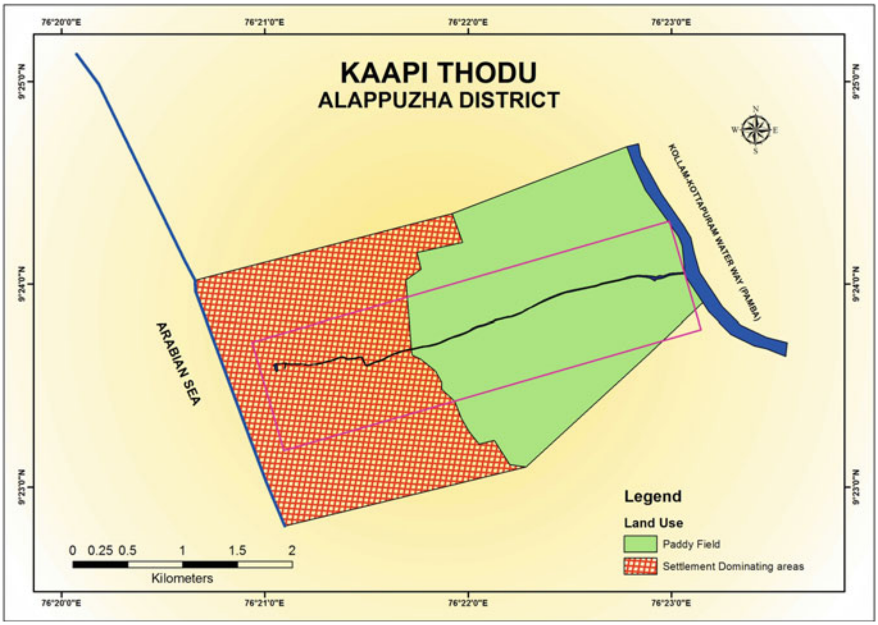
water body results in degradation of its physical, chemical and biological qualities. Many studies have been carried out on this issue (Jayaraman et al. 2003; Damotharan et al. 2010; Prasanna and Ranjan 2010).

Solid wastes pose serious problems in many big cities and towns in Kerala. Kappithode is a canal which flows by the side of the Ambalappuzha flyover in Alappuzha district, and its pollution continues unabated, despite the promise made by the authorities to clean it up. It was in 1983 that the problem attracted public attention for the first time. Two students of Ambalappuzha Government Lower Primary School situated by the side of the canal fell unconscious after inhaling poisonous gases that emanated from the canal. It happened again in 1984, and six students fell unconscious in the classroom.

In 1985, the High Court issued directives to control pollution—to dredge the canal to increase its depth, to take steps to remove impediments for the easy flow of water in the canal, to ensure that liquid waste from the prawn peeling sheds was discharged into the canal only after purification, and to prevent the dumping of solid waste into the canal. But the directives have not been implemented even after 20 years. The present study deals with the examination of water quality as well as bacteriological parameters of Kappithodu.

Materials and Methods

The study area Kappithodu extends from 9° 23′ 36.74″N to 9° 24′ 3.09″N latitude and 76° 21′ 3.42″E to 76° 23′ 4.14″E longitude. The three sampling stations were selected and designated as S I, S II, and S III. Water samples were collected during pre-monsoon, monsoon, and post-monsoon from October 2013 to September 2014. The samples were collected in clean polyethylene, white 2.0 L cans, labeled properly, and brought to the laboratory for further analysis. All physicochemical parameters were analyzed using standard methods (APHA 2008). A bacteriological study was also conducted to find out the extent of pollution. (Cabral 2010).



Result

The water samples collected from Kappithodu during pre-monsoon, monsoon, and post-monsoon seasons were analyzed. Different parameters including pH, hardness, temperature and concentration of chloride, sulphate, nitrate, iron, zinc, manganese, and lead were chosen for the study. Water samples were collected from upper, middle, and lower reaches of the stream. Extreme values of pH were obtained from lower reach of the stream. pH was highest during the pre-monsoon season in the month of March in the lower reach of the stream (9.23) and lowest during post-monsoon period in the month of October at the lower part of stream (5.82). The pH value in the water from upper region of stream ranged between 6 and 7 in all seasons. But in the water samples from lower reach showed considerable variation during pre-monsoon, monsoon, and post-monsoon periods.

During monsoon season, the hardness of water in the upper part of the stream was between 153 and 156. The mean value of water hardness in the upper reach of Kappithodu was low compared to middle and lower reach. The hardness of water was highest during pre-monsoon period (345) in the lower reach of the stream and lowest during monsoon period (153) in the upper reach. The temperature of water was highest during pre-monsoon season in the month of May in the lower reach (28.56) and lowest in the month of July in the upper reach (15.64). The average temperature of water was also high during pre-monsoon and low during post-monsoon period. The mean temperature of water in the lower reach was high compared to upper and middle part of stream. The concentration of chloride was above 200 mg/l in the middle and lower reach of the stream but in the upper part of stream, chloride concentration was below 190 mg/l. The average chloride concentration was lowest during monsoon season in the upper reach of the stream (153 mg/l). The concentration of chloride was highest in the month of May in the lower part of Kappithodu. Sulphate concentration is highest in the middle part of the stream in the month of May (29.65 mg/l) and lowest in November in the upper reach (19.53 mg/l). The average sulphate concentration has extreme values in monsoon season in the upper and lower reaches of Kappithodu. The mean sulphate concentration in both pre-monsoon and monsoon seasons in the three collection sites ranges between 20 and 30 mg/l.

Average nitrate concentration is 3.21 in pre-monsoon, 1.92 mg/l in monsoon and 2.16 in post-monsoon season. Average nitrate concentration in the middle reach in pre-monsoon season is high compared to other sites and seasons (4.29 mg/l). Nitrate concentration in upper reach in monsoon season is between 1 and 1.5 mg/l only. Concentration of iron is below 1 mg/l in all seasons and sites with average values 0.67 mg/l in pre-monsoon season, 0.35 in monsoon and 0.67 mg/l in post-monsoon season. Average iron concentration is low in pre-monsoon season in the middle reach compared to other sites and seasons (83 mg/l). Iron concentration is low in all the collection sites in the month of June (0.19, 0.2, 0.2 mg/l). Highest concentration of iron was observed in the middle part and lowest in the upper part. Average nitrate concentration is 3.21 in pre-monsoon, 1.92 mg/l in monsoon and 2.16 in post-monsoon seasons. Average nitrate concentration in the middle reach in pre-monsoon season is high compared to other sites and seasons (4.29 mg/l). Nitrate concentration in upper reach in monsoon season is between 1 and 1.5 mg/l only. Average zinc concentration is 0.6, 0.3, and 0.5 mg/l in pre-monsoon, monsoon and post-monsoon seasons. Zinc concentration in upper and middle reaches is comparatively low in monsoon season. Highest zinc concentration was observed in the month of May in the middle site (0.09 mg/l). Zinc concentration in pre-monsoon season was higher compared to the other two seasons.

Manganese concentration is lower in lower reach and higher in upper reach in all the three seasons. During post-monsoon season, manganese concentration in upper reach is between 0.5 and 0.6 mg/l. But during pre-monsoon season upper part of the stream has low manganese concentration (0.26–0.27 mg/l). Concentration in the upper part is above 0.1 mg/l in monsoon and post monsoon seasons. Lead concentration is low in the upper and high in lower reach in all the three seasons. Lowest lead concentration is in the upper part of the stream in March (0.23 mg/l) and highest in June in lower reach (0.695 mg/l). The average lead concentration is low in the lower reach in monsoon season compared to other sites and seasons (0.69 mg/l).

I. pH Values

Sites	Pre-monsoon			Monsoon			Post-monsoon		
	March	April	May	June	July	August	September	October	November
1	6.3	6.5	6	6.33	6.23	6.15	6.5	6.4	6.7
2	7.1	6.9	7.5	7.5	7.13	7.62	7.45	7.52	7.61
3	9.23	8.5	9	6.1	6	5.9	5.86	5.82	5.94

II. Hardness

Sites	Pre-monsoon			Monsoon			Post-monsoon		
	March	April	May	June	July	August	September	October	November
1	184.66	186	185	153	154	156	165	176	182
2	298	296	310	261	275	240	285	274	270
3	321	334	345	311	293	282	318	326	329

III. Chloride

Sites	Pre-monsoon			Monsoon			Post-monsoon		
	March	April	May	June	July	August	September	October	November
1	180	188	186	152	159	148	121.3	126	123
2	230	238	240	210	195	206	216	223	211
3	256	245	259	221	231	236	228	231	236

IV. Temperature

Sites	Pre-monsoon			Monsoon			Post-monsoon		
	March	April	May	June	July	August	September	October	November
1	18.56	17.36	17.56	16.53	15.64	17.5	17.36	17.64	18.64
2	22.65	23.53	23.45	18.56	18.96	19.56	19.6	19.86	20.42
3	27.56	26.56	28.56	22.36	23.43	23.86	23.56	22.56	24.65

V. Sulphate

Sites	Pre-monsoon			Monsoon			Post-monsoon		
	March	April	May	June	July	August	September	October	November
1	20.36	22.53	23.56	26.96	28.65	29.56	22.36	20.53	19.53
2	24.36	26.35	29.65	22.53	23.46	21.75	25.63	21.56	23.56
3	22.56	23.65	21.53	20.35	21.56	19.65	25.34	24.65	23.86

VI. Nitrate

Sites	Pre-monsoon			Monsoon			Post-monsoon		
	March	April	May	June	July	August	September	October	November
1	2.36	2.13	2.73	1.45	1.32	1.12	1.96	1.85	1.79
2	4.12	4.53	4.23	2.53	2.13	2	2.86	2.95	2.76
3	3.52	2.53	2.76	2.13	2.56	2.1	1.65	1.86	1.72

VII. Iron

Sites	Pre-monsoon			Monsoon			Post-monsoon		
	March	April	May	June	July	August	September	October	November
1	0.056	0.7	0.7	0.19	0.36	0.39	0.54	0.5	0.6
2	0.79	0.8	0.9	0.2	0.4	0.5	0.9	0.8	0.8
3	0.36	0.8	0.9	0.2	0.3	0.6	0.6	0.8	0.5

VIII. Zinc

Sites	Pre-monsoon			Monsoon			Post-monsoon		
	March	April	May	June	July	August	September	October	November
1	0.02	0.05	0.07	0.03	0.036	0.026	0.04	0.05	0.06
2	0.06	0.08	0.09	0.03	0.02	0.026	0.05	0.058	0.057
3	0.05	0.08	0.07	0.04	0.046	0.049	0.056	0.059	0.061

XI. Manganese

Sites	Pre-monsoon			Monsoon			Post-monsoon		
	March	April	May	June	July	August	September	October	November
1	0.026	0.027	0.026	0.16	0.36	0.39	0.5	0.5	0.6
2	0.032	0.034	0.038	0.053	0.056	0.059	0.042	0.041	0.048
3	0.063	0.068	0.069	0.086	0.089	0.087	0.096	0.091	0.097

X. Lead

Sites	Pre-monsoon			Monsoon			Post-monsoon		
	March	April	May	June	July	August	September	October	November
1	0.231	0.246	0.241	0.315	0.321	0.356	0.365	0.354	0.368
2	0.531	0.512	0.521	0.586	0.579	0.569	0.596	0.597	0.599
3	0.621	0.653	0.646	0.695	0.686	0.694	0.596	0.613	0.623

In the present study, the presumptive coliform counts were 800/100, 1200/100, 1800/100 ml in stations I, II, and III respectively.

Discussion

The results showed that the pH value ranges from 4 to 7.3. According to BIS (1991) recommendation, the pH value has to be within 6.5–8.5 range. Turbidity value is in the limit 5.3–21.2. The hardness value ranges from 153 to 345 in the current study. High level of calcium and magnesium ions in water results in hardness of water. Value of hardness above 300 indicates very hard water. Highest total hardness value was reported during summer season and lowest hardness value was reported during monsoons. High hardness can be noticed during these seasons because Ca and Mg salts soluble faster during summer due to increased temperature (Rathod Kalpana et al. 2014). Chloride value ranges between 9.0 and 17.6 mg/l. As per IS: 10500-2012 desirable limit for chloride is 250 mg in 1000 mg/l. In this study area, the chloride value was found to be too low as compared to the permissible limit (Jyotsna et al. 2014). Nitrate value was found to be 1.1–2.8 mg/l. Nitrate value usually depend on land use practices of the areas nearby water bodies (Hulyal and Kaliwal 2011).

Microbial studies revealed that all the three study sites selected were highly contaminated with coliform bacteria as per APHA (2008) (Table 1). Coliform bacteria are commonly considered as indicator organisms of water pollution. The high count of coliform bacteria indicates the release of large quantity of human excreta into the water. *Pseudomonas* and *Klebsiella* were rich in the effluents coming from peeling centers. According to US EPA, water samples containing coliform are considered as the main indicators of water pollution from domestic waste. WHO standard says that total and fecal coliform ranges from 1 to 10/100 and 0/100 ml, respectively (World Health Organization 2003).

Microbial study revealed that all the three stations in Kappithodu were contaminated with coliform, *Pseudomonas* and *Klebsiella*. From the water quality analysis of physico-chemical parameters of different seasons at different stations, it is found that station III is highly polluted than station I and station II. The water samples had high concentration of phosphates and nitrates. This usually results in algal blooms and this in turn causes eutrophication, a condition without oxygen which affects life of plants and animals in the aquatic ecosystem. Microbial studies revealed that all the three study sites selected were highly contaminated with Coliform bacteria as per APHA (2008) (Table 1). Coliform bacteria are commonly considered as indicator organisms of water pollution. The high count of Coliform bacteria indicates the release of large quantity of human excreta into the water. *Pseudomonas* and *Klebsiella* were rich in the effluents coming from peeling centers. According to US EPA, water samples containing Coliform are considered as the

Table 1 Coliform *Bacteria* counts during the study period

Study area	Coliform count (ml)
Station I	800/100
Station II	1200/100
Station III	1800/100

main indicators of water pollution. WHO standard says that total and fecal Coliform ranges from 1 to 10/100 ml and 0/100 ml, respectively (WHO 2003).

The major challenge of twenty first Century century is the scarcity of safe drinking water. Microbiological analysis of drinking water should be conducted continuously for ensuring the quality as recommended by Cabral (2010). The ground water sources in and around the study area is seriously polluted due to the percolation of polluted water. Health of the lower and middle class population living in the premises is reported to be badly affected. Children of nearby schools frequently get affected by food poisoning due to the contamination of the groundwater used for cooking in the schools.

Conclusion

Kerala is rich in streams and rivers, but these vital environmental resources are getting polluted from multiple sources rendering useless many of the water bodies as in the case of Kappithodu. Industrial units with inadequate waste management provisions, failures of the municipal administrations to address the domestic waste management crisis and other increasing sources of pollution are contributing to expanding the morbid population. The growing threat to the water bodies adversely affect the achievement of the Sustainable Developmental goals.

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Degradation of Heptachlor by High-Carbon Iron Filings (HCIF)

Yangdup Lama and Alok Sinha

Abstract The contamination of groundwater due the extensive use of organochlorine pesticide (OCP) has posed a serious threat to human life. The in situ remediation of contaminated groundwater by the use of zerovalent iron (ZVI) has acquired the deserved attention from researchers around the world. High-carbon iron filling (HCIF) was used to treat the aqueous solution of Heptachlor in batch reactors, which revealed the decline in the aqueous concentration of Heptachlor due to reductive dehalogenation and adsorption process. The expression $\frac{\mathbf{d}C_T}{\mathbf{d}t} = -\boldsymbol{k}_1 \cdot \boldsymbol{M} \cdot \boldsymbol{C}_a^N$ described the decline in the total concentration of Heptachlor solution (C_T) as a function of its aqueous concentration (C_a), where M is the mass concentration of HCIF. The kinetic coefficients N and k_1 were derived to be 2.24 and 1.69×10^{-3} h^{-1} g^{-1} iron L respectively. Freundlich isotherm, expressed as $\boldsymbol{C}_S = \boldsymbol{K} \cdot \boldsymbol{C}_a^m$, could be employed to describe the equilibrium partitioning of Heptachlor to the HCIF surface, where $K = 4.76 \times 10^{-3}$ g^{-1} L and $m = 0.9717$ was observed. The experiments revealed that HCIF can be potentially used as reactive material for in situ treatment of groundwater contaminated with Heptachlor.

Keywords Groundwater · High-carbon iron filings (HCIF) · Heptachlor Reductive dehalogenation · Adsorption

Introduction

Halogenated organic compounds (HOCs) like halogenated solvents, pesticides, herbicides are widely used for household agricultural and industrial applications. These compounds are persistent and toxic to entire ecosystem. They are having very long half lives and are toxic and carcinogenic at very low concentrations in drinking water. Groundwater resources can be contaminated by these chlorinated organic compounds

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and can render the groundwater unfit for drinking (Vogel et al. 1987; Jeffers et al. 1989). Among volatile compounds, inhalation of vinyl chloride (VC) has been shown to cause liver, brain, and lung cancer in humans (McCann et al. 1975). The U.S. EPA classifies VC as a known human carcinogen. Inhalation of perchloroethylence (PCE) has been shown to result in an increased occurrence of liver tumors in mice and kidney tumors and leukemias in rats (Lazarew 1929). 1, 2-Dibromoethane is a potential carcinogen and can cause liver and kidney damage (Rajagopal and Burris 1999). Polychlorinated biphenyls, a very toxic group of compounds, are very persistent and hence resistant to natural degradation. About 400 million kg of PCBs are dispersed into geo-, aqua-, atmo-, and biosphere, with majority being concentrated into geo-sphere because of their low volatility, low solubility in water, and high affinity for particulates (Nelson 1972). Chlorinated phenols, benzenes, and napthalenes are toxic to aquatic animals (Verschueren 1983). Systemic effects of acute toxic doses of monochlorobenzene included damage to the liver and kidney, and effects on bile and pancreatic flow (Verschueren 1983). Among pesticides and herbicides, alachlor is listed as a probable human carcinogen and metolachlor is listed as a possible carcinogen (Eykholt and Davenport 1998). Chlorinated pesticides like aldrin, chlordane were reported as toxic to aquatic life and ingestion by rats can cause liver damage (Martin 1968; Khan et al. 1979). Dieldrin has been reported as carcinogenic (McCann et al. 1975). High levels of Heptachlor can increase the risk of diabetes (Type 2) by 7% (Harmon 2010). The International Agency for Research on Cancer and the EPA have categorized it as a possible human carcinogen (ATSDR 2007). The USEPA maximum contaminant level (MCL) for drinking water is 0.0004 mg/L for Heptachlor and 0.0002 mg/L for Heptachlor epoxide (ATSDR 2007).

Treatment of contaminated groundwater can be achieved by "pump and treat" method, where the groundwater is pumped out and passed through a set of treatment chain and pumped back to subsurface after treatment. This involves huge cost (Mackay and Cherry 1989). Hence, the current trend is shifting to in situ methods of treatment of groundwater where the groundwater is passed through a subsurface permeable reactive barrier (PRBs) which contains a reactive material like zerovalent iron (ZVI) and gets decontaminated which results in economical treatment (Gillham and O'Hannesin 1994; Keum and Li 2004).

This paper deals with the remediation of halogenated pesticide, heptachlor, by using high-carbon iron filings (HCIF). The HCIF surface not only reductively dehalogenate the halogenated organic compounds, but also adsorbs the compounds (Sinha and Bose 2006, 2007, 2009a, b, 2011). In this study, the kinetic rate constant for reduction and adsorption of heptachlor by HCIF surface have been determined.

Materials and Methods

Commercially available cast iron was turned to chips on a lathe machine and then converted into filings in a ball mill. The resulting filings were sieved through 425 μm (40 mesh) sieve and portion retained on 212 μm (80 mesh) sieve was collected and used as high-carbon iron filings (HCIF). For a typical experiment, approximately 5 g of HCIF was added 20 mL batch reactor, and filled with deoxygenated aqueous solution of 1 mg/L Heptachlor prepared (prepared in deionized Milli-Q water) without head space. Stock solution of heptachlor was prepared in methanol. Aqueous volumes in the batch reactors were determined gravimetrically. Approximate mass of heptachlor added to a batch reactor was 20 μg. Control vials having 20 μg of heptachlor, without HCIF, were also prepared. All vials were rotated at 50 rpm such that the vial axis remained horizontal at all times. Ambient temperature was approximately 30 ± 1 °C during mixing. Vials were removed, at specified times, for analysis of heptachlor. Vials were removed at 1, 2, 5, 12, 24, 48, and 60 h and analyzed for aqueous and solid phase concentration.

500 μL of aqueous phase samples were withdrawn from batch reactors using a micro syringe. The micro syringe was pierced through the septa, such that the headspace is not created. The withdrawn aqueous samples were added to GC auto-sampler vials along with 750 μL n-hexane and sealed. These vials were thoroughly mixed on a vortex mixer to enable the partitioning of heptachlor to n-hexane. The solvent phase (n-hexane) was analyzed by gas chromatograph equipped with an electron capture detector (GC-ECD) for heptachlor concentration. This method resulted in an extraction efficiency of 95% for heptachlor. For determination of adsorbed heptachlor on HCIF, the aqueous contents of batch reactor was transferred to another vial by means of a cannula. 5 mL of n-hexane was added two times to the HCIF left in the batch reactors and the mixture was vortex mixed for 10 min for partitioning of adsorbed heptachlor to n-hexane. The sorbed mass was determined by measuring the heptachlor concentration in n-hexane.

Results and Discussion

The batch reaction of heptachlor with un-rusted HCIF was carried out for the period of 396 h. The pH and the ORP were observed to vary from 7.3 to 10.9 and −490 to −630 mV respectively (Fig. 1). Decline in the total concentration of heptachlor

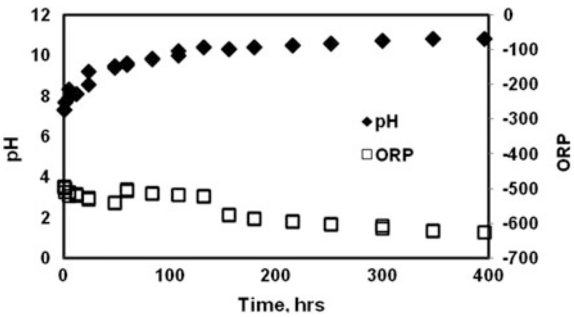

Fig. 1 pH and ORP variation during interaction of heptachlor with HCIF

during its interaction with un-rusted HCIF was observed (Fig. 2). The total and the aqueous concentration of heptachlor observed after 396 h was 0.144 and 0.08 μmol L^{-1} corresponding to 94.62 and 96.94% in decrease in total and aqueous heptachlor concentration. The following expression; $\frac{\mathbf{d}C_T}{\mathbf{d}t} = -\boldsymbol{k}_1 \cdot \boldsymbol{M} \cdot \boldsymbol{C}_a^N$ describes the decline in the total concentration of heptachlor solution (C_T) as a function of its aqueous concentration (C_a), where M is the mass concentration of HCIF. The plot of ln ($-\mathrm{d}C_t/\mathrm{d}t$) versus ln C_a (Fig. 3), the kinetic coefficients n and k_1 were evaluated to be 2.24 and 1.69×10^{-3} h^{-1} g^{-1} iron L respectively. Freundlich isotherm, expressed as $\boldsymbol{C_S} = \boldsymbol{K} \cdot \boldsymbol{C}_a^m$, could be employed to describe the equilibrium partitioning of Heptachlor to the HCIF surface where, $K = 4.76 \times 10^{-3}$ g^{-1} L and $m = 0.9717$ was observed (Fig. 4).

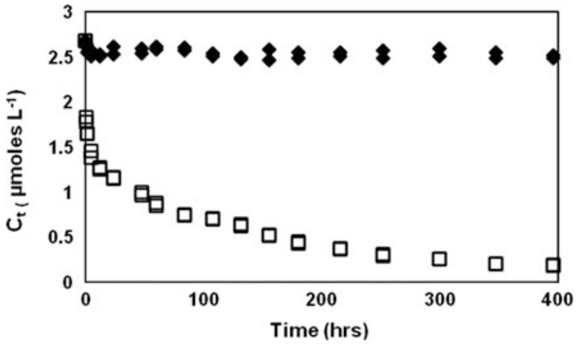

Fig. 2 Decline in total concentration of heptachlor with time

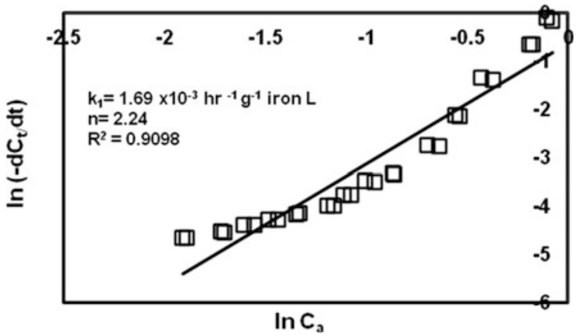

Fig. 3 Linearized plot of heptachlor degradation versus aqueous phase concentration of heptachlor

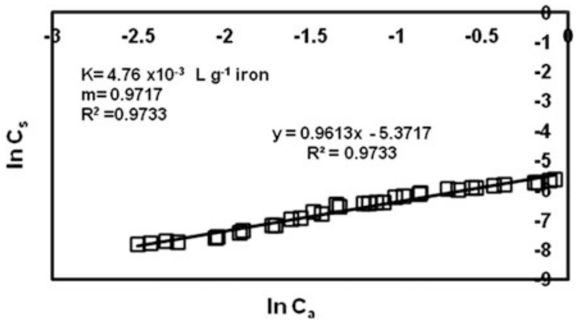

Fig. 4 Partitioning of heptachlor on HCIF

Conclusions

Batch experiments demonstrated that the organochlorine pesticide, Heptachlor, can be successfully dehalogenated by using cast iron particles. Heptachlor reduced to 96.9% of its original concentration within 400 h of contact time. The study revealed that the adsorption of heptachlor plays an important role in reducing the aqueous concentration of heptachlor in batch reactors in initial stage. The adsorption phenomenon of heptachlor to graphite nodules present on HCIF surface can be described by Freundlich isotherm. Hence, HCIF can be used as a reactive material for in situ remediation of groundwater contaminated with organochlorine pesticide, heptachlor. Further studies involving reduction of heptachlor, in flow through system, simulating groundwater conditions, are required to be carried out and pathways of reduction of heptachlor are also a matter of concern.

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Part III
Generation of Pollution

Biomedical Waste Generation and Management in Public Sector Hospital in Shimla City

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Abstract Biomedical waste disposal is very important due to its infectious nature. Proper management of biomedical waste is necessary for maintaining good human health and environment. Biomedical Waste (Management and Handling) rules 1998 under the Environmental Protection Act, 1986 have been passed by government of India which is to be followed strictly to avoid menace. The purpose of the article is to differentiate between the Biomedical Waste Management practices such as collection, storage, transportation, and disposal along with the generation of biomedical waste undertaken in major public and private sector hospitals in Shimla city. A cross-sectional study and semi-structured interview considering the various biomedical waste management practices and personnel handling of the biomedical waste undertaken in the major public and private sector hospitals in Shimla city through detailed analysis and questionnaire prepared will be used for the purpose of study. The study will quantify the actual values and unveil the difference that lie in management procedures followed by these hospitals in Shimla. The present paper presents some initial findings of the questionnaire analysis carried out in a major public hospital in Shimla.

Introduction

A hospital is a complex institution visited by people very frequently without any distinction of age, sex, race, and religion. This is above the normal population of hospital namely patients and staff (Rao et al. 2004). Waste production is not only restricted to hospitals or research activities but waste can also be produced at homes through dialysis or using insulin injections and even during animal health activities in rural areas. This is dangerous and needs proper disposal. Although industrial waste, municipal solid waste, agricultural waste, etc., are harmful and may pollute

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the surrounding air, water and soil, their treatment and disposal are less harmful as compared to the effects produced from treatment and disposal of biomedical waste due to production of toxic effluents from the burning of biomedical waste (Levendis et al. 2001; Soliman and Ahmed 2007; Jindal et al. 2013).

Hospital waste is highly toxic in comparison to the other wastes. Though, 75–90% of waste produced by health care institutes from administration unit and housekeeping cells, is non- toxic, the remaining 10–25% of the waste is regarded as 'hazardous' and may create variety of health risks (Shalini et al. 2012; WHO 2013). Infectious diseases such as HIV, Hepatitis (all kinds), and tetanus all are very common in people associated with handling of biomedical waste. In order to prevent such deadly infections and to protect the environment, The Ministry of Environment and Forest (India) formulated and notified biomedical waste (management and handling) rules in 1998 that issues guidelines to all institutes producing biomedical waste to ensure safety and soundness in management of their wastes (Da Silva et al. 2005).

Advancement in healthcare facilities around the globe has led to serious improvement of biomedical waste management in developed countries. However, despite strict regulations in the Indian context, the paradox of the situation is that the healthcare facilities which are basis for maintenance and restoration of public health have caused a huge health risk due to improper management of waste by people in charge and have posed a huge threat to environment (Mathur et al. 2012). Globally categorized as a serious issue, biomedical waste demands appropriate and necessary steps of management and disposal worldwide (Kumari et al. 2013). The waste disposal is overseen by government agencies but regulations have to be abided by private healthcare organizations too (Radha et al. 2009).

Improper management of waste may lead to change in microbial ecology and spread of antibiotic resistance. Thus, the best disposal option should aim at the minimization of toxic substances from medical institutes to the environment. In the light of above facts and figures, the study is to be carried at the capital of the state Himachal Pradesh i.e. Shimla. The city is located at 31° 6′ 12″ north latitude and 77° 10′ 20″ east longitude and 2,206 m above the mean sea level. The population of the city according to the 2011 census was found to be 8,13,384.

The main aim of the study to be conducted is to study, evaluate, and compare the waste management steps, waste handling procedures, and treatment methods being undertaken by the majority of the public and private sector hospitals in Shimla City to prevent the spread of infections diseases due to improper disposal of hospital waste.

Management of Biomedical Waste

In 1980s in United States, a huge chaos was raised by people about hospital waste hovering around and children playing around thus the management of biomedical waste became an issue of concern. The US Medical Waste Tracking act of 1988 was enacted and enforced on November 1, 1988 (Dayananda 2004). A huge outburst against various agencies by public was observed to put pressure on Government of India to enact appropriate laws in country against various practices of disposal of biomedical waste. The Ministry of Environment and Forest of Government of India has enacted Biomedical Waste (Management and Handling) rules which became effective from July 20, 1998. The rules have six schedules as briefly described below.

Schedule 1 classifies the biomedical waste into ten categories (The Gazette of India 1998).

Schedule 2, describes the color coding scheme and types of containers to be used for collection and storage of biomedical waste.

Schedules 3 and 4, recommend that containers should be appropriately labeled with biohazard or cytotoxic symbol to avoid risk. In case the waste is to be transported offsite, appropriate measures needs to be taken to make containers leak proof to avoid any spillage.

Schedule 5 describes the treatment and disposal options for each category of waste.

Schedule 6, makes it compulsory for all the hospitals, clinics, nursing homes and veterinary institutes, animal house and slaughter house to install appropriate waste management amenities in place.

Before the enforcement of Biomedical Waste (management and handling) rules, the municipal or government authority was solely responsible for handling all types of waste appropriately and efficiently, but now it has become mandatory for all health care organizations to manage their waste according to the rules enacted by government (Patil and Pokhrel 2005).

Incineration is the most general method for biomedical waste treatment and is most apt for combustible materials. However, some material like body parts and urine bags cannot be disposed by incineration thus needing other methods for the treatment. Incineration leads to 80% reduction in waste volume and also decontamination of waste being incinerated (Ferreira and Veiga 2003). It is the responsibility of the producer of the waste to take measures for proper and safe disposal of waste so that there is no undesirable effect on environment. The setting up of incinerator in hospitals with more than 50 beds is compulsory under Section 15(1) of the Environmental (protection) Act 1996 according to which whoever fails to abide by the orders issued by the government will be punished by "imprisonment for term extending up to 5 years or 1,00,000 Rupees cash, or both and an additional fine may be imposed extended up to 5000 Rupees per day if there is continued delay or negligence after conviction for first such failure or contravention (Yadav 2001).

Incineration is the most widely used technology for waste treatment but it imposes a great risk of environmental and health hazard due to wide varieties of pollutants released from the burning of biomedical waste such as dioxins, furans, etc. Further, incineration has been concluded as the most expensive treatment for biomedical waste management in developing countries (Diaz et al. 2005). Therefore other methods such as plasma pyrolysis and electro-thermal deactivation

(ETD) may be used and encouraged as alternatives to incineration (Jang et al. 2006). However, these alternatives are costly procedures and are often not implemented due to high operation and maintenance costs.

Methodology

The study was conducted in the major public hospital of Shimla city. From the survey conducted and the data acquired, the bed capacity is about 800 and daily patient frequency in public sector hospital was about 777 patients on a daily basis. The name of the hospital has not been disclosed due to the administrative reasons. The data collected from the different units is based on the interview sessions with the person in charge, survey of the hospital wards, field visits and the crucial site observations.

Observation

The field observation involved critical examination of the quantification of waste, segregation, collection, transportation, final treatment and disposal as well as the occupational safety of the person in charge, the intensity with which the guidelines were being followed in the hospitals and various regulations imposed by the administrative unit for maintenance of a safe and healthy environment. It also concentrated upon problems faced by the workers and the staff due to improper disposal at disposal sites.

Questionnaire Session

The prepared questionnaire (Vasistha et al. 2015) was utilized and the questionnaire was framed with the purpose of obtaining knowledge about the present waste generation and strategy of management being followed in the hospital and determining the various factors which restrict the proper management and disposal of waste being generated in various wards at the hospitals.

Management and Implementation at Public Sector Hospital

The public sector hospital has 33 departments. The Waste management in the hospital premises is done by a team of 3 main doctors with nurses and other workers for collection and disposal of waste. The annual statistics show that the

Table 1 Generation of biomedical waste for public sector hospital in various wards (kg)

S. No.	Ward name	Type 1 (yellow bag)	Type 2 (red bag)	Type 3 (blue bag)	Type 4 (black bag)	Total per day	Total per week	Total per year
1	O.P.D skin	–	2.50	3.25	4.00	9.75	68.25	24,911.25
2	O.P.D. surgery	3.11	2.72	3.60	4.12	13.55	94.85	34,620.25
3	Minor O.T.	7.35	4.73	1.12	3.45	16.65	116.55	42,540.75
4	O.P.D. E.N.T.	2.77	2.21	0.50	5.82	11.3	79.1	28,871.5
5	Cardio–thoracic	8.73	4.34	23.43	9.92	46.42	324.94	1,18,603.1
6	Microbiology	1.17	1.50	4.53	5.78	12.98	90.86	33,163.9
7	Causality and O.P.D.	7.47	8.56	8.00	11.32	35.35	247.45	90,319.25

total no. of admitted patients was 31,872 out of which 31,771 patients were discharged. The total no. of treatment days for patients observed were 2,44,503. The maximum amount of infectious and noninfectious waste generated is in the cardio–thoracic vascular surgery, O.T. and I.C.U. department which is about 46.42 kg of waste/day followed by causality and O.P.D. department which is about 35.35 kg/day and minor O.T. about 16.65 kg/day. The used syringes are disinfected with chlorine solution before treatment. The details of waste generation are presented in Table 1. The instruments used for the diagnosis are reused after sterilization. The average inpatients are 669 with average bed occupancy of 84. The various processes of collection, segregation, transportation, and disposal in the public sector hospital have been described in the following paragraphs below.

The collection of the waste at the public sector hospital is done by workers assigned to particular wards. The wards such as minor O.T. and causality, cardio–thoracic where the waste production is high due to high rate of cases per day, the collection occurs 3 times a day, once at 7.30 am in the morning, second at 1.30 pm in the evening and third at 6.30 pm in the evening. For other wards, the collection is twice a day. For general waste the municipality is responsible and frequency of removal is once a day. The waste is segregated at the point of generation in hospital as per the waste characteristics. Appropriate color-coded high-density polyethylene bags are used according to schedule 2 of Biomedical Waste (Management and Handling) Rules, 1998 after the waste segregation has been carried out. Though no prescribed routes are followed, in public sector hospital the waste is collected and directly taken to the incineration plant on campus for the further treatment. The public sector hospital uses on site incineration plant for treatment of biomedical waste. The chlorine solution is used for disinfection of sharps and plastic waste. The autoclave is used for thermal treatment of culture and stock, sharps, syringes, cathedras, blood and urine bags, surgery waste; laboratory waste (excluding chemicals), etc. The sharps such as needles are mutilated by needle destroyers and the destroyed needles are then disinfected with 0.5% chlorine solution for 30 min to

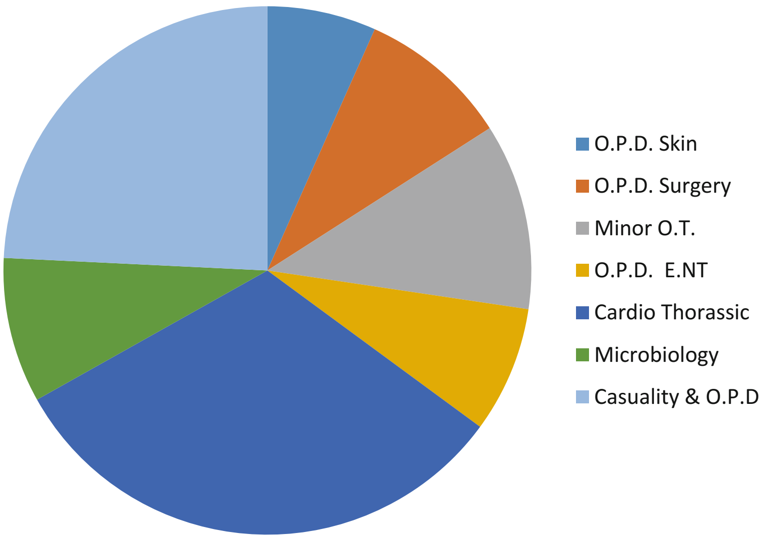

Fig. 1 Ward-wise waste percentage composition (yearly)

1 h. The final disposal of the waste though is incineration process. Table 1 illustrates the generation of biomedical waste in the public sector hospital and Fig. 1 shows the percentage composition from all the different ward categories (yearly).

Results and Discussions

It is observed that the public sector hospital segregates the waste using appropriate methodology following guidelines prescribed in Schedules 1 and 2. The workers handling biomedical waste are aware enough to understand the oddness of the situation; hence they follow the guidelines given to them by higher personnel. A regular report is submitted to Pollution Control Board at the year end. Also regular visits are paid by board members to the hospital to know the current status of the biomedical waste management. From Table 1, it is observed that the cardio–thoracic ward generates the maximum biomedical waste and the O.P.D Skin Ward generates the least amount of biomedical waste. This is due to the fact that the cost of treatment for skin grafting, plastic surgery, etc., are fairly high enough and not affordable by common people as the income and standard of living of people in and around the place is not high enough as compared to the cost of the treatment. Thus, the number of treatments and patients per day are limited in this ward so the amount of waste produced is less. Figure 1 also corroborates this fact. It was also determined that incineration process is utilized for treatment of biomedical waste.

Regular visits to the hospital and analysis of questionnaire data revealed that the hospital disposes off their sharps and needles by landfill in secured pits.

After interaction with the staff and the workers of the incineration plant it was found that the biomedical waste management was followed at its best but at the incinerator plant site of the public sector hospital there is a need of infection control and good environmental maintenance, as the building housing the incinerator needs immediate repairs and maintenance. Further, very few workers are involved in the actual incineration process of waste and thus there is a need to increase the number of personnel to improve the biomedical waste management at the incinerator location.

Conclusion

From the above discussions, the authors conclude that the hospital is a role model in the management of biomedical wastes in accordance with the biomedical waste (management and handling) rules as prescribed by the GOI. This is particularly significant in context of the limited study carried out in the area of biomedical waste management in and around the state; the hospital could be set as a very good example of biomedical waste management. This has been successful due to support from state- and national-level government, acceptance by the local people by providing a shared-use incinerator facility for other hospitals. Also, there exists a scope for huge improvement in the region.

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Fuel Loss and Related Emissions Due to Idling of Motorized Vehicles at a Major Intersection in Delhi

Niraj Sharma, P.V. Pradeep Kumar, Anil Singh and Rajni Dhyani

Abstract Traffic intersections are considered as air quality hotspots as they mostly exceed the prescribed air quality standards specified by various regulatory agencies due to high vehicular activities, idling, and related vehicular emissions. Delay at traffic intersections results in fuel loss due to idling of vehicles and related emissions. In the present study, Ashram Chowk, a major intersection in Delhi has been selected. Nearly 3.4 lakh vehicles pass through Ashram intersection daily, out of which nearly 20% (~ 60,000 nos.) of the traffic faces average time delay (or idling) for time varying from 6 to 8 min delays per hour. In the present study, a methodology has been developed for the estimation of emissions (such as CO_2, CH_4, CO, NO_x, NO_2, NMVOC, etc.) from fuel loss occurring during idling of vehicles using IPCC emission factors. The study highlights the importance of reducing fuel losses at intersections to achieve sustainable air quality.

Introduction

Countries around the world are concerned with the impact of transportation on the environment and human health. Vehicles have increased many folds in India, nearly 10.5% annual vehicular growth has been observed in India from 2002 to 2012, especially in metro cities (MoRTH 2013). Delhi, the capital city of India, has seen 7.7% increase in 2002–2012. It has vehicular pollution of nearly 8 million and constitutes around 4.6% of the total traffic in India. In Delhi, consumption of diesel and petrol by the road sector has seen substantial growth over the past two decades. The

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road transport sector consumes 35% of the total liquid commercial fuel consumption by all sectors (Singh et al. 2008). Due to increased personalized transportation mode than public transportation system, large numbers of vehicles are on road leading to congestion and traffic jams. The fuel consumption and fuel consumption by various categories of vehicles depend upon the driving cycle of the city. Driving cycle affects the fuel consumption of a vehicle. In urban areas idling, due to red light stop or due to congestion or traffic jam also constitute the part of driving cycle. The direct effect of idling of vehicle is fuel loss as well as related emissions from burning of fuel. Fuel consumption may be small when one quantifies it for a vehicle, but when hundreds of vehicles are idle at various intersections or due to a traffic jam in the city its magnitude increases and in turn emissions. The variety of settings in which vehicular idling occurs, can be broadly categorized into three domains: (1) idling to warm the engine; (2) idling while waiting for something unrelated to traffic (e.g. waiting for a passenger; in a drive-through); and (3) idling while in traffic (e.g. at stoplights; in traffic jams) (Guttikunda 2009). Unnecessary vehicle idling is a common source of GHGs emission (CO_2, CH_4, N_2O, CO, NMVOCs, SO_2, NO_x) and other air pollutants. Not only does it contribute to the global climate change but it also wastes a large amount of fuel threatens our energy future (Morshed 2010). Natural Resource of Canada (NRC 2009) reported that idling longer than 10 s uses more fuel and produces more CO_2 compared to restarting the engine. Similarly, Burgess et al. (2009) reported that idling vehicles in the city produce 130,000 tons of CO_2 in New York City (USA). Apart from idling, these vehicles also emit 940 tons of NO_x, 2,200 tons of VOCs, 24 tons of soot particles, and 6,400 tons of CO each year. The study reported that citywide idling wasted an average of 30,000 gallons of gasoline and 20,000 gallons of diesel on an average weekday, apart from fuel costs due to idling when engines run longer than necessary. In European countries like Italy, Austria, Germany, The Netherlands, France, etc., the recommended guideline for turning off the engine range from 10 to 60 s (NRC 2011). In a study conducted by Central Road Research Institute (CRRI) in 2005 estimated that fuel worth of Rs. 1,000 crore is wasted every year in Delhi by vehicles idling at 600 signalized traffic signals and was around 15% of the total fuel consumed annually in Delhi. In addition, the time loss to the commuters is also associated with the delays. Further, 0.37 million kilograms of CNG, 0.13 million liters of diesel, and 0.41 million liters of petrol wasted every day due to idling of vehicles costing around Rs. 27.25 millions per day and Rs. 9944.5 million per year. The running engines during idling also generate emissions, which are harmful both to human health and ecology (Parida and Gangopadhyay 2008). In the present study, an effort has been made to quantify the fuel consumption during idling by various categories of vehicles and estimation of related emissions at a major intersection in Delhi.

Methodology

For the present study, Ashram Chowk has been selected. It is one of the busiest intersections of Delhi city and caters to both urban and regional traffic. National

Highway-2 (NH-2) is a part of intersection joining Mathura to Delhi. The intersection connects adjoining Faridabad and Noida city to Delhi. The intersection caters to the urban traffic throughout the day and intercity traffic (mostly commercial) during the night.

The present study pertaining to estimation of emissions due to idling of vehicles at signalized intersection have two components: (i) carrying out fuel consumption study at idling on various test vehicles of different types, categories, fuel usage(s), etc., (ii) converting the fuel losses as estimated in step (iii) into emissions by employing appropriate emission factors (i.e. IPCC) and various other input parameters collected from primary surveys and/or secondary sources.

Fuel Consumption Measurement

Measurement of fuel consumption at idling was carried out on petrol and diesel powered various categories of vehicles. Depending on the type of vehicle and engine technology, a different type of fuel flow detector was used for petrol and diesel powered vehicles [(i) MF-2200, (b) FP-214OH and (iii) FP-213S fuel flow detector (ONO SOKKI, Japan) with measurement capability of up to 0.1 ml]. Depending on fuel type and engine type, these fuel flow detectors were connected with a fuel flow meter to accurately measure the flow rate of fuel. For petrol and diesel vehicles, fuel connections for the existing vehicle were removed and the fuel flow detector was connected on-line. The duration of the measurement for fuel consumption measurement studies for different types of test vehicles was 40 min with the first 10 min measurement was to account for engine warm up and for the engine to hot stabilize (Pradeep et al. 2014). In the present study, fuel consumption at idling data for different categories of CNG and LPG vehicles were adopted from earlier CRRI Study (Parida and Gangopadhyay 2008) and used for estimation of fuel losses as well as corresponding emissions at the intersection.

Emission Estimation Methodology

Quantification of emissions from idling of motor vehicles at various signalized intersections require a variety of input parameters, including (i) fuel consumed by different categories of motor vehicles during idling, (ii) number of vehicles of different types and categories of vehicles [cars (4W), two wheelers (2W), three wheelers (3W), buses, light commercial vehicles (LCV), heavy commercial vehicles (HCV), multi-axle vehicle (MAV)] idling at selected signalized intersection, (iii) vehicles idling at intersection are further categorized by fuel type (petrol, diesel, CNG, LPG) and technology type (2 strokes, 4 strokes, etc., for 2Ws) from the information gathered from fuel stations surveys carried out at selected intersection (iii) traffic delays due to vehicles idling at intersection and (iv) fuel-based emission

Table 1 Input data required for estimation of emissions during idling at intersection

S. No.	Input data	Unit	Types of survey	Source
1	Idling vehicles (24-h) at signalized intersections	Vehicles/h	Manual count	Primary survey
2	Categorization of vehicles based on • Fuel type (petrol, diesel, CNG, LPG) • Technology type (2 strokes, 4 strokes etc. for 2Ws)	No. of vehicles	Fuel station survey	Primary survey
3	Age profile/vintage of vehicles	Number or %	Fuel station survey	Primary survey
4	Fuel consumption by different categories of vehicles during idling petrol and diesel vehicles	ml/10 min	Fuel flow measurement	Primary data
5	Average hourly time delays at various signalized at intersections for each category of vehicles	seconds	Time delay survey	Primary survey
6	Net calorific value (NCV)	$TJ/10^3$ t	Secondary data	IPCC (2006), Singh et al. (2008)
7	Emission factor (EF)	t/TJ	Secondary data	IPCC (2006)

Table 2 Net calorific value (NCV) and IPCC emission factors

Fuel type	NCV ($TJ/10^3$ t)	Emission factor-(kg/TJ)					
		CO_2	CH_4	N_2O	CO	NO_x	NMVOC
Petrol	44.80	69300	19.8	1.92	8000	600	1500
Diesel	43.33	74100	3.9	3.9	1000	800	200
CNG	48.00	56100	92	3	400	600	5
LPG	47.00	63100	62	0.2	400	600	5

factor(s) for different categories of vehicles which converts fuel consumed by these idling vehicles to corresponding air pollutants/emissions. Table 1 shows that methodology/surveys required collecting the above input parameters.

In the present study, fuel-based emission factors (IPCC 1996, 2006) (Table 2) were used to convert quantity of fuel consumed during idling of these vehicles to corresponding emissions. The IPCC emission factors expressed in the terms of kg/TJ (energy terms) uses net caloric value (NCV) of different types of fuels to estimate emissions in terms of following six pollutants, viz., CO_2, CH_4, CO, N_2O, NO_x, and NMVOC. Therefore, fuel consumption (expressed in ml/10 min) determined for different fuel type, categories and vintage of vehicles during fuel consumption studies at idling were converted in terms of mass (i.e. gm/s) (1 ml petrol = 0.74 g; 1 ml diesel = 0.83 g) for ease of calculation and its conversion in terms of energy (MJ/gm) and then emissions (gm/MJ).

Emissions (kg per hour) were estimated using default gas-specific emission factors (t/TJ) for each fuel type used and other inputs by using the following equation (1):

$$E_i = \left[\sum V_{j\,(ky)}.\,Fc_{(j,f,ky)}.D_f.T_{(j,f,ky)}.NCV_f.EF_{(f,i)}\right]/1000 \qquad (1)$$

where,

E_i	Total emission of pollutants type *i* (kg/h)
$V_{j\ (ky)}$	vehicle type *j* of vintage *ky* (no. of vehicles)
$FC_{(j,\ f,\ ky)}$	Fuel consumption during idling by vehicle type *j* using fuel type *f* of vintage *ky* (l/h)
D_f	Density of fuel *f* (kg/l)
$T_{(j,\ f,\ ky)}$	Time delay at traffic intersections by vehicle type *j* of fuel type *f* of vintage *ky* (s)
NCV_f	Net Calorific value for fuel type *f* [Tera-joule/tons (TJ/t)]
$EF_{(f,\ i)}$	Emission factor for fuel type *f* of pollutant type *i* [tons/Tera-joule (t/TJ)]

Results and Discussion

The fuel consumption during idling was estimated for cars petrol (Car-P), cars diesel (Car-P), 2 W-4S (motorcycles) and buses (Bus-D). In Fig. 1, fuel consumption of different categories of and vintage vehicles has been compared. The variations in fuel consumption among different categories and type of vehicles were observed could be due to differences in engine capacity, vehicle technology, fuel quality, etc. The mean value of fuel consumption at idling is predominantly dependent upon engine capacity and vehicle technology and it varies from 144 to 900 ml/h for the observed vehicles tested in different vehicle categories.

The diurnal traffic variation at Ashram intersections has been shown in Fig. 2, it could be easily observed that private vehicles such as 4Ws (cars) (51%) and 2Ws

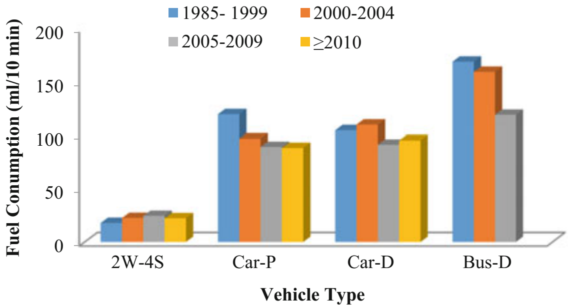


Fig. 1 Idling fuel consumption of vehicles (petrol and diesel): model year basis

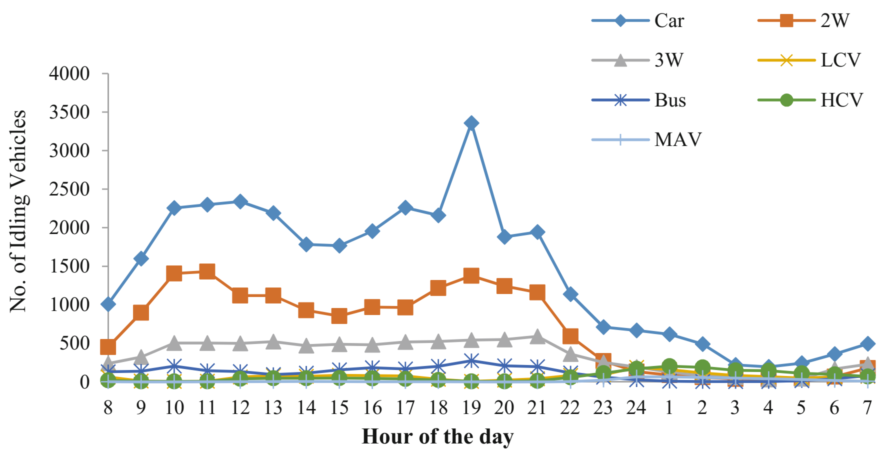
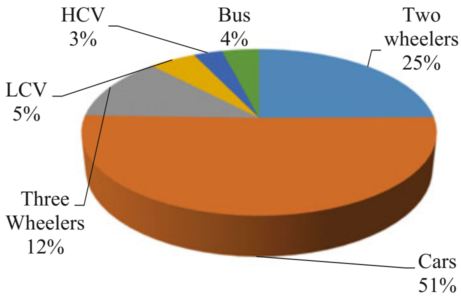


Fig. 2 Number of various vehicles idling at Ashram intersection

Fig. 3 Percentage distribution of different categories of vehicles at Ashram intersection



(scooter, motorcycle, etc.) (25%) are dominant vehicle categories followed by 3Ws, LCVs, buses, HCVs/MAVs (Fig. 3). Ashram intersection is a high-traffic volume intersection (traffic volume > 2 lakh/day) it caters to ~2,39,749 vehicles/day (excluding traffic pass intersection by flyovers) out of which nearly 28% of vehicles (i.e. ~67000 vehicles) idle per day. The selected intersection has been classified as high traffic intersection according to the traffic volume.

High arrival rate of vehicles than departure rate of traffic volume at almost all intersections leads to longer queues, longer delay time and congestion are the main reasons for the longer idling time. The average delay at the intersection ranged in between 400 and 550 s per hour (Fig. 4). The maximum delay was observed during evening peak hours (1700–1800 h) and minimum during early morning hours.

Fuel loss estimated at Ashram intersection using fuel consumption per vehicle, idling traffic, time delay by using above discussed methodology. It was estimated that in a day, ~4200 kg of fuel is lost during idling at Ashram, out of which ~2,000 L is Petrol, 1,100 L Diesel, 1,900 kg CNG and 44 kg LPG is lost due to idling of vehicles (Fig. 5).

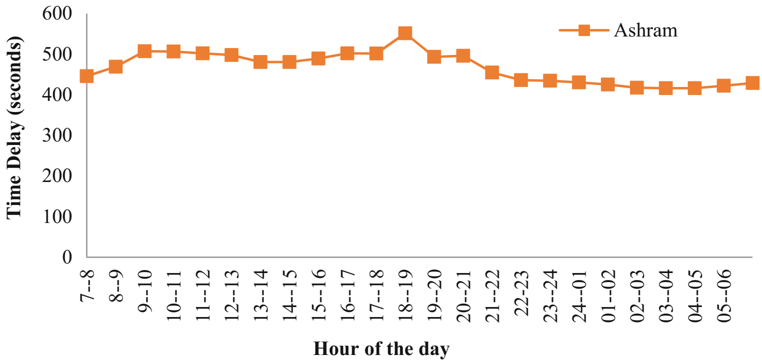
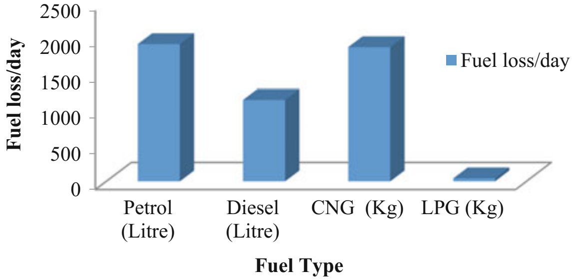


Fig. 4 Hourly delay of vehicles at Ashram intersection

Fig. 5 Fuel loss per day at Ashram intersection



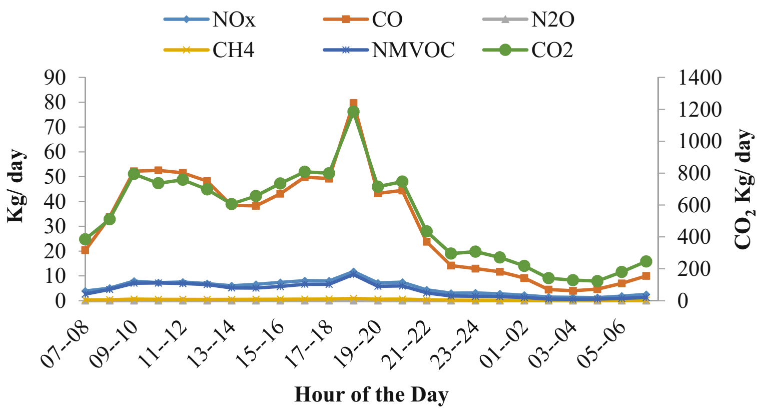


Fig. 6 Diurnal variation in GHGs emissions due to idling of vehicles at Ashram intersection

Greenhouse gases (CO_2, CH_4, and N_2O) emissions and indirect greenhouse gas (CO, NO_x and NMVOC) emitted from vehicles were estimated using IPCC emission factors. It was observed that CO_2 has highest contribution to emission load among all the GHGs estimated followed by CO, NO_x NMVOC, and CH_4 (Fig. 6). The morning peak and evening traffic peaks have resulted in corresponding high emissions during those hours.

Among all the pollutants it was estimated that high CO emissions has been contributed by large share of petrol-(rich mixture due to low air: fuel ratio) driven vehicles ($\sim$57%) in total idling vehicles. Emission NO_x and N_2O are mainly from diesel vehicles (lean air: fuel ratio) which are $\sim$20% of total vehicular fleet idling at Ashram intersections. Similarly, CH_4 could be contributed by CNG driven vehicles which are around 23% of total traffic volume.

Conclusions

Signalized traffic intersections are considered as urban hotspots due to high air pollution levels caused by high vehicular activities. Apart from effective red signal time, a high number of vehicles, traffic congestion and are the main reasons for unnecessary idling of vehicles at signalized intersections, which results in deterioration of air quality many times exceeding the air quality standards prescribed by local regulatory authorities. In the present study, idling fuel consumption of various categories of vehicles was estimated, further, Ashram intersection in Delhi was selected for estimation of emissions due to idling of vehicles. It was observed that nearly 6000 of vehicles idle at Ashram intersection per day, which results in nearly 4200 kg/day of fuel loss. The fuel loss accrued results in the release of emission of various GHGs, making it an apt example of an urban hotspot. Further, if we convert the fuel loss due to idling in monetary terms it was estimated that nearly Rs. 3,00,000/days is wasted. With nearly 600 signalized intersections in Delhi the fuel loss and corresponding emissions could be detrimental economically and environmentally. The environmental and monetary losses due to idling could be reduced by efficient public transport, which not only helps in reducing congestion, pollution, and is less costly and uses energy efficiently. In cities like Delhi, short trip commutation problems could be reduced by effectively and organized use of non-motorized transport system. Comprehensive traffic management, planning along with extensive public transportation system could help to reduce the fuel loss and related emissions.

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Emission Inventorisation and Modelling of Non-Methane Volatile Organic Compounds from Petrol Distribution Centres in an Urban Area

Sunil Gulia, Richa Sehgal, Sumit Sharma and Mukesh Khare

Abstract Non-methane volatile organic compounds (NMVOCs) are associated with various respiratory, cardiovascular and cancerous diseases. Emission of NMVOCs from petrol distribution centres in urban areas is one of the major sources. This study focuses on the estimation of emission load of NMVOCs from petrol distribution centre in one of the metropolitan cities of India, i.e., Delhi city. It is estimated that approximately 3190 tone of NMVOCs are emitted every year from petrol pumps in Delhi city. Further, AERMOD has been used to simulate NMVOCs concentrations over Delhi city in three different seasons (winter, summer and post-monsoon). Further, AERMOD's predicted NMVOC concentration are compared with monitoring data at three different locations in Delhi city for winter period and observed satisfactory performance of AERMOD. It is observed that ambient NMVOCs concentrations exceed the NAAQS in Delhi city.

Keywords Urban air pollution · NMVOCs · Petrol retail distribution center
Emission load · AERMOD

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Introduction

Urban air quality is deteriorated in most of the megacities of the world. In developing countries, the problems of poor air quality is serious due to increasing demand of motorized road transportation, which is one of the dominant source of urban air pollution (Singh et al. 2007; Ramachandra and Shwetmala 2009; CPCB 2010). In addition to the emission from combustion of fuels, the fugitive emissions of pollutant such as VOCs due to their volatile nature is one of the major problem in urban area. The non-methane organic compounds are grouped as NMVOCs as the majority of them having similar behavior in the atmosphere. In literature, it is observed that considerable attention has been paid on management of criteria air pollutants, however, NMVOCs have steadily grown unnoticed. They are potentially carcinogenic and mutagenic in nature at specified concentrations levels and may provide significant risk to human health (Edgerton et al. 1989). In addition to that NMVOCs act as important pre-cursors of ground level Ozone formation and secondary particulates known as secondary organic aerosols (SOA). Past studies indicate that VOCs concentration in Delhi city is exceeded the national ambient air quality standard (Srivastva et al. 2005; Singh et al. 2012; Chauhan et al. 2014). The major source reported in these studies are paints industries, evaporation fossil fuel and vehicles exhaust emission. Evaporation of fossil fuel at fuel distribution centre is one of the major sources of NMVOCs. It may evaporates from fuel storage tanks, during loading and unloading of fuel, injection systems and refueling in vehicles. Gasoline vapors evaporates during refueling adding pollutants like benzene, toluene, ethylbenzene and xylene to the ambient air. The important factors affecting the evaporation of gasoline are temperature fluctuations, permeation of fuel through hoses and fitting etc. High ambient temperatures cause large evaporative losses. There is a clear need for an evaluation of these hidden sources of NMVOCs, their emission load and control in the urban area.In the present study, an attempt has been tried to evaluate the impacts of evaporative emission of NMVOCs from petrol station in Delhi city. The study includes emission inventory development of NMVOCs and prediction of NMVOCs concentrations over Delhi city.

Materials and Methods

The methodology of evaluation of impacts of NMVOCs emission from Petrol filling stations on urban air quality in Delhi city is carried out in three steps: (1) Data collection such as total number of Petrol filling stations in Delhi city, capacity of Petrol storage at each station, number of vehicles coming for Petrol filling etc., (2) Emission inventory development of NMVOCs and (3) Air quality modeling using AERMOD for prediction of NMVOCs concentration over Delhi city.

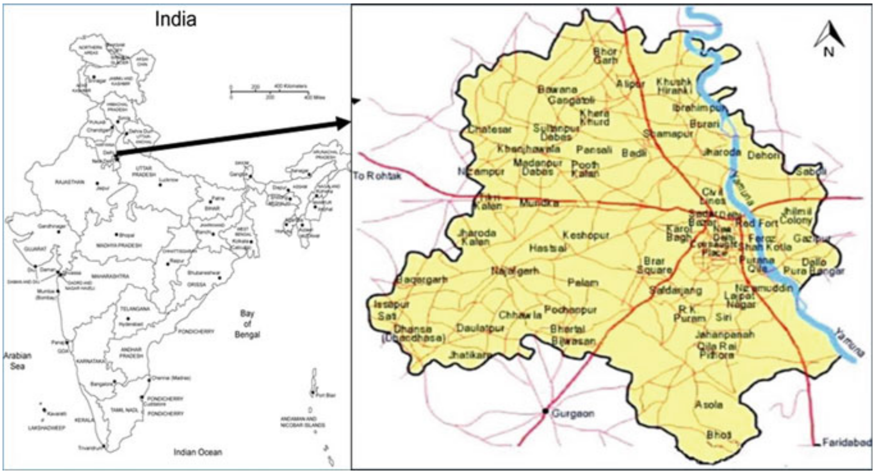

Fig. 1 Delhi city map

The Study Site

Delhi is one of the seventeen declared NAAs in India (CPCB 2006). It has a population of 22.2 million and is located at an average altitude of about 215 m above mean sea level (Fig. 1). It has tropical steppe climate. In summer, the city experiences dry weather with temperature reaching 45–48 °C. During winter, frequent ground based inversion conditions occur with temperature reaching 4–5 °C. The monsoon season experiences more than 80% of the annual rainfall. Past studies (Aneja et al. 2001; Mohan and Kandya 2007; Goyal et al. 2010) have reported frequent violations of NAAQS, particularly during winters.

Data Collection

The secondary data on Petrol consumption in Delhi city across various petrol/diesel/CNG pumps has been collected from The Energy and Resources Institute, New Delhi (Table 1). The TERI has carried out fuel stations survey and collected data on total number of stations and other related information for each distribution centre.

Emission Load Estimation

NMVOCs emission rate generated from evaporation of Petrol at filling stations has been estimated using following equation.

Table 1 Data showing amount of petrol in Delhi from April, 2012 to March, 2013

Distributor company	Petrol consumption in Delhi city (kL)											
	Apr, 12	May, 12	June, 12	July, 12	Aug, 12	Sept, 12	Oct, 12	Nov, 12	Dec, 12	Jan, 13	Feb, 13	Mar, 13
IOCL	40,813	41,703	44,265	44,843	43,993	41,468	42,504	41,399	41,084	39,027	37,314	41,268
BPCL	25,801	26,431	29,051	29,355	28,010	26,402	27,181	26,062	26,806	24,566	23,685	26,015
HPCL	22,595	23,233	24,372	25,212	24,147	22,358	23,657	22,955	22,850	21,521	20,921	23,761
Total	89,209	91,367	97,690	99,410	96,150	90,229	93,342	90,416	90,740	85,115	81,921	91,045

Table 2 Emission factors for petrol filling station in (mg/l)

Emission sources	Emission rate (mg per litre throughout)
Underground tank filling	
Submerged filling	880
Splash filling	1,380
Submerged filling and vapor balance	40
Underground tank breathing/emptying	120
Vehicle refueling	
Displacement losses (uncontrolled)	1,320
Displacement losses (controlled)	132
Spillage	80

Source AP-42, USEPA (2015)

$$E = \mathrm{ef}_i * V_i * 10^{-6}$$

where

E Emission rates of NMVOCs from evaporation of petrol at filling stations (kg yr^{-1})
ef Emission factor for Petrol evaporation (mgl^{-1})
V Annual sales of petrol in Delhi city (l yr^{-1})

Later, emission of NMVOCs from Petrol distribution stations are distributed in grid cell over the whole city. The equations used for calculation of grid wise emission is as follows (Table 2).

$$E_k = \frac{E * N_k}{N}$$

where

E_k Annual emissions of NMVOC in k grid cell, (kg yr^{-1})
E Total emissions of NMVOC inDelhi city (kg yr^{-1})
N_k Number of service stations in k grid cell
N Total number of filling stations in Delhi city

Air Quality Dispersion Modelling

The prediction of ambient NMVOCs concentrations is carried out using AERMOD model, an USEPA recommended air quality dispersion model for regulatory purposes. It is a Gaussian based dispersion model. It incorporates AERMET (Meteorological Preprocessor) replacing the P-G stability class and AERMAP, to process terrain features. Input data for AERMET includes hourly cloud cover observations, surface meteorological observations, such as, wind speed and direction, temperature, dew point, humidity and sea level pressure and upper air soundings. The AERMAP uses gridded terrain data to calculate the representative terrain-influence height (Cimorelli et al. 2004). AERMOD are set-up using grid emission data, topographical features and meteorological conditions of Delhi city for a period of one week in the winter season of year 2013.

Results and Discussion

NMVOCs Emission Load

The NMVOCs emission load due to evaporation Petrol at filling stations in Delhi city is estimated 3190 tons/year. Further, the total emission load has been distributed grid wise over Delhi city. Each grid cell size is 2.5 km × 2.8 km. The total number of Petrol filling stations in Delhi city are 324. The maximum emission load in grid cell with 8 number of filling stations is 78.76 tons/yr = 2.49 g/s. However, emission from single filling station is estimated to be 0.312 g/s. Figure 2 shows the grid wise emission load of NMVOCs in Delhi city.

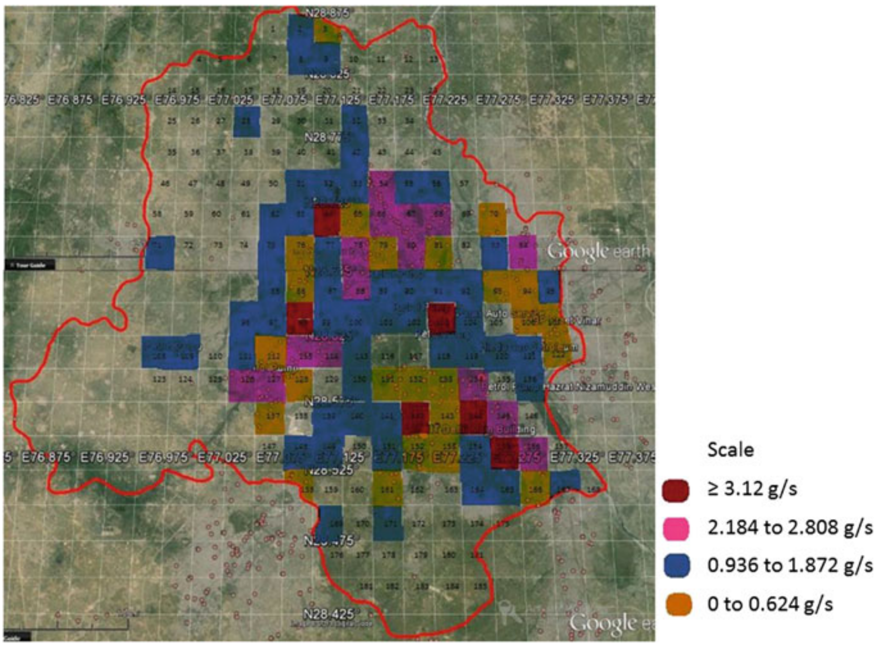

Fig. 2 Grid wise NMVOCs emission rate over Delhi city

NMVOCs Concentrations Prediction

AERMOD has been setup using each grid as unit area source. Total 221 numbers of grids have been considered in the modelling as source of NMVOCs. Each grid is defined by universal transverse mercator (UTM) coordinate system. The centre of each grid is defined as receptor point and total 221 numbers of receptor points have been defined in the model. In addition to these, the three selected air quality monitoring stations of Civil Line, Dwarka and Anand Vihar are also defined as receptor points. The results of these three receptor points will be used for model validation. The prediction has been carried out for three different season in year 2013 i.e. winter (month of January), summer (month of May) and Post monsoon (month of October). The meteorological data has been taken from Indian Meteorological Department for the study period. Figure 3 indicates spatial distribution of NMVOCs concentrations over Delhi city along with respective windrose

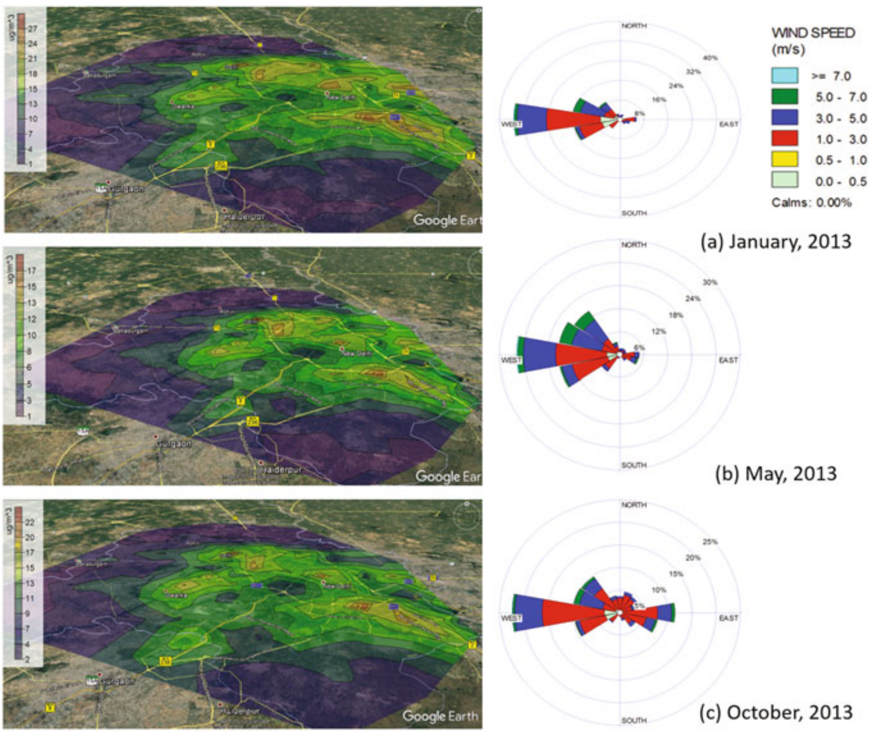

Fig. 3 NMVOCs concentration distribution over Delhi city during 2013

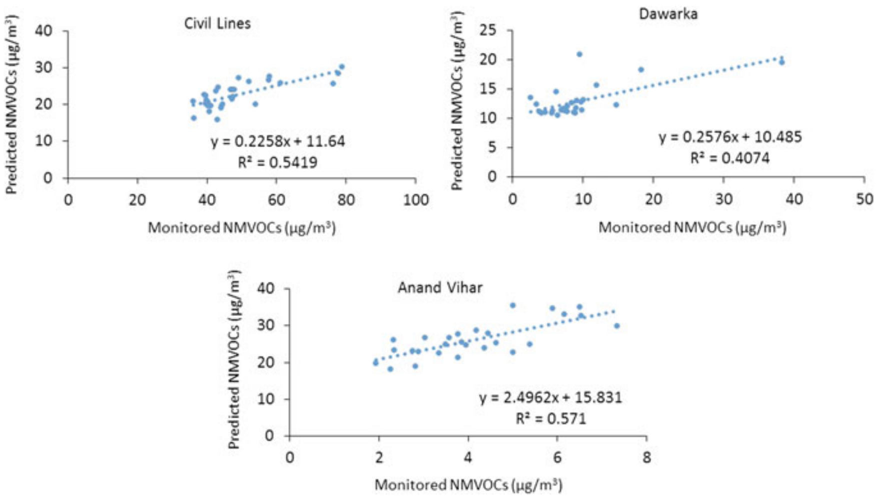

Fig. 4 scatter plot of predicted and monitoring NMVOCs concentrations

plot of three season. The higher NMVOCs concentration in winter season compared to post monsoon and summer seasons clearly indicate the impacts of calm meteorological condition in winter season. Further, it is also found the NMVOCs concentration are found higher in Centre, East and South east of Delhi city (downwind side). It is due to high emission load in these area and due to transport of pollutants emitted in West and North West of Delhi city (upwind side).

Model Validation

The validation of AERMOD prediction has been carried out by comparing the predicted and monitoring NMVOCs concentrations (Benzene) at three different location in Delhi city (Fig. 4). The monitoring data have been collected from the DPCC operated air quality monitoring stations at Civil lines, Dwarka and Anand Vihar for the month January, 2013. Figure 4 describe the scatter plot of predicted and monitoring concentrations data at all three locations. The value of r^2 in range of 0.41–0.57 indicate satisfactory performance of AERMOD in predicting NMVOCs concentrations. However, AERMOD is slightly under predicted which may be due to non-consideration of other significant sources of NMVOCs in the modelling study. The NMVOCs concentration are found exceeding the specified standards of 5 µg/m^3 (MoEF 2009).

Conclusions

The study has been carried out with aim of emission inventorisation and prediction of NMVOCs concentrations over Delhi city using AERMOD. The NMVOCs emission loads from Petrol stations in Delhi city is 3190 tons/year. Further, AERMOD predict satisfactorily the NMVOCs concentration over Delhi city. The modelling results indicates higher NMVOCs concentration in winter season followed by post monsoon and summer seasons. The values of NMVOCs are found to be exceeded the specified NAAQS value which needs to be control to reduce the exposure level and its harmful impacts on environment. This kind of study will assist decision makers to manage increasing air pollution level by simulating the control measures such as vapor recovery systems (VRS) at the petrol distribution centres.

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Comprehensive Physicochemical Characterization of Coal Combustion Residues from a Thermal Power Station of India

Ritesh Kumar

Abstract Coal combustion residue is a by-product from combustion of pulverized coal in thermal power stations and is considered as a waste material. Coal combustion residues contain many chemical elements that may be potentially harmful to the environment. Coal combustion residue handling and disposal is a major problem from an environmental point of view. Though the utilization in India has shown increase in percentage value, still we are to make sufficient effort to fulfill the promise of 100% utilization. Although some of the coal combustion residues are used as construction materials and as backfill material that provides ample opportunity for its bulk use, most of them are still disposed of in settling ponds, also known as ash ponds or landfills. The study here presents comprehensive physicochemical characterization of coal combustion residues from a thermal power station of India. The present study is aimed to provide the database relevant to its finding better utilization potential and also see the effect of land disposal of such ash on the quality of groundwater and surface water through the laboratory study simulating field conditions.

Keywords Coal combustion residues · Fly ash · Bottom ash and pond ash Characterization · Utilization

Introduction

The Indian power sector generated approximately 967.150 BU of electricity in 2013–14 (Ministry of Power 2015). The growth in the power sector during the past 60 years and especially in the past two decades has been phenomenal. Of the total power generated, more than 50% has been contributed by coal-fired power station (TEDDY 2014/15; BP 2015). This growth of the power sector during the last one and a half decade has taken place due to increasing electricity demand and

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industrialization which has led to the per capita increase in power consumption in India to 1010 kWh in 2014–2015. The installed capacity, which was 72,320 MW in 1993–1994, has now reached 284, 303 MW as on December, 2015 (TEDDY 2014/15; All India Installed Capacity: CEA Report 2015).

Coal-fired power stations are still the main source of power generation in India. Coal is the readily available raw material for power generation as India has vast reserves of thermal grade coal. The estimated coal reserves as on 01.04.14 in India are 301.564 BT (TEDDY 2014/15; Coal Reserves in India-MCL 2014; Coal Reserves-MoC 2016. The production of coal has increased from about 70 MT in early 1970s to 565.766 MT in 2013–2014 (TERI 2014/15). Coal that is used for power generation in the country is mostly low-grade coal containing 30–50% ash (Kumar 2003; Ministry of Power 2008; Mishra 2004; Zamuda and Sharpe 2007). The combustion of coal at the coal-fired power stations produces ash residues of inorganic minerals.

Around 132 thermal power stations are there in the country that contributes about 60% of country's total electric power installed capacity (List of Thermal Power Stations up to 2016). These thermal power stations at the same time produce more than 100 MT of coal combustion residues (CCRs) per year that is causing great environmental concern in the form of air, water and land pollution besides its proper handling and disposal (Dhadse et al. 2008; Ahmad et al. 2014; Haque 2013). Disposal of such a huge amount of CCRs craves for huge tract of land besides having several environmental implications in the disposal environment. In country like India, where land resources is very limited, proper management of CCRs is the need of the hour not only in our country, but also throughout the world and all this requires proper understanding of CCRs through its characterization study.

In India, mostly two types of ashes are produced namely, fly ash and bottom ash. Fly ash is a by-product from the combustion of pulverized coal in thermal power stations, and is removed by mechanical collectors or electrostatic precipitators as a fine particulate residue from the combustion gases. Fly ash can further be classified into two types, Type F and Type C. Type F ash is produced from bituminous coal, has low lime content, and possesses little cementitious value by itself. Type C fly ash is produced from sub-bituminous or lignite coals, has higher lime content and possesses some cementitious qualities of its own. Bottom ash is the coarser portion that is collected at the boiler bottom. Wet system of disposal is followed by most of the thermal power stations in India. In this system of disposal, fly ash is hydraulically removed from ESPs hoppers and in slurry form sent to the nearby ponds made for this purpose. Similarly, bottom ash is crushed to the required fineness and then hydraulically sent to the nearby ponds like fly ash.

In India, at present around 61.37% of CCRs are being utilized, which is still low as compared to some of the other developed countries of the world where utilization is close to 100% (CEA-Annual Report 2012–13). The ash utilization in 1992–1993 was 2–3% (Kumar and Mathur 2005). Though in our country the situation has changed since last one and a half decade we have to go a long way to fulfill the promise of 100% utilization. Table 1 shows the status of world energy at end 2013. Tables 2 and 3 show the year-wise power generation in India from 2000–2001 to

Table 1 Status of world energy at the end 2014 (BP 2015)

	2014	Change 2014 over 2013 (%)
Electricity		
Generation (TWH)	23536.5	1.5
Coal		
Reserves (MT)	891531	–
Production (MT)	8164.9	−0.7
Production (MT of oil equivalents)	3933.5	−0.7
Consumption (MT of oil equivalents)	3881.8	0.4

Table 2 Year-wise power generation in India (2003–2004 to 2013–2014) (TEDDY Annual Report 2003/04, 2004/05, 2005/06, 2009, 2014/15; CEA Annual Report 2011/12, 2012/13, 2014/15)

Year	Generation (BUs)
2003–04	558.30
2004–05	587.40
2005–06	617.50
2006–07	662.50
2007–08	704.50
2008–09	723.80
2009–10	771.60
2010–11	811.10
2011–12	876.40
2012–13	912.06
2013–14	967.15

Table 3 Year-wise per capita electricity consumption in India (2005–2006–2012–2013) (Garg 2012; CEA Annual Report 2011/12, 2012/13, 2014/15)

Year	Consumption (kWh)
2005–06	631
2006–07	672
2007–08	717
2008–09	734
2009–10	779
2010–11	819
2011–12	884
2012–13	917
2013–14	957
2014–15	1010

2013–2014 and per capita electricity consumption in India from 2000–2001 to 2013–2014, respectively. Table 4 shows the per capita consumption of electricity by leading countries of the world. Table 5 shows the India's CCRs utilization scenario. Similarly, Table 6 provides the data on CCRs utilized by the leading countries of the world.

Table 4 Comparative per capita consumption of electricity (kWh) (Garg 2012)

Countries	Consumption (kWh)
World	2782
OCED countries	8486
Middle East	3384
Former USSR	4660
Latin America	1956
Non-OECD Europe	3378
China	2471
Asia	719
Africa	571
India	566

Table 5 Year-wise CCRs utilization in India (2002/03–2011/12) CEA Annual Report 2010/11, 2011/12, 2012/2013

Year	Utilization (%)
2002–03	22.68
2003–04	29.39
2004–05	38.04
2005–06	45.69
2006–07	50.86
2007–08	53.00
2008–09	57.11
2009–10	62.60
2010–11	55.79
2011–12	58.48

Table 6 Utilization of fly ash by various countries (Kumar and Mathur 2005)

S. No.	Country	Utilization (%)
1	Australia	40
2	Canada	40
3	China	35
4	Czechoslovakia	40
5	Denmark	85
6	France	70
7	Germany FR	85
8	Greece	45
9	Hungary	50
10	India	41
11	Israel	80
12	Japan (a)	40
13	Netherlands	100
14	Poland	100
15	South Africa	35
16	U.K.	60
17	U.S.A	35

This paper provides a comprehensive characterization of CCRs from an Indian thermal power station. The paper also covers long-term leaching study to assess their feasibility as a fill material in mining areas with respect to its potential of contaminating ground/surface water in the disposal environment due to the leachate generated from it when used in bulk. The actual aim of this paper is to suggest CCRs suitability as a fill material in an environmentally friendly manner.

Materials and Methods

Selection of Thermal Power Station

Bokaro thermal power station (BTPS) and the ash ponds are close to the surface water bodies. The effluents from the ash ponds are discharged to the river Konar. Besides this there are chances of ground water pollution due to leachates entering the ground water reservoir. So, in order to monitor the effluents and the leachates, which may contain trace/heavy elements to the alarming limits, this thermal power station was chosen for study.

Geographical Location and Study Area Details

Bokaro thermal power station (BTPS) is one of the four thermal power stations under Damodar valley corporation (DVC), Jharkhand, India that has the generating capacities of 630 MW. BTPS covering an area of about 65 ha is located in the state of Jharkhand about 55 km from Dhanbad. It is located on the bank of the river Konar in Bokaro district. Figure 1 shows the location of the thermal power station and the ash ponds along the river Konar in the state of Jharkhand. It is the first low-grade coal burning power station constructed by the DVC. The power station is divided into two parts, namely, plant A and plant B. Plant A was the nation's biggest thermal power station in the sixth decade of the past century with a captive coal mine. Plant A had 4 units and plant B has 3 units. Plant A had an installed capacity of 247.5 MW and its generation capacity was 175 MW. Plant B has installed as well as generating capacity of 630 MW. Plant A is now closed due to environment-related problems and only plant B is operational. The entire power generated at plant B is supplied to DVC grid. The first unit of plant A was commissioned in February 1953 and the first unit of plant B was commissioned in March 1986. This site for the power plant was chosen because of easy availability for water from Konar River, coal from Bermo Colliery, and potentiality for ash disposal. The power generated at BTPS is utilized by TISCO, Jamshedpur; copper industry at Ghatshila; various industries at Dalmianagar; IISCO, Burnpur; collieries in West Bengal and Jharkhand; CESC, Kolkata; railways for traction; and Governments of West Bengal and Jharkhand for

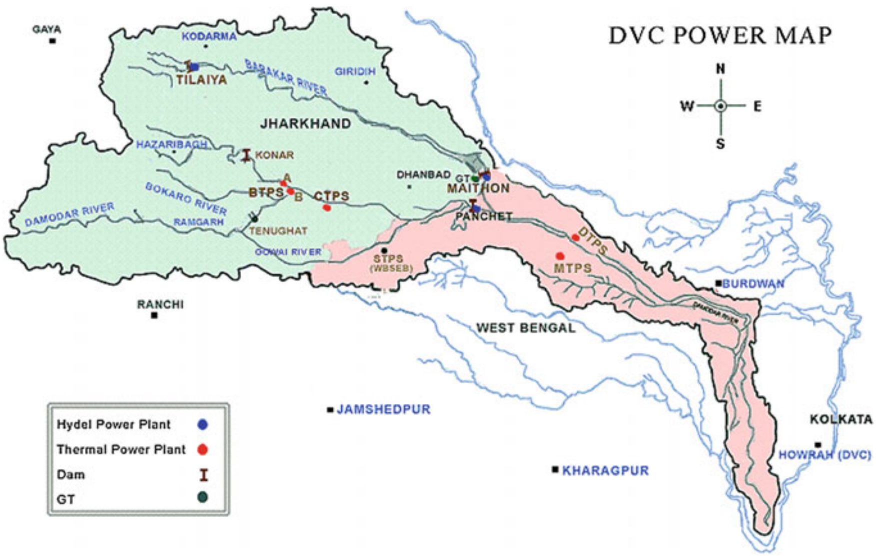


Fig. 1 Location of Bokaro thermal power stations along the River Damodar

Table 7 Composition of coal being used at BTPS (Kumar 2009)

Parameters	Range
Fixed carbon (%)	36.28–47.77
Volatile matter (%)	15.87–18.12
Moisture (%)	0.91–1.11
Ash (%)	34.23–40.25
Gross calorific value (kcal/kg)	4670–4970

rural and urban distribution. Table 7 shows the characteristics of coal being used at Bokaro Thermal Power Station.

Ash Pond and Ash Handling System

Wet system of ash collection is followed at BTPS in which CCRs are disposed off to the nearby ponds in slurry form via hydraulic transportation. There are three ponds and CCRs are disposed off to these ponds via pipelines. The ash handling system at BTPS is designed to handle bottom ash at the rate of 240 ton/h and fly ash at the rate of 60 ton/h. These capacities are based on the use of coal having maximum ash content of 31% and ash removal once per 8-h shift.

Table 8 Status of ash evacuation from BTPS (Lac cu.m) (Kumar 2009)

Thermal power station	Progress									Total progress
	1997–98	1998–99	1999–00	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	
BTPS	0.4	3.5	6.34	3.374	4.01	9.97	11.76	11.47	12.08	62.904

Ash Utilization at BTPS

DVC has taken up significant role in ash utilization in the form of mine filling (Table 8). Ash is evacuated and transported in protective manner and dumped in abandoned open cast mines from BTPS ash pond site to S&T patch quarry no. 5 of Kargoli seam at Bokaro colliery of CCL.

Sampling

Fly ash samples one from the front field (FA#A) and other from the back field (FA#B) and similarly bottom ash samples one from the front field (BA#A) and other from the back field (BA#B) were collected on five different days over a week and a final homogenized sample for each of the fly ash and bottom ash from the front and the back fields were prepared by mixing the appropriate portions. Similarly, pond ash samples were collected from the ash ponds site from five different locations on five different days over a week and a final homogenized sample was prepared mixing appropriate portions. The CCR samples after coning and quartering method were then taken for physicochemical characterization and leaching studies.

Experimental

Physical Characterization

Particle size analysis was done using sieves of standard size ranging from 72 to 400 mesh. Moisture content, bulk density, water holding capacity, specific gravity, porosity, optimum moisture content, maximum dry density and Atterberg's limit were analyzed following the standard method of analysis.

Shear strength of the samples was also studied to study the maximum load that the samples can bear before undergoing failure. SEM and EDXA studies were conducted using Hitachi Instruments of Tokyo, Japan, Model No. S-415A. TEM studies were conducted using Model H-600, Hitachi Instruments Ltd., Tokyo, Japan. X-ray diffractograms of samples were obtained using Philips Diffraction Unit Model-PW

1011. Perkin Elmer FT-IR Spectrometer Spectrum 2000 Model was used for recording FTIR spectra of the CCR samples. Chemical compositions of the CCR samples were analyzed using Philips XRF Model-PW 2400 of Netherland Make.

Chemical Characterization

pH and Electrical conductivity (EC) was measured in a 1:2 soil–water suspension using CyberScan pH meter Model 510 and conductivity meter Model 200. Organic carbon and total and available ions in CCRs was determined using standard method of analysis. Organic carbon was found using Walkley–Black Method. Available N was estimated by the Kjeldhal extraction and titration technique, available P using Olsen's P method and available K was found by ammonium acetate method. The total CHNS were determined using CHNS analyzer, Model 2400 Ser II. DTPA Extractable Elements (Pb, Zn, Cu, Fe, Mn, Ni, and Cd) were determined using DTPA extraction fluid followed by analysis of elements in flame photometer (Systronics Flame Photometer Model 128 for Sodium and Potassium measurement) and atomic absorption spectrophotometer (Atomic Absorption Spectrophotometer GBC-902 for analysis of other elements) (Maiti 2001).

Leaching Studies

Leaching studies were carried out using four different methodologies considering the various conditions that the CCR samples are likely to encounter (in the real world) when exposed to the environment. The leachates after having collected were then analyzed for several elements in flame photometer and atomic absorption spectrophotometer.

Results and Discussion

Physical Characterization

The physical characteristics of coal combustion residues (Table 9) from Bokaro Thermal Power Station are discussed below:

The moisture content of CCR samples varied from 0.12 to 2.60%. The fly ashes were found to have low moisture content compared to bottom ashes. Moisture content is an important parameter as it helps in finding the amount of moisture to achieve good compaction or the plastic or liquid limit behavior during handling. The moisture content depends upon the type of storage or disposal being followed

Table 9 Physical characteristics of CCR samples from BTPS

Parameters	Samples				
	FA#A	FA#B	BA#A	BA#B	PA
Moisture content (%)	0.17	1.12	0.70	2.60	0.21
Water holding capacity (%)	87.20	87.58	61.82	55.97	75.59
Permeability ($\times 10^{-4}$ cm/s)	2.32	2.12	2.50	1.19	2.12
Specific gravity	2.47	2.53	2.11	2.40	2.60
Surface area (m^2/g)	2.2	2.0	1.5	1.6	2.0
Bulk density (g/cc)	0.978	0.742	0.830	0.906	0.960
Porosity (%)	60.40	70.67	60.66	62.25	50.16
Atterberg limits					
LL (%)	25	32	30	23	21
PL (%)	NA	NA	NA	NA	NA
Proctor test					
OMC (%)	21.57	18.76	29.32	31.78	20.68
MDD (g/cc)	1.31	1.29	1.15	1.07	1.27
Proximate analysis					
Moisture (%)	0.17	1.12	0.70	2.60	0.21
Ash (%)	81.82	90.82	90.40	91.98	93.50
Volatile matter (%)	4.50	1.17	1.54	1.07	2.70
FC (by diff.) (%)	13.51	6.89	7.36	4.35	3.59
Sieve analysis					
Cc	1.0907	0.8803	1.2073	1.2061	0.7836
Cu	3.3556	1.8612	2.6617	2.2437	3.500
Loss on ignition (%)	26.68	9.76	9.47	9.25	12.54

for any particular material and the sample collection method employed. As in BTPS wet system of disposal is followed, the chances of CCR becoming airborne during handling is ruled out. Holding of CCR in ash pond and that too, for a long time may create nuisance when the pond gets dried up and the wind is blowing. On the other hand high moisture content reduces its suitability for several economic uses. High moisture content is undesirable for use in manufacture of Portland cement, asbestos sheet, etc.

Water holding capacity of any material is controlled by chemical and physical nature of the material. Any material is said to be at its maximum water holding capacity when water fills all its pore spaces and there is no space. The water holding capacity of fly ashes were more (87.20 and 87.58%) compared to bottom ashes (61.82 and 55.97%) and pond ash (75.59%). Fly ashes had low moisture content and so water holding capacity was greater compared to bottom ashes. High water holding capacity of fly ashes was also due to greater percentage of fines present. Fine particles mean more surface area and so more water adsorptions. In case of CCR samples water holding capacity is found to be more than those of natural soils.

Specific gravity was found to vary from 2.11 to 2.60. In case of all the five samples, the specific gravity was above 2.00 and that not enough variation can be seen among the samples. Presence of unburnt carbon and cenospheres may be the reasons for the low specific gravity of the CCRs. Due to low specific gravity the flowability of the CCRs is better which makes it suitable stowing material in place of sand for underground mines.

Table 9 indicates that permeability varied from 1.19×10^{-4} to 2.50×10^{-4} cm/sec. Permeability observed, in general, was low. This was due to higher percent of fines and high compressibility of CCRs. Such material can be used in improving the water retention capacity of the sandy soil, where water easily drains away owing to high porosity. Low permeability is a problem when using it as a stowing material.

Surface area was found to vary from 1.5 to 2.2 m^2/g. It can be seen that the surface area of fly ashes is more compared to bottom ashes. Surface area is also related to the percentage unburnt carbon in CCRs. The unburnt carbon is highly porous and so has effect on the surface area of CCRs. Surface area is one of the important parameters of any particulate matter. The pre-concentration of trace elements on the particles mainly depends upon its surface area.

Bulk density of CCRs was less than 1.00 and it varied from 0.742 to 0.978 g/cc. Low bulk density is hindrance in the use of CCR as a stowing material as it takes time to settle. However, such problem can be overcome by the use of some flocculating agent as is being experimented in CMRI. The transportation of such CCRs is also economical compared to sand when using CCRs as backfill or stowing material. Such CCRs can also be used for modifying the texture of clayey soil for reducing the plasticity. This can further help in increasing the workability of such clayey soil.

Liquid limit of the samples was found to vary from 21 to 32%. Plastic limit of the samples could not be found, as the materials could not be rolled to conduct plastic limit test. Liquid limit of sand or sand like material is another very important parameter in construction related works where such liquid limit make CCRs behave as a viscous fluid and this can be at the cost of the stability of the structures.

Optimum moisture content (OMC) and maximum dry density (MDD) were found to vary from 18.76 to 31.78% and 1.07 to 1.31 g/cc respectively. OMC and MDD are important parameters as their knowledge enables one to measure the density achievable for good compaction as a function of moisture. The results of OMC were made use of in packing the materials in open column for conducting leaching experiments. The knowledge of OMC and MDD is also very important in the sense it provide guideline when using CCRs as a structural fill material.

Pore space was found to vary from 50.16 to 70.67%. Pore space in case of fly ashes was more compared to bottom ashes and pond ash. High pore space of fly ashes can be the reason for their high water holding capacity.

From the proximate analysis study, it is observed that the carbon content in the samples varied from 3.59 to 13.51%. High percentage of carbon is an indicator of incomplete combustion in the PCC boilers. Volatile matter varied from 1.07 to 4.50%. Ash content varied from 81.82 to 93.50%. The loss on ignition varied from

9.25 to 26.68%. Loss on ignition was close to 10% except in the case of FA#A sample, where it was observed to be too high. LOI should be as low as possible for using fly ash in PPC. Also, unburnt carbon should be minimum so that it can be used as a replacement of Portland cement in concrete or as a consolidated underground fill. Pozzolanic activity of CCR decreases with increase in carbon content.

The particle size analysis was also carried out for samples under study. Sieves used for this ranged in size from 72 to 400 mesh. From the sieve analysis plot coefficient of conformity (C_c) and uniformity coefficient (C_u) were calculated. C_c and C_u values for the CCR are given in the Table 7. The C_u of the samples varied from 1.8612 to 3.500. For C_u close to 1, on comparison with soil, coal combustion residue samples cannot be put under uniformly graded material as C_u is either equal to 2 or greater than 2. The C_c values were in the range 0.7836–1.2173. For C_c between 1 and 3, material is classified as well graded material. On comparison with soil, coal combustion residue samples can be classified as well graded material except for FA#B and PA. Mean diameter of the particles was close to 50 μ except BA#A (69.9 μ) and BA#B (82.10 μm).

Table 10 shows the results of shear strength test. The results of shear stress were used to find out cohesion and the angle of friction. From the study of shear stress and normal stress of CCR samples from BTPS, it was found that the samples such as FA#A, FA#B, and BA#B had cohesion value of 0.05 kg/cm^2 and above compared to BA#A and PA samples whose cohesion was equal to zero and so cohesionless. The angle of friction of the samples was in the range 30°–45°. In case of FA#A, FA#B, and BA#B samples both cohesion and angle of friction contributed to the shear strength compared to BA#A and pond ash samples where shear strength was mainly due to the angle of friction.

The results of the environmental characterization of coal combustion residues (CCRs) from BTPS for assessing their characteristics for various uses were also carried out. The characteristics of coal combustion residue (CCR) samples as determined by instrumentation techniques are discussed below.

Results of the X-ray diffraction analysis are presented in Table 11. The X-ray diffractograms are shown in Fig. 2i–v. X-ray diffraction was performed to know the crystalline phases present in the CCR samples. From the results one can see that in all the five samples the major component consisted of quartz and the minor components included magnetite and hematite.

Table 10 Results of shear stress at failure of CCR samples

S. No.	Normal stress σ (kg/cm^2)	Shear stress at failure τ_f (kg/cm^2)				
		FA#A	FA#B	BA#A	BA#B	PA
1	0.5	0.450	0.450	0.413	0.425	0.413
2	1.0	0.763	0.738	0.838	0.775	0.800
3	1.5	1.025	1.063	1.250	1.163	1.250
4	2.0	1.425	1.375	1.750	1.525	1.675
5	2.5	1.725	1.775	2.075	1.850	2.100

Table 11 Summary of XRD analysis of CCR samples from BTPS

Plant	Samples	XRD analysis	
		Major	Minor
BTPS	FA#A	Quartz	Hematite, magnetite
	FA#B	Quartz	Hematite, magnetite
	BA#A	Quartz	Magnetite
	BA#B	Quartz	Hematite, magnetite
	PA	Quartz	Magnetite

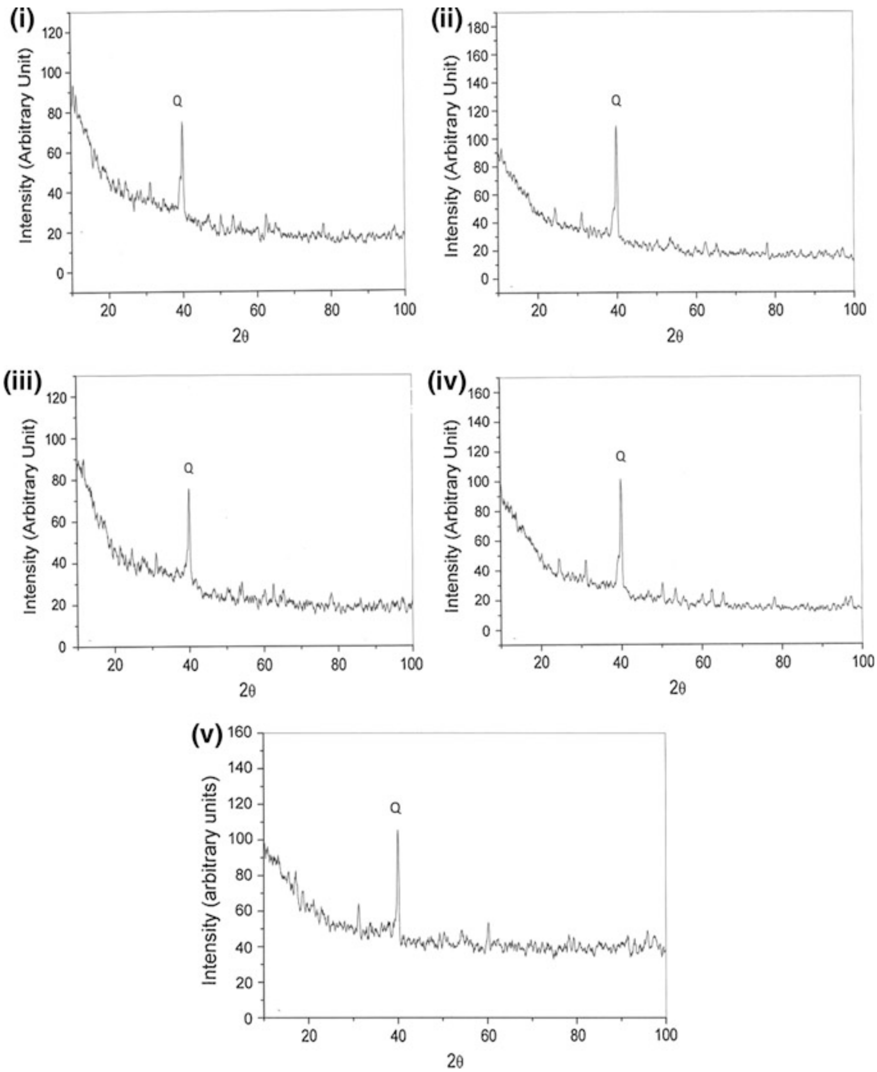


Fig. 2 X-Ray diffractograms of BTPS samples **i** FA#A **ii** FA#B **iii** BA#A **iv** BA#B and **v** PA; Q stands for Quartz

Table 12 Summary of SEM study of CCR samples from BTPS

Plant	Samples	SEM (Observations)
BTPS	FA#A	Mostly spherical in shape with size varying from less than 1 to 100 μm
	FA#B	Some cenospheres could also be seen from the micrographs
	BA#A	A few plerospheres could also be seen from the micrographs
	BA#B	Cenospheric particles show frequent bursts which is inductive of chemical activity having occurred within them
	PA	Surfaces of some particles show extensive mechanical damage caused by impactation
		Small size particles were seen sticking to the larger spherical particles possibly on account of the convexity of the surfaces
		Leached particles were observed to be smoother. This shows the washout of the elements residing on the surface with time. Plot of OPCE also shows this decreasing trend
		Some spongy morphology could also be seen from the micrographs

The morphological features of the leached and unleached CCR samples were examined with the help of scanning electron microscope using scanning electron microscopy (SEM) technique. Table 12 gives the observation made with respect to SEM studies of CCR samples. These are also shown in Fig. 3a–e. The study of the micrographs of the unleached CCR samples in general indicated that CCR consisted primarily of spherical particles with nodules present on it. The particles were of different sizes and ranged from 1 to 100 μm. Similarly, study of the micrographs of leached CCR samples clearly shows the leaching pattern that has taken place. The particles in the leached samples lacked agglomeration and were more dispersed than one can observe in the case of unleached samples. Thus, one can conclude that the surface film or the irregularities caused the unleached particles to agglomerate.

Figure 4 shows few micrographs of the leached CCR samples. One can easily observe the leaching (using distilled water) phenomenon that has taken place and that the surfaces of the leached particles were smoother. It means that the material residing on the surface has been washed away during leaching. Surfacial element mostly present included alkali and alkaline earth metals, i.e., sodium, potassium, calcium, and magnesium. As these got washed away due to the first flush phenomenon, their presence in the leached samples also decreased considerably. Decrease in concentration of these elements with time can be very well observed from the plot of the open column percolation experiment results for these elements (Fig. 6). Some of the particles on the leached samples were found distorted as can be seen from the micrographs of the leached samples. Distortion of particle surface is due to dissolution or disruption of the surface making the wall thinner and thinner and finally the wall ruptures.

As pointed out the particles are mostly spherical in shape and they are either hollow spheres commonly known as cenospheres or solid spheres or may be containing many smaller spheres within a sphere known as plerosphere. All three can be seen from the micrographs. Cenospheres and plerospheres are present in

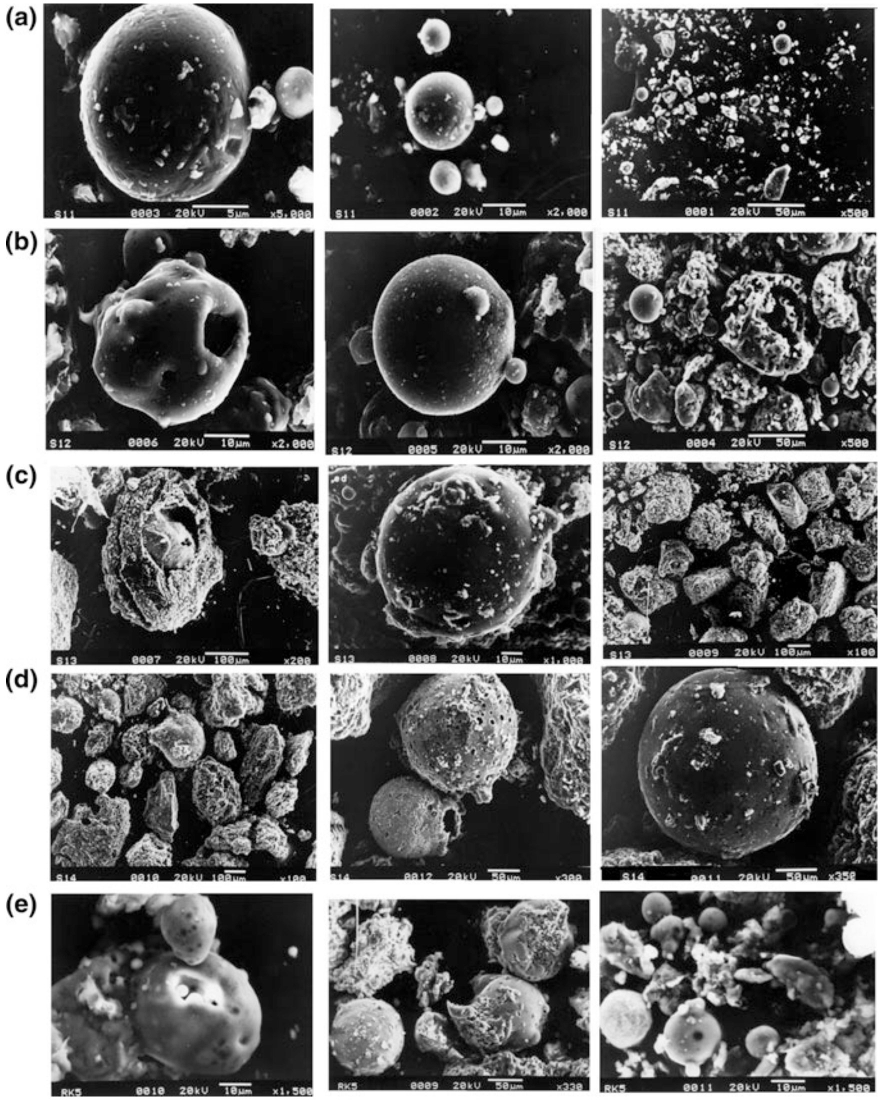


Fig. 3 Scanning electron micrographs of BTPS **a** FA#A, **b** FA#B, **c** BA#A, **d** BA#B and **e** PA before leaching

very low amount. Some spongy morphology can also be noticed from the micrographs. A point of special importance is the fact that most of the particles are found to be of spherical nature. Due to being spherical mixed with cement it can add workability to cement concrete mix. Being spherical and hollow can be used as filler in paints and so on.

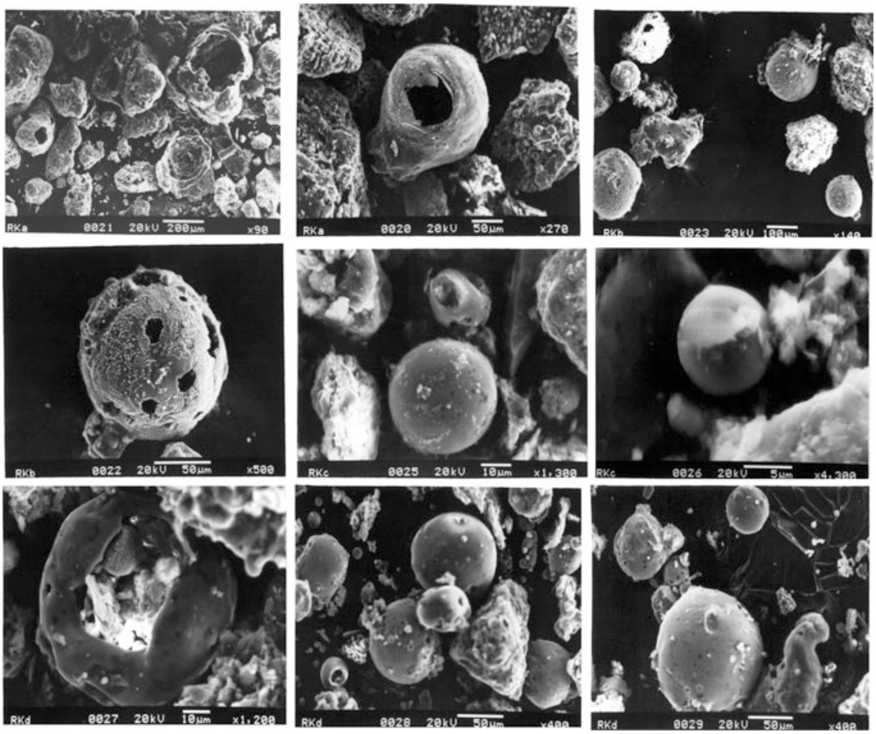


Fig. 4 Scanning electron micrographs of CCR samples after leaching

Table 13 Summary of EDXA of CCR samples from BTPS

Plant	Samples	Si	Al	Fe	Na	K	Ca	Mg	S	Ti
BTPS	FA#A	25.97	14.85	3.34	2.52	1.63	0.62	0.12	0.02	0.97
	FA#B	21.67	14.56	3.75	6.35	1.42	0.89	0.92	0.06	2.16
	BA#A	25.88	17.36	2.07	1.93	1.27	0.09	0.02	–	1.32
	BA#B	26.40	15.93	1.36	1.10	1.66	0.32	0.64	–	1.04
	PA	23.20	12.20	8.54	4.36	1.16	0.37	0.90	0.21	1.06

The observations of EDXA analysis are given in the Table 13. This study was performed to determine the trace element contents in the CCR samples. The study shows that the CCR samples are typically formed of Si–Al–Fe system with traces of sodium, potassium, calcium, magnesium, sulfur, and titinium.

The observations of the composition of CCR samples using XRF/EDXA technique are given in the Table 14. The study shows that the CCR samples belong to SiO_2–Al_2O_3–Fe_2O_3 system. The main components in all the samples were quartz (SiO_2) and alumina (Al_2O_3), which accounted for more than 70% of the total. Other component Fe_2O_3 was less than 10% in all the samples except in BTPS PA (12%).

Table 14 Summary of compositional analysis of CCR samples from BTPS

Plant	Samples	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	CaO	MgO	SO_3	TiO_2
BTPS	FA#A	55.56	28.06	4.78	3.40	1.96	0.86	0.20	0.05	1.61
	FA#B	46.37	27.51	5.36	2.55	1.71	1.24	1.51	0.14	3.60
	BA#A	55.37	32.79	2.95	2.60	1.53	0.13	0.03	–	2.19
	BA#B	56.48	30.11	1.94	1.48	2.00	0.44	1.05	–	1.73
	PA	49.63	23.05	12.21	5.87	1.40	0.52	1.50	–	1.77

Table 15 Summary of qualitative analysis of CCRs samples from BTPS

Plant	Samples	Major	Minor	Traces
BTPS	FA#A	Fe, Al, Si, Ti	Ca, Mg, Zr	Y, Sr, Rb, Zn, Cu, Ni, Mn, Cr, S, P
	FA#B	Fe, Al, Si, Ti, K	Ca, Mg, Zr	Y, Sr, Rb, Pb, Ga, Zn, Cu, Mn, Cr, S, P
	BA#A	Fe, Al, Si, Ti	Ca, Mg, Zr, K	Y, Sr, Rb, Pb, Ga, Zn, Cu, Mn, Cr, S, P
	BA#B	Fe, Al, Si, Ti, K	Ca, Mg	Zr, Sr, Rb, Ga, Zn, Cu, Ni, Mn, Cr, Ba, S, P, Y
	PA	Fe, Al, Si, Ti	Ca, Mg, Zr, K	Y, Sr, Rb, Ga, Zn, Cu, Ni, Mn, Cr, Ba, S, P

Minor amounts of CaO, K_2O, MgO, TiO_2, and SO_3 were also observed in the samples. There are fluctuations in the chemical composition of the samples mostly due to the different mineral component in the parent coals. These fluctuations are also related to the compositions of the parent rocks in the formation of peat and coal and also the plant species involved in the coal formation.

The observations of the qualitative analysis using XRF technique are also given in the Table 15. From the results so obtained it can be seen that the major components in almost all the samples were iron, aluminum, silicon, titanium and potassium. Minor components mainly included calcium, magnesium, zirconium, manganese and zinc. Common elements in the traces were barium, nickel, copper, rubidium, sulfur, phosphorus, yttrium and strontium.

The FTIR study showed that CCR samples collected from various plants showed a broad band due to the presence of O-H stretching. O-H stretching of CCRs was between 3300 and 3611 cm^{-1}. CCR samples of FCI alone showed a characteristic band due to the presence of carbonyl group. Oxides of phosphorus and oxides of silicon were also observed in all the samples. P-O bending was between 1079 and 1084 cm^{-1}. Table 16 gives the observations of the FTIR spectra of CCR samples.

Chemical Characterization

The coal combustion residue (CCR) samples from BTPS were analyzed for its various chemical characteristics. The observation of the study is presented in Table 17. The five samples were analyzed for pH, electrical conductivity (EC), organic carbon, available nitrogen, phosphorus and potassium, cation exchange

Table 16 Summary of FTIR analysis of CCR samples from BTPS

Vibrations W. No. (cm^{-1}) samples	O–H (Str) (3700–3200)	>C = O (1735–1710)	–C = C–(Ar) (1600–1500)	P–O (Str) (1100–1000)	Si–O–Si (sym.) (∼800)	Kaolinite (∼695)	P–O (Bend.) (600–500)	Si–O–Si (Defor) (∼460)
FA#A	3541	–	–	1085	796	–	566	467
FA#B	3447	–	–	1086	795	–	566	466
BA#A	–	–	–	1084	796	–	560	470
BA#B	3528	–	–	1085	796	–	564	464
PA	3449	–	–	1084	794	–	–	454

Table 17 Chemical properties of CCR samples from BTPS

Parameters	Samples				
	FA#A	FA#B	BA#A	BA#B	PA
pH	6.08	6.12	5.98	6.43	6.71
Electrical conductivity (mmhos/cm)	0.780	0.381	0.186	0.136	0.086
Organic carbon (%)	0.72	0.23	0.48	0.50	0.99
Available nitrogen (kg/ha)	40.77	18.82	15.68	21.95	25.09
Available phosphorus (kg/ha)	0.47	0.15	0.07	0.24	0.84
Available potassium (kg/ha)	336.00	259.84	210.56	188.16	448.00
Cation exchange capacity (meq/100 g)	4.92	2.24	1.62	1.40	39.65
DTPA extractable elements (ppm)					
Fe	0.048	BDL	0.084	0.032	12.496
Cu	1.556	0.822	0.866	0.790	0.488
Mn	0.688	0.128	BDL	BDL	0.778
Zn	1.640	4.960	0.674	0.546	0.538
Pb	0.310	BDL	0.046	BDL	0.060
Ni	0.358	0.804	0.674	0.772	0.600
Cr	BDL	BDL	BDL	BDL	BDL
Cd	0.192	0.162	BDL	BDL	BDL
Co	0.150	0.168	0.212	BDL	0.196
Ultimate analysis (%)					
Carbon	10.97	8.93	11.34	6.59	6.30
Hydrogen	–	–	–	–	0.40
Sulfur	0.08	0.10	0.03	0.10	0.02
Nitrogen	0.47	0.13	0.43	0.09	0.29
Oxygen (by diff.)	88.48	90.84	88.20	93.22	92.99

capacity (CEC), calcium carbonate, ultimate analysis, and DTPA extractable elements.

The pH of the samples varied from 5.98 to 6.71. Electrical conductivity varied from 0.086 to 0.780 mmhos/cm. Organic carbon varied from 0.23 to 0.99%. Available nitrogen varied from 15.68 to 40.77 kg/ha. Available phosphorus and potassium varied from 0.07 to 0.84 kg/ha and 188.16 to 448.00 kg/ha respectively. The cation exchange capacity (CEC) of the samples varied from 1.40 to 39.65 meq/100 g. In all cases except pond ash CEC was below 5 meq/100 g. Calcium carbonate percentage was found to vary from 4.0 to 10.0%. Lime requirement test for the CCR was also done. As the pH of the buffer suspensions was above the one given in the chart, no lime requirements were observed for the sample under study.

The observation of the ultimate analysis in terms of CHNS is also given in the Table 17. Carbon content varied from 6.30 to 11.34%. Nitrogen varied from 0.09 to 0.47% and sulfur varied from 0.02 to 0.10%. In fact, carbon percentage on average was less than 10%, nitrogen was around 0.3% and sulfur less than 0.10%.

The results of the micronutrients and the heavy metals study are given in Table 17. The value of the bio-available (DTPA) extractable Fe, Mn, Zn, and Cu ranged from BDL to 12.496, BDL to 0.778, 0.538 to 4.960, and 0.488 to 1.556 ppm respectively. Characterization of CCRs for nutrients has indicated that the CCR is a source of N, P, K, Fe, Cu, Mn, and Zn. The presence of heavy metals as Pb, Ni, Co, and Cd ranged from BDL to 0.310, 0.358 to 0.804, BDL to 0.212, and BDL to 0.192 ppm respectively. Heavy metals as Cr were reported as BDL.

Leaching Characteristics

Open Column Percolation Experiments

The summarized results of analysis of BTPS leachates are presented in Table 18. pH of the leachates obtained from the CCR samples of BTPS were observed in the range 5.70–10.51. These were mostly within the permissible limit as per IS: 2490 except in the case of FA#A from 300 to 600 days pH was above the permissible limit. Most of the time pH was in the alkaline range. Conductivity of the ash samples showed decreasing trend with time with high value in the initial study period. Conductivity varied between 0.026 and 1.303 mmhos/cm. TDS of the ash

Table 18 Summary of the leachate analysis (open column percolation experiment) of BTPS CCR samples

Parameters	FA#A	FA#B	BA#A	BA#B	PA	(IS: 2490, 1981)	
						Inland surface water	On land for irrigation
pH	5.97–10.51	5.82–9.10	5.80–9.50	5.70–8.99	5.86–9.03	5.5–9.0	5.5–9.0
Conductivity	0.042–0.750	0.037–0.820	0.125–1.303	0.026–0.852	0.052–0.920	–	–
TDS	21–375	19–410	63–652	13–426	30–460	2100	–
Iron	BDL–0.740	BDL–1.220	BDL–1.924	BDL–0.762	BDL–1.369	–	–
Lead	BDL–0.420	BDL–0.396	BDL–0.462	BDL–0.700	BDL–0.490	0.1	–
Magnesium	BDL–15.53	0.039–38.00	BDL–58.33	0.193–40.00	0.065–44.00	–	–
Calcium	1.00–103.92	0.265–189.20	0.342–54.83	0.726–44.00	0.798–102–20	–	–
Copper	BDL–0.190	BDL–0.068	BDL–0.246	BDL–0.482	BDL–0.090	3	–
Zinc	BDL–0.380	BDL–0.372	BDL–0.274	BDL–1.045	BDL–1.529	5	–
Manganese	0.009–0.057	0.010–0.105	0.007–0.148	0.008–0.039	0.007–0.076	–	–
Sodium	3–56	3–49	2–51	3–37	3–47	–	60
Potassium	2–42	2–36	2–26	2–21	2–33	–	–

Note Cr, Ni, Co, Cd, Se, Al, Ag, As, B, Ba, V, Sb, Mo, Hg were reported as BDL in the samples
BDL Below Detectable Limit; Concentration of Elements in mg/l; *TDS* in ppm; Conductivity in mmhos/cm

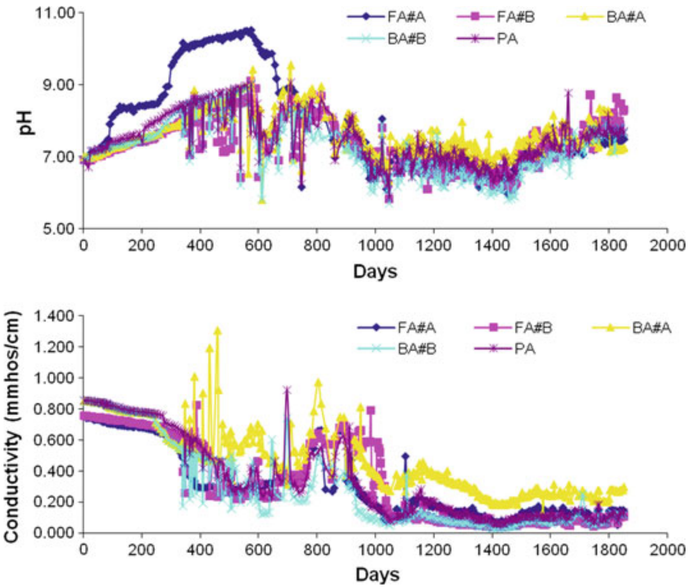
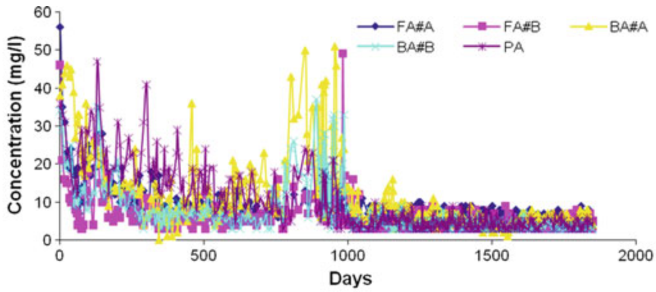


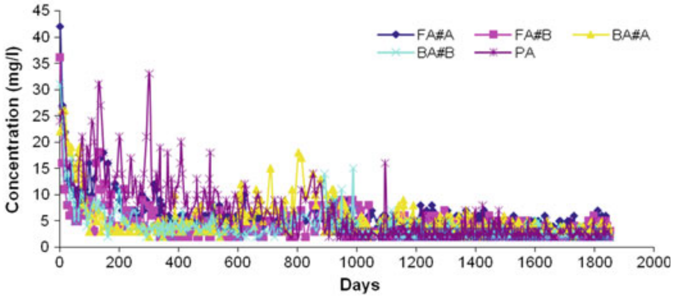
Fig. 5 Open column leachate analysis for pH and conductivity

samples varied between 13 and 652 ppm. TDS was observed within the permissible limits as per IS: 2490 as can be seen from the Table 16. Figure 5 gives the plot of pH and conductivity with time for the BTPS CCR samples.

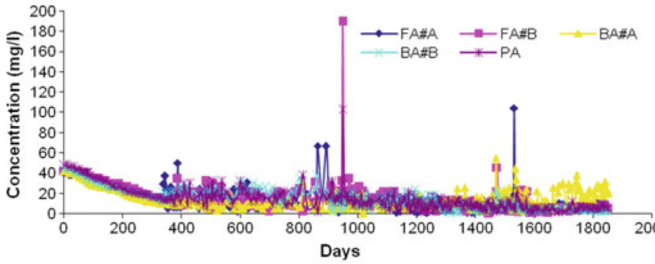
Of the total 23 elements studied for leaching only nine such as, iron, lead, magnesium, calcium, copper, zinc, manganese, sodium, and potassium were observed in the leachates. Iron varied from BDL to 1.904, lead from BDL to 0.700, magnesium from BDL to 44.00, calcium from 0.265 to 189.20, copper from BDL to 0.482, zinc from BDL to 1.529, manganese from 0.007 to 0.148, sodium from 2.00 to 56.00, and potassium from 2.00 to 42.00 mg/l, respectively. Calcium, magnesium, sodium, and potassium showed regular leaching and were observed during the entire period of study. Others showed intermittent leaching. Others, such as, chromium, nickel, cobalt, cadmium, selenium, aluminum, silver, arsenic, boron, barium, vanadium, antimony, molybdenum and mercury in the leachates were below the detection limit in the entire study period. Tests results have shown the presence of micro as well as macronutrients in the leachates. Figure 6 gives the leaching plots for four surficial elements that were found in the leachates of open column percolation experiments.



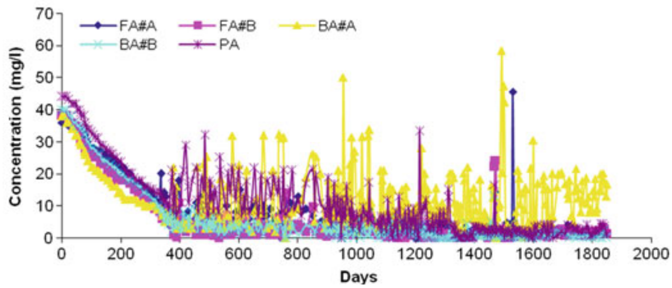
(i) Open Column Leachate Analysis for Sodium



(ii) Open Column Leachate Analysis for Potassium



(iii) Open Column Leachate Analysis for Calcium



(iv) Open Column Leachate Analysis for Magnesium

Fig. 6 Open column leachate analysis for **i** Sodium; **ii** Potassium; **iii** Calcium and **iv** Magnesium

Table 19 Summary of the leachate analysis (acid digest test) of BTPS CCR samples

Parameters	FA#A	FA#B	BA#A	BA#B	PA	(IS: 2490, 1981)	
						Inland surface water	On land for irrigation
Iron	52.39	82.41	79.56	152.90	613.60	–	–
Lead	BDL	BDL	0.017	BDL	BDL	0.1	–
Magnesium	3.127	3.579	8.253	9.591	29.246	–	–
Calcium	2.80	4.00	8.80	6.50	25.50	–	–
Copper	0.075	0.094	0.068	0.077	0.359	3	–
Zinc	0.203	0.276	0.154	0.073	0.739	5	–
Manganese	0.984	0.638	0.796	1.329	0.906	–	–
Sodium	28.10	24.60	25.00	25.40	2.10	–	60
Potassium	1.7	7.6	5.2	7.0	13.5	–	–
Chromium	BDL	0.760	BDL	0.375	2.836	2	–
Nickel	0.108	0.118	0.173	0.070	0.483	3	–

Note Co, Cd, Se, Al, Ag, As, B, Ba, V, Sb, Mo, Hg were reported as BDL in the samples
BDL Below Detectable Limit; Concentration of Elements in mg/l; *TDS* in ppm; Conductivity in mmhos/cm

Acid Digest Test

The summarized results of analysis of BTPS leachates are presented in Table 19. Of the total 23 elements studied for leaching only eleven such as, iron, lead, magnesium, calcium, copper, zinc, manganese, sodium, potassium chromium and nickel, were observed in the leachates. Iron varied from 52.39 to 613.60, lead from BDL to 0.017, magnesium from 3.127 to 29.246, calcium from 2.80 to 25.50, copper from 0.068 to 0.359, zinc from 0.073 to 0.739, manganese from 0.638 to 1.329, sodium from 2.10 to 28.10, potassium from 1.70 to 13.50, chromium from BDL to 2.836 and nickel from 0.070 to 0.483 mg/l, respectively. Others, such as, cobalt, cadmium, selenium, aluminum, silver, arsenic, boron, barium, vanadium, antimony, molybdenum, and mercury in the leachates was below the detection limit in the entire study period. Tests results have shown the presence of micro as well as macronutrients in the leachates. Chromium and nickel were also observed in the leachate of acid digest test.

24-h Shake Test

The summarized results of analysis of BTPS leachates obtained from 24-h Shake test are presented in Table 20. pH of the leachates obtained from the CCR samples of BTPS were observed in the range 5.47–6.38. This was within the permissible limit as per IS: 2490. pH was in the neutral range. Conductivity varied between

Table 20 Summary of the leachate analysis (ASTM 24-h shake test) of BTPS CCR samples

Parameters	FA#A	FA#B	BA#A	BA#B	PA	(IS: 2490, 1981)	
						Inland surface water	On land for irrigation
pH	5.67	6.22	6.38	6.06	5.47	5.5–9.0	5.5–9.0
Conductivity	0.198	0.096	0.054	0.041	0.084	–	–
TDS	99	48	27	21	42	2100	–
Iron	0.071	0.045	0.096	0.216	0.155	–	–
Lead	BDL	BDL	BDL	BDL	BDL	0.1	–
Magnesium	13.19	3.15	1.28	0.92	2.14	–	–
Calcium	6.34	3.37	1.64	0.42	2.67	–	–
Copper	BDL	BDL	BDL	BDL	0.014	3	–
Zinc	0.032	0.020	0.010	0.011	0.044	5	–
Manganese	BDL	0.031	BDL	BDL	BDL	–	–
Sodium	64.30	39.80	72.80	72.70	6.20	–	60
Potassium	4.50	2.80	1.80	1.70	3.76	–	–

Note Cr, Ni, Co, Cd, Se, Al, Ag, As, B, Ba, V, Sb, Mo, Hg were reported as BDL in the samples
BDL Below Detectable Limit; Concentration of Elements in mg/l; *TDS* in ppm; Conductivity in mmhos/cm

0.041 and 0.198 mmhos/cm. TDS of the ash samples varied between 20 and 99 ppm. TDS was observed within the permissible limits as per IS: 2490 as can be seen from the Table 18.

Of the total 23 elements studied for leaching only seven, such as, iron, magnesium, calcium, zinc, manganese, sodium, and potassium were observed in the leachates. Iron varied from 0.045 to 0.216, magnesium from 0.92 to 13.19, calcium from 0.42 to 6.34, zinc from 0.010 to 0.032, manganese from BDL to 0.031, sodium from 6.20 to 72.80, and potassium from 1.70 to 4.50 mg/l, respectively. Others, such as, lead, copper, chromium, nickel, cobalt, cadmium, selenium, aluminum, silver, arsenic, boron, barium, vanadium, antimony, molybdenum and mercury in the leachates were observed to be below the detection limit. Tests result like open column percolation experiments indicates the presence of micro as well as macronutrients in the leachates.

Toxicity Characteristic Leachate Procedure (TCLP)

The summarized results of analysis of BTPS leachates collected through TCLP test are presented in Table 21. pH of the leachates obtained from the CCR samples of BTPS were observed in the range 4.25–5.08. Conductivity varied between 3.56 and 4.54 mS/cm. TDS of the ash samples varied between 1.78 and 2.27 ppt. Both

Table 21 Summary of the leachate analysis (TCLP test) of BTPS CCR samples

Parameters	FA#A	FA#B	BA#A	BA#B	PA	(IS: 2490, 1981)	
						Inland surface water	On land for irrigation
pH	4.30	4.29	4.25	4.28	5.08	5.5–9.0	5.5–9.0
Conductivity	4.46	3.56	4.18	4.23	4.54	–	–
TDS	2.24	1.78	2.10	2.12	2.27	2100	–
Iron	0.077	0.089	0.022	0.053	0.037	–	–
Lead	BDL	BDL	BDL	BDL	BDL	0.1	–
Magnesium	61.020	7.512	5.831	4.850	8.317	–	–
Calcium	379.37	304.13	314.93	416.48	506.00	–	–
Copper	0.030	0.215	0.078	0.021	0.047	3	–
Zinc	0.799	2.140	1.950	1.280	0.670	5	–
Manganese	0.791	0.314	0.220	0.226	0.201	–	–
Sodium	1857	1452	1508	1595	1575	–	60
Potassium	11.60	8.10	7.80	6.20	11.88	–	–
Chromium	BDL	0.803	0.414	BDL	BDL	2	–
Nickel	0.381	0.112	1.819	0.080	BDL	3	–

Note Co, Cd, Se, Al, Ag, As, B, Ba, V, Sb, Mo, Hg were reported as BDL in the samples
BDL Below Detectable Limit; Concentration of Elements in mg/l; *TDS* in ppt; Conductivity in mS/cm

conductivity and TDS was observed at a higher level as can be seen from the Table 19.

Of the total 23 elements studied for leaching only ten, such as, iron, magnesium, calcium, copper, zinc, manganese, sodium, potassium, chromium and nickel were observed in the leachates. Iron varied from 0.022 to 0.089, magnesium from 4.850 to 61.020, calcium from 304.13 to 506.00, copper from 0.021 to 0.215, zinc from 0.670 to 2.140, manganese from 0.201 to 0.791, sodium from 1452 to 1857, potassium from 6.2 to 11.88, chromium from BDL to 0.803, and nickel from BDL to 1.819 mg/l, respectively. Others, such as, lead, cobalt, cadmium, selenium, aluminum, silver, arsenic, boron, barium, vanadium, antimony, molybdenum, and mercury in the leachates were below the detection limit. The study has indicated that the leachates had higher concentration of sodium, calcium, and magnesium in all the four samples.

Comparative Study of the Leachates from the Laboratory Study and Disposal Sites

Table 22 gives the summarized results of the pond ash leachates obtained in the laboratory from different methods. Table 23 shows the summarized results of the analysis of the leachates generated in the laboratory simulating field condition (Open Column Percolation Experiments) and the leachates collected from the disposal site (pond ash effluents) of BTPS.

The study of the ash pond effluents has clearly shown the elements, such as, mercury, barium, vanadium, nickel, selenium, arsenic, cadmium, and lead to be below detectible limits. Trace elements, such as, chromium and cobalt was also observed at the BDL level. Zinc, manganese, cobalt, and chromium were present in low concentration in the effluent samples. pH, conductivity, and TDS as well as concentration of element in the ash pond effluents were on a bit higher side but within the permissible limits as per IS: 2490. Calcium, magnesium, sodium, and potassium were observed at higher concentration compared to other elements in the ash pond effluents as well as in case of leachates from open column percolation experiments.

Table 22 Summarized results of the pond ash leachates from different methods

Parameters	Open column percolation test	ASTM 24-hr shake test	Acid digest test	Toxicity characteristic leaching procedure (TCLP)	(IS: 2490, 1981)	
					Inland surface water	On land for irrigation
pH	5.49–10.51	5.47–7.22	–	4.25–5.20	5.5–9.0	5.5–9.0
Conductivity	0.023–1.954	0.034–0.198	–	3.56–5.44	–	–
TDS	12–977	17–99	–	1.78–2.73	2100	–
Iron	BDL–1.924	BDL–1.257	9.37–613.60	BDL–0.091	–	–
Lead	BDL–0.700	BDL–0.033	BDL–0.093	BDL–0.111	0.1	–
Magnesium	BDL–144.90	0.533–15.34	3.127–423.80	0.887–114.80	–	–
Calcium	BDL–189.20	0.42–19.43	2.66–149.60	304.13–538.97	–	–
Copper	BDL–0.482	BDL–0.014	BDL–0.359	0.021–0.215	3	–
Zinc	BDL–1.529	0.010–0.063	0.036–0.751	0.047–2.140	5	–
Manganese	BDL–0.724	BDL–0.031	0.241–6.287	0.067–0.791	–	–
Sodium	2.00–88.00	4.80–72.80	2.00–28.10	1452–1857	–	60
Potassium	2.00–42.00	1.00–6.20	2.00–37.10	4.49–26.10	–	–
Chromium	BDL	BDL	BDL–3.621	BDL–0.803	2	–
Nickel	BDL	BDL	BDL–0.483	BDL–1.819	3	–
Cobalt	BDL	BDL	BDL–0.058	BDL	–	–
Cadmium	BDL	BDL	BDL–0.275	BDL	2	–

Note Se, Al, Ag, As, B, Ba, V, Sb, Mo, Hg were reported as BDL in the samples
BDL Below Detectable Limit; Concentration of Elements in mg/l; *TDS* in ppm; Conductivity in mmhos/cm. *Note* In case of TCLP TDS is in ppt and Conductivity in mS/cm

Table 23 Summary of the leachate analysis of pond ashes

Parameters	BTPS		(IS: 2490, 1981)	
	OPEC for pond ash	Ash pond effluents (disposal site)	Inland surface water	On land for irrigation
pH	5.86–9.03	6.97–8.97	5.5–9.0	5.5–9.0
Conductivity	0.052–0.920	0.549–0.897	–	–
TDS	30–460	275–449	2100	–
Iron	BDL–1.369	0.113–3.634	–	–
Lead	BDL–0.490	BDL–0.158	0.1	–
Magnesium	0.065–44.00	0.077–55.00	–	–
Calcium	0.798–102–20	3.265–117.30	–	–
Copper	BDL–0.090	0.019–0.107	3	–
Zinc	BDL–1.529	0.765–1.754	5	–
Manganese	0.007–0.076	BDL–0.083	–	–
Sodium	3.00–47.00	5.00–37.00	–	60
Potassium	2.00–33.00	4.00–53.00	–	–

Note Cr, Ni, Co, Cd, Se, Al, Ag, As, B, Ba, V, Sb, Mo, Hg were reported as BDL in the samples
BDL Below Detectable Limit; Concentration of Elements in mg/l; *TDS* in ppm; Conductivity in mmhos/cm

In general, leachates of open column percolation experiment and ash pond effluents do not pose any environmental threat as far as leaching of trace elements/toxic metals are concerned. Results of open column percolation experiment and ash pond effluents are comparable as can be seen from the Tables 20 and 21. Open column percolation methodology can very well be relied upon for the long-term leaching study of CCRs compared to other methodologies discussed above. This is the best method that simulates the actual field condition, as one would observe in the field.

Conclusion

The study of physical properties of CCR samples has shown the suitability of the material like sand and thus these can be used as alternatives of sand for mine fills. The chemical characteristics of CCR samples have also established that the samples are sources of nutrients and that if these samples are used in soil having such deficiencies then the problems can be solved. Further leaching studies have tried to remove the apprehensions to a greater extent regarding contamination of ground and surface water due to trace/heavy element leaching. Both short term and long-term leaching study have been conducted simulating the field situation to understand the behaviour of disposed CCR samples and its effects on ground and surface water. The study of effluents collected from the ash pond site that was getting into the surface stream was also carried out to compare the actual results with the simulated one to establish the validity of laboratory study. Effect of harsh condition such as leaching in acidic and acid buffered environment which was least likely to encounter in the actual field situation was also done to study the mobility of some other elements. The concentration of trace and heavy elements was found to be well below the permissible limits as per IS: 2490. Overall, the study has shown no environmental hazards due to leaching and that these can be used for their bulk utilization especially for reclamation of mined out areas in and around the vicinity of the power plant under study.

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Influence of Semi-arid Climate on Characterization of Domestic Wastewater

Vinod Kumar Tripathi and Pratibha Warwade

Abstract Rapid urbanization causes increase in urban population. Over half of the world's population lives in cities. By 2050, seven out of every 10 people will be city dwellers. India is a part of this global trend. Nearly 28% of India's population lives in cities and this is expected to increase to 41% by the year 2020. Urban population will generate huge amount of domestic wastewater (WW). The promising alternative for disposal of wastewater is its utilization for irrigation after treatment. To utilize domestic wastewater, it is vital to generate the information about of different quality parameters and their variations due to seasonal weather conditions. Physiochemical water quality parameters (EC, pH, turbidity, total solids, NH_4–N, NO_3–N, P, K, Na, Ca, Mg, CO_3, HCO_3 and heavy metals (Cu, Zn, Mn, Fe, Cr, Mo) of domestic wastewater were determined for the period of one year. The data set is used to present spatial and temporal variations of the domestic wastewater quality. Identification of wastewater quality parameters responsible for temporal variations due to effect of semi-arid climate was done through multivariate cluster analysis. Correlation study between the identified parameters was also conducted. Wastewater was slightly acidic in nature with mean value of pH 6.87. Highest concentration was observed for total solids. Concentration of ammoniacal nitrogen was higher than nitrate nitrogen; similarly bicarbonate concentration was higher in comparison to carbonate concentration. In the category of heavy metals highest concentration with mean value 0.98 mg l^{-1} was observed with iron and least with molybdenum with mean value 0.01 mg l^{-1}. Most of the water quality parameters concentration was higher during summer season, moderate during winter season and least during rainy season. Correlation study between quality parameters shows the presence of bicarbonate with calcium and magnesium.

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Presence of calcium, magnesium and bicarbonate play important role for the quantum of total solids in domestic wastewater. Wastewater quality was under safe limit throughout the year in terms of irrigation water quality indices SAR and Mg/Ca ratio. But it was under safe to moderate limit in terms of residual sodium carbonate (RSC) index. Cluster analysis divides the months of a complete year in three clusters. First cluster have six months (July, August, September, October, November and December), second cluster have four months (January, February, March and April) and third cluster have two months (May and June).

Introduction

Worldwide unsystematic and untreated disposal of wastewater is the biggest challenge to environmental scientist and engineers. This problem started long back but intensified during the last few decades, and now the situation has become alarming in India (Girija et al. 2007). During the past three decades, the effects of domestic wastewater and effluents, the point source pollution, on the water quality of canals, streams and rivers have received some attention but very little attention has been reported about the sewage water quality of the receiving water bodies. The input of large quantities of nutrients mainly nitrates and phosphates into river waters caused eutrophication and its related effects (House and Denison 1997). These nutrients particularly phosphorus is often the limiting nutrient in such systems (Neal et al. 2002). Sewage effluent containing sulphate may produce hydrogen sulphide that in the form of sulphur is poisonous; so the untreated sewage should be treated in the sewage treatment plant (STP) before letting into the receiving water bodies.

Rapid trend of global urbanization causes wastewater generation to the tune of 38254 Million Litre Per Day (MLD) from Class I cities and Class II towns of India (CPCB 2005). Wastewater is a mixture of domestic effluent consisting of black-water (excreta, urine and fecal sludge, i.e. toilet wastewater), grey water (kitchen and bathing wastewater), water from commercial establishments and institutions, hospitals, industrial effluent. Contribution of different sources, water utilized in those sources affects the quality of wastewater. Its quality in drain is dependent upon rainfall, soil properties, agricultural activities, exploitation of water resources and kind of industries. The quantitative contribution of different sources also affects the quality of mixed wastewater. The indiscriminate release of sewage has severely deteriorated the aquatic environment leading nutrient enrichment of the receiving water body (Akpan 2004), affecting environment health worldwide. Indian rivers and canals especially in their urban portions are grossly polluted due to release of domestic and industrial wastewater (CPCB 2005; Girija et al. 2007).

Worldwide wastewater is emerging as an alternative water resource for irrigation. The main driving forces for the growth of wastewater irrigation are global scarcity of freshwater resources with the problem of wastewater disposal. Estimates on the extent of this practice range widely, but figures point at about 20 million ha of land irrigated in this way, most of it in Asia, Latin America and sub-Saharan Africa (Keraita et al. 2008). In the world more than 4–6 million hectares (M ha) are irrigated with wastewater or polluted water (Jimenez and Asano 2008; UNHSP 2008). A separate estimate indicates 20 million ha globally, an area that is nearly equivalent to 7% of the total irrigated land in the world (WHO 2006). The wastewater for irrigation poses risk to the environment and endangering the health of the farmers and produce consumers.

Studies on water quality in Indian rivers receiving municipal sewage and effluents have been carried out by many earlier investigators, e.g. River Ganga (Sinha et al. 1991) and Kathajodi River in Cuttack city in Orissa (Das and Acharya 2003; Girija et al. 2007) also reported the water quality assessment of an urban stream polluted with untreated effluents at Guwahati in Assam (India). The present study assessed the seasonal effects of point source pollution, untreated and treated sewage on the water quality parameters. It is imperative to characterize domestic wastewater resources on the basis of physiochemical properties with respect to time for effective pollution control and better water resource management. This results in huge and complex data matrix comprised of a large number of physiochemical parameters, which are often difficult to interpret and draw meaningful conclusions (Dixon and Chiswell 1996).

In the present paper, physiochemical water quality parameters of domestic wastewater were determined. The data set is used to present spatial and temporal variations of the domestic wastewater quality. Identification of wastewater quality parameters responsible for temporal variations due to effect of semi-arid climate was done through multivariate cluster analysis.

Materials and Methods

Study Area

Study was conducted at Indian Agricultural Research Institute (IARI), Pusa, New Delhi, India, which is located within 28° 37′ 22″N and 28° 39′N latitude and 77° 8′ 45″E and 77° 10′ 24″E longitude covering an area of about 475 ha at an average elevation of 230 m above mean sea level. On east side Arawali range indicates the highest point while on western side natural drain forms the last western boundary of the farm. Soil of the research farm is alluvial in origin and sandy loam in texture (Typic mixed hypothermic ustocrept). Water table in the farm area is about 5–7 m (Natrajan et al. 2004). The climate of IARI is subtropical, semi-arid with hot dry summer and cold winter and the area falls in Agro-eco-region-IV (Semi-arid with alluvium derived soil). The mean annual temperature is 24 °C with months of May and June having 30 years normal maximum of 40 °C, and January with the normal minimum temperature of 14 °C. The minimum temperature dips as low as 1 °C. The mean annual rainfall is 710 mm of which as much as 75% is received during the monsoon season (July to

September). The domestic wastewater samples were collected from natural drain passing through IARI near the western boundary. The contribution of wastewater in this drain is urban runoff and domestic effluent from group housing and hostels.

Water Sampling and Preservation

Domestic wastewater samples were collected from the drains in each month during the study period (January to December, 2009). Collection of wastewater samples from the drain was done across the drain at the depth of 15 cm below the surface and at three points then mixed. The preservation and transportation was performed according to the standard methods (APHA 2005).

Analysis of Wastewater Samples

Wastewater samples were analyzed for the level of pH, electrical conductivity (EC), total solids (dissolved and undissolved), turbidity, total soluble salts (TSS), ammoniacal nitrogen (NH_4–N), nitrate nitrogen (NO_3–N), phosphate (P), potassium (K), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), carbonate (CO_3^-), bicarbonate (HCO_3^-), copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), chromium (Cr) and molybdenum (Mo). All the water quality parameters were expressed in milligram per litre (mg l^{-1}), except EC (dS m^{-1}). To prepare all the reagents analytical grade chemicals and double glass distilled deionized water were used during analysis. The glassware was washed with dilute nitric acid followed by distilled water. Using few water quality parameters temporal variation in three indices namely sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and Mg/Ca ratio were estimated. SAR and RSC were estimated using Eqs. 1 and 2.

$$SAR = \frac{Na^+}{\left[\frac{Ca^{2+} + Mg^{2+}}{2}\right]^{1/2}} \tag{1}$$

$$RSC\left(mel^{-1}\right) = \left(CO_3^{2-} + HCO_3^-\right) - \left(Ca^{2+} + Mg^{2+}\right) \tag{2}$$

Statistical Analysis

Descriptive statistical parameters were analyzed for domestic wastewater quality parameters. To get the range of any quality parameter minimum and maximum values were analyzed. On the basis of total values for a particular parameter arithmetic mean was also determined. To estimate statistical dispersions from mean of any quality data standard deviation and standard error was calculated using MS Excel spread sheet.

Cluster Analysis

Clustering is a multivariate technique of grouping rows together that share similar values. It can use any number of variables. The variables must be numeric for which numerical differences makes sense. The identification of these clusters goes a long way towards characterizing the distribution of values. Hierarchical agglomerative clustering (a combining process) was applied on entire parameters of water quality. The method starts with each point (row) as its own cluster. At each step the clustering process calculates the distance between each cluster (monthly, row) and combines the two clusters (month) that are closest together. This combining continues until all the points (month) are in one final cluster. The number of clusters can be chosen that seems right and cuts the clustering tree at a given point. The combining record is portrayed as a tree, called a dendrogram, with the single points as leaves, the final single cluster of all points as the trunk, and the intermediate cluster combinations as branches.

Results and Discussion

Physiochemical Properties of Domestic Wastewater

Descriptive statistics (minimum, maximum, mean, standard deviation and standard error) of WW quality for 20 parameters is presented in Table 1. Maximum electrical conductivity (EC) 1.90 dS m^{-1} was observed with small standard error (SE) as shown in Table 1. pH is the indicator of acidic and alkaline condition of water status. pH was in the range of 6.6–7.32 with the mean of 6.87. It shows the acidic nature of WW. A pH range of 6.5–8.5 is recommended by BIS (1986) and CPCB (2005) for irrigation purpose. Maximum standard deviation of 211 mg l^{-1} and standard error of 60.90 was observed for total solids. Maximum and minimum variation was also higher with total solids. It may be due to presence of more contaminants like heavy metals and soil particles from the drains. Turbidity of WW was high and in the range of 33–68 NTU. The higher turbidity of WW was due to presence of surface runoff and foreign particles from anthropogenic pollution and stream bed material.

Sodium content in WW was in the range of 109–226 mg l^{-1}. Ammoniacal nitrogen (NH_4–N) in WW was observed in the range of 19.7–37.5 mg l^{-1} but nitrate nitrogen (NO_3–N) was in the range of 3.19–8.31 mg l^{-1}. Higher content of

Table 1 Descriptive statistics of wastewater quality parameters

Quality parameters	Unit	Minimum	Maximum	Mean	Standard deviation	Standard error
EC	dS/m	1.63	1.90	1.74	0.08	0.02
pH		6.60	7.32	6.87	0.21	0.06
Total solids	mg/l	733	1297	989	211	60.90
Turbidity	NTU	33	68	55.33	11.46	3.31
TSS	mg/l	1043	1217	1116	52	15.11
NH_4–N	mg/l	19.72	37.52	28.66	5.42	1.57
NO_3–N	mg/l	3.19	8.31	5.45	1.54	0.45
P	mg/l	1.18	11.36	6.91	3.21	0.93
K	mg/l	15.80	60.70	30.00	13.44	3.88
Na	mg/l	108.80	226.11	169.94	33.30	9.61
Ca	mg/l	68.00	136.00	94.67	20.84	6.02
Mg	mg/l	25.20	38.40	32.13	4.52	1.31
CO_3	mg/l	12.00	78.00	43.50	22.76	6.57
HCO_3	mg/l	440.00	610.00	516.13	53.76	15.52
Cu	mg/l	0.03	0.19	0.09	0.05	0.01
Zn	mg/l	0.01	0.11	0.05	0.02	0.01
Mn	mg/l	0.03	0.16	0.08	0.04	0.01
Fe	mg/l	0.25	2.00	0.98	0.62	0.18
Cr	mg/l	0.00	0.46	0.06	0.13	0.04
Mo	mg/l	0.00	0.01	0.01	0.00	0.00

ammoniacal nitrogen in WW was due to conversion of nitrate nitrogen into ammoniacal nitrogen under reduction process. Lower dissolved oxygen in WW is also evident for this fact. This represents influence of agricultural runoff from the soil as nitrogenous fertilizers are extensively used in this region. Mean Phosphorus (P) content in WW was 6.91 mg l^{-1}. It may be due to presence of industrial effluent, sewage water and urban runoff. The similar result was observed by Goldman and Horne (1983). Potassium (K) content was higher in comparison to phosphorus (P) content. Calcium (Ca) content was higher than Magnesium (Mg) content but bicarbonate content was higher than carbonate content. It shows the presence of calcium bicarbonate and magnesium carbonate in WW. It was due to conversion of carbonate into bicarbonate under slightly acidic pH condition. The mean value of pH was 6.6 for WW.

Highest copper content of 0.19 mg l^{-1} was observed in WW with mean value 0.08 mg l^{-1}. It is evident from the fact that urban industries are contributing their poor quality effluent in WW. Highest mean value 0.04 of Zinc (Zn) was observed for WW due to higher metal content in urban runoff and industrial wastewater stream joining the WW drain. Manganese (Mn) content with mean value 0.078 mg l^{-1} was detected in WW. Iron (Fe) content was highest among heavy metals (Cu, Zn, Mn, Mo, Cr, Fe) with mean value 1 mg l^{-1}. Maximum concentration of chromium (Cr) was 0.46 mg l^{-1}.

Presence of heavy metals responsible for physiological effect as on kidney, digestive system, circulatory system, nervous system, etc. and various other organs and systems of the body. High level of copper may lead to chronic decease anaemia, ingesting copper may also implicated in coronary heart disease and high blood pressure.

Temporal Variation in Water Quality

Seasonal variation in domestic wastewater (WW) quality is presented in Fig. 1. Electrical conductivity (EC) was constant in summer season with little variation. It may be the reason that supply for domestic and industrial water consumption was from the Yamuna river having lower EC in other than summer months. There is another possibility for lower water supply and higher evaporation from drainage channels causes increase in concentration of salts. pH of wastewater also followed the same trend, i.e. higher hydrogen ion concentration during rainy season, least during summer season and moderate during winter season. In summer season maximum exploitation of GW causes such increment. pH of WW was lower than GW for entire year due to addition of acidic nature industrial effluent and surface runoff. Total solid (TS) of WW was observed higher in Nov, Dec and Jan to May. It may be due to higher concentration of pollutant. In summer season highest concentration of TS, 1300 mg l^{-1} was observed. Turbidity (T) in WW was in the range of 33–68 NTU. It may be due to uneven distribution of rainfall in the catchment area of WW drainage channel and higher amount of rainwater added to the WW. Total soluble salt (TSS) concentration is directly related to electrical conductivity of water. Hence, similar seasonal variation was observed for EC and TSS.

Sodium (Na) content was higher during summer season with wastewater due to higher concentration and excess exploitation of GW. It was added to WW after utilization in domestic and industrial sector. Ammoniacal nitrogen was higher during winter season (November–February) but after that the concentration was reduced. It may be due to reduction in volatilization loss and lower demand of fertilizers by microorganism because there growth rate decreases due to effect of drop in temperature during winter season. Maximum nitrate nitrogen content 8.3 mg l^{-1} was observed in the month of February of winter season but ammoniacal nitrogen was always higher in comparison to nitrate nitrogen for all the seasons of a year. The nitrate ion is usually derived from anthropogenic sources like untreated domestic sewage and its effluents, agriculture watershed and storm water containing nitrogenous compounds (Luiza et al. 1999). Ravindra et al. (2005) also reported NO_3 in winter and summer seasons were 5 and 9 mg/l, respectively, in the Yamuna river in Haryana before entering to Delhi. During the study P and K concentrations were higher during the month of May and June in summer season with P, 11.4 mg l^{-1} and K, 62.6 mg l^{-1}. It may be due to slow rate of flow and stagnant water in WW drains.

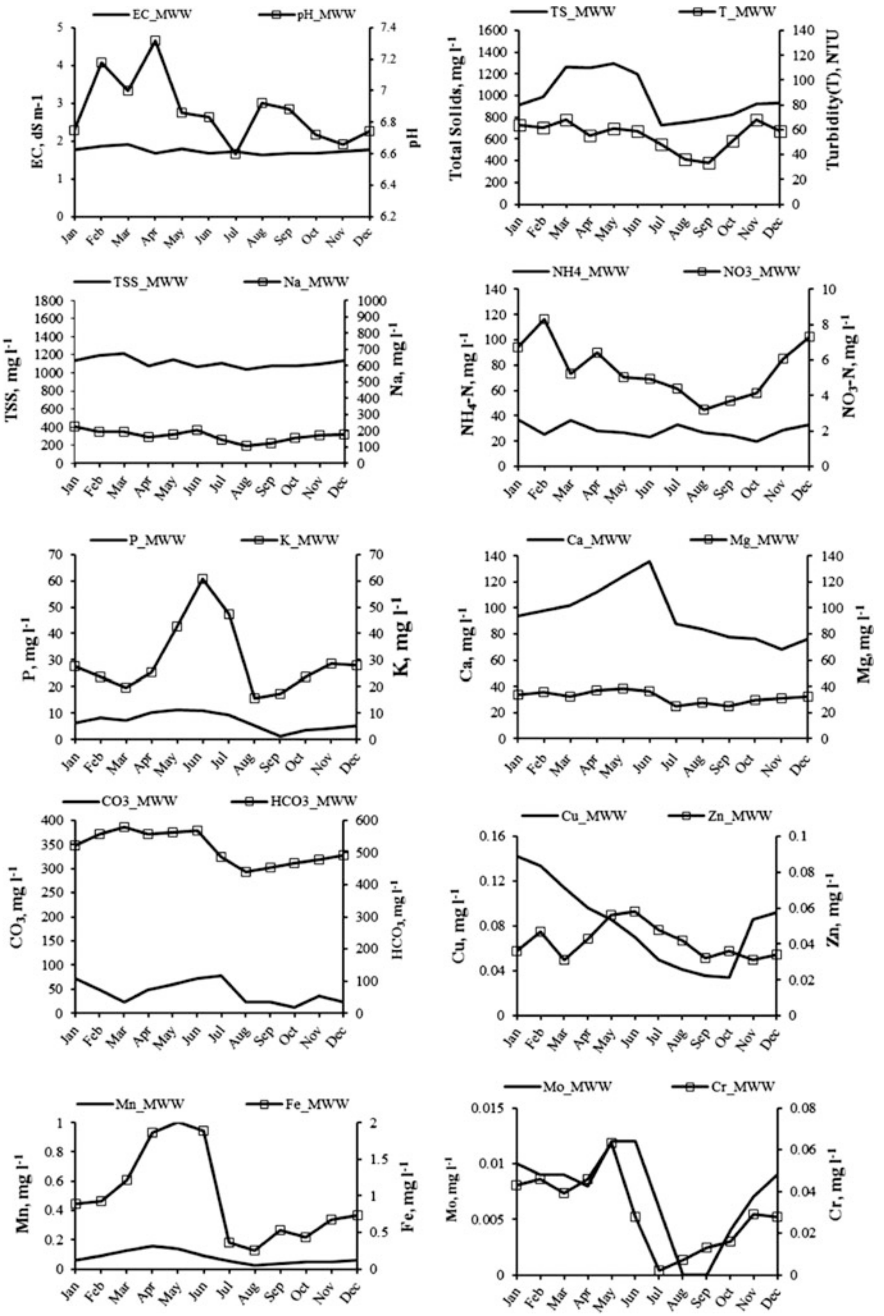

Fig. 1 Temporal variation in wastewater quality

Higher concentration of Calcium and Magnesium was observed during summer season and starting of the rainy season. The main reason for higher concentration in July and August can be explained by the runoffs from agricultural fields and watersheds affecting the quality of water. Carbonate and bicarbonate followed the identical trend for seasonal variation with higher concentration during winter and summer and lower during rainy season. It may be due to dilution of WW after addition of good quality freshwater in the form of rainfall. They are also highly correlated. Presence of metals (Cu, Zn, Mn, Fe, Mo and Cr) with maximum value was observed during summer, moderate during winter and minimum during rainy season.

Temporal Variation in Water Quality Indices

Water quality indices viz. Sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and Mg/Ca ratio and its limit for safe irrigation is presented in Fig. 2. SAR was less than 10 for the entire year of study. Hence, on the basis of index SAR the WW can be used directly for irrigation (Richards 1954) without any intervention. The RSC is important for carbonate and bicarbonate rich irrigation waters. It indicates their tendency to precipitate Ca^{2+} as $CaCO_3$. In the present study lower carbonate content and higher bicarbonate was observed in WW. Richards (1954) has categorized RSC (mel^{-1}) under safe (RSC < 1.25), moderate (RSC 1.25–2.5) and unsafe (RSC > 2.5) in the context of irrigation. On the basis of RSC, WW were suitable for irrigation, except during the month of July. In July WW were unsafe since rainfall causes maximum pollution into WW drain as runoff. Another point of view irrigation requirement will be minimum or nil during July as rainy month. Behaviour of calcium and magnesium is not same in the soil system. Magnesium deteriorates soil structure particularly when water has dominated sodium so much that it becomes highly saline. High level of Mg usually promotes higher developments of exchangeable Na in the irrigated soils. Based on the ratio of Mg to Ca, waters were categorized safe if ratio is less than 1.5, moderate from 1.5 to 3.0, unsafe if more than 3.0 (Tandon 2005). Entire year Mg/Ca ratio was less than 1.5 shows its suitability for irrigation.

Temporal Similarity and Period Grouping

Cluster analysis applied to detect temporal similarity grouping of twelve months on the basis of water quality parameters for WW. The dendogram of cluster analysis is shown in Fig. 3. The clustering procedure generated three groups have similar characteristic features. Similarity in water quality has been shown through Cluster 1 (July, August, September, October, November and December) shows similar water quality during rainy season to mid-winter. After middle of the winter (January and

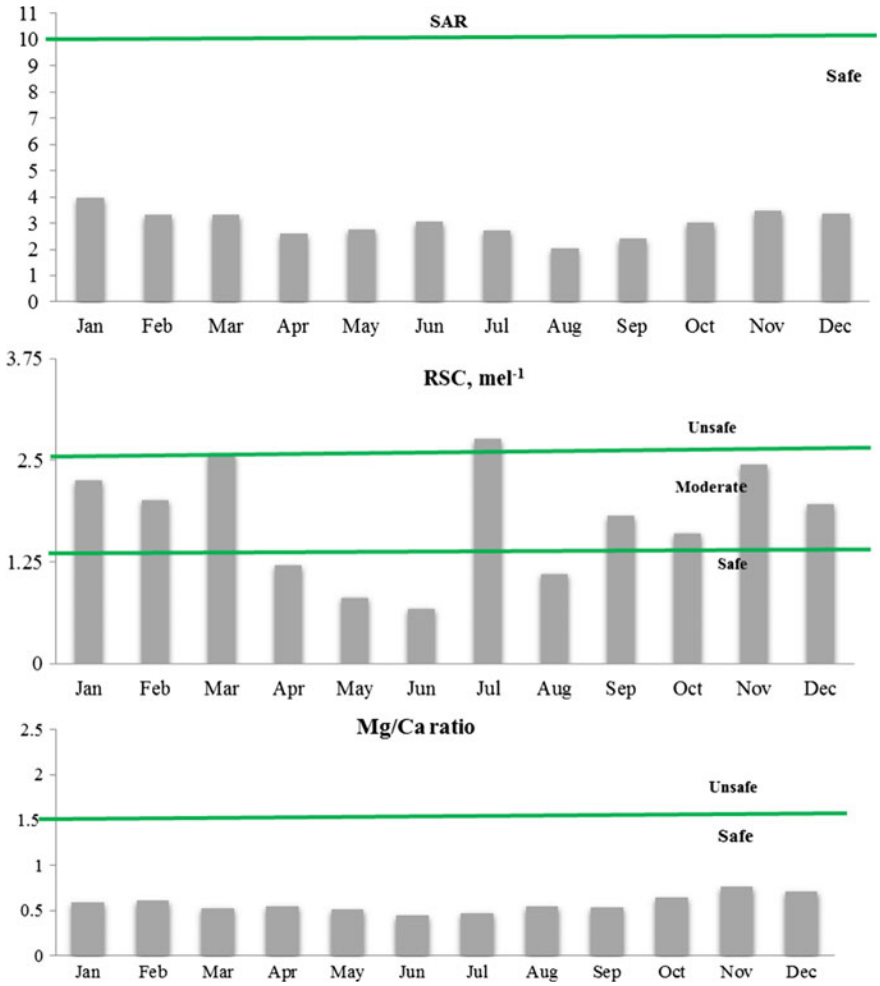

Fig. 2 Water quality indices (SAR, RSC and Mg/Ca ratio) and their limit for suitability to irrigation

February) and March, April shows Cluster 2. It means more pollutant (untreated sewage and industrial effluents) in WW made effect in water quality from January. Cluster 3 (May and June) is same due to unchanged weather condition. Spatial grouping on the basis of water quality by cluster analysis was performed by Singh et al. (2004) and Simeonova et al. (2003).

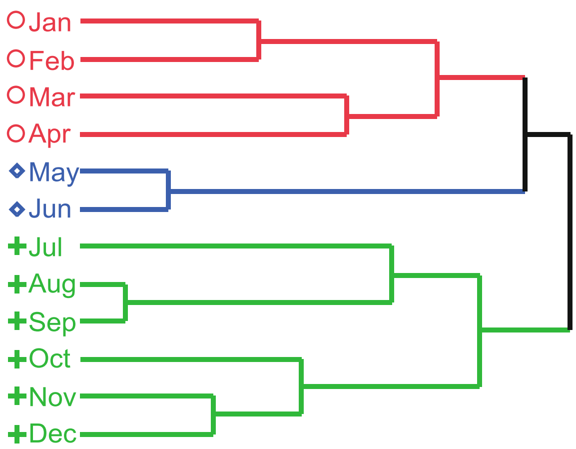

Fig. 3 Dendogram showing temporal similarity for WW through three clusters

Conclusions

Utilization of treated municipal wastewater for irrigation is a viable alternative to protect environment, save freshwater and saving of nutrients for plant production. It is indispensable to study the impact of semi-arid climate on domestic wastewater with respect to its quality parameters so that it can be used extensively for irrigation purpose in sustainable manner. The domestic wastewater passing through perennial drains was analyzed for different physiochemical properties (EC, pH, turbidity, total solids, NH_4–N, NO_3–N, P, K, Na, Ca, Mg, CO_3, HCO_3 and heavy metals (Cu, Zn, Mn, Fe, Cr, Mo). The spatio-temporal quality of wastewater shows acidic nature. Availability of major nutrients and micro elements in wastewater provides the opportunity for its use in irrigation to fulfill crop water and nutrient demand. It also provides the opportunity for alternative disposal of wastewater. Most of the water quality parameters concentration was higher during summer season, moderate during winter season and least during rainy season. Wastewater is under safe limit throughout the year in terms of irrigation water quality indices SAR and Mg/Ca ratio. Cluster analysis is useful to provide information about seasonal distribution of water quality data and showing the cluster of months with similar quality. Information generated from the present study will be useful for integrated water resources planning and management.

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Anomalous Features of Black Carbon and Particulate Matter Observed Over Rural Station During Diwali Festival of 2015

P.C.S. Devara, M.P. Alam, U.C. Dumka, S. Tiwari and A.K. Srivastava

Abstract Black carbon (BC) aerosol is the second most powerful climate forcing agent, ahead of methane, and second only to carbon dioxide, formed through the incomplete combustion of fossil fuels, bio-fuel and biomass, and is emitted in both anthropogenic and naturally occurring soot. In this communication, we present some interesting results of BC, particulate matter (PM), in conjunction with concurrent satellite and surface meteorological products, obtained during the recent Diwali festival episode of November 2015 over a rural station characterized by sparse population and complex terrain. This comprehensive study revealed (i) a clear diurnal variation of BC, PM_1, $PM_{2.5}$, and PM_{10} mass concentration with dual maxima (bimodal), one around early morning and the other around mid-night hours, due to emissions from traffic with minimum concentration around afternoon hours due to well-known planetary boundary-layer dynamics, (ii) the PM showed higher concentration (more than two-fold) during the festive period as compared to the pre- and post-festive periods, (iii) the aerosol optical depth (AOD) showed initially higher and subsequent dilution due to local meteorology, (iv) angstrom exponent (AE) showed larger values implying enhancement in fine-mode particles due to festive activity and (v) The NOAA-HYSPLIT air-mass back-trajectory analysis and CALIPSO satellite imageries portray contribution from the trans-boundary pollution through long-range transport mechanism. The results are explained by considering the terrain-induced meteorological conditions and local anthropogenic activities.

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Introduction

Firework displays during festive celebrations such as Diwali (festival of lights) can cause acute air pollution as they release various gases, particulate air pollutants, and toxic materials. Black carbon (BC) aerosol is one of the prominent constituent that is associated with these activities. BC also may act as cloud condensation nuclei, altering the size distribution and optical properties of clouds (Twomey 1977). BC aerosol surface can act as catalytic oxidation of SO_2 to sulfate and for the destruction of ozone (Disselkamp et al. 2000). Diwali is celebrated by cleaning and decorating homes with lights, oil lamps, and festive lights. A variety of pyrotechnics employed in these works produce various visual, light, sound, gas, and smoke effects. Most importantly, fireworks are set off by children and they mainly consist of rockets, Roman candles, sparkles, and wheels, etc. On this auspicious occasion, harmful gases and toxic substances are released into the environment by bursting fireworks. As a result, the RSPM (respirable suspended particulate material) levels go high as small particles are emitted. Moreover, to overcome shortage of electricity, generators by using diesel, coal that also cause air pollution. The BC particles are small enough (<1 μm), their presence in fireworks affects lungs, insomnia, heart, asthma, and bronchitis. Also, many children face accidents due to mishandling of fireworks and it causes burning, cutting, etc. Also, it has been observed that mortality and morbidity rate increases in Diwali period because of RSPM (Khaparde et al. 2012). Several researchers in India and elsewhere studied the impact of particulate matter and toxic gases released during celebrations like Diwali, etc. on short-term environmental air-quality degradation, negative effects on human health, and also on long-range climate change (for example, Devara et al. 2015; Betha and Balasubramanian 2013; Chatterjee et al. 2013; Thakur et al. 2010; Bach et al. 2001).

This paper mainly focuses on approaches followed for capturing mass concentration of various particulate matter, black carbon aerosols in particular, some of the most sensitive and representative of the influence of fireworks on environmental air quality, dispersion and transport phenomena, possible health impacts, and combat processes. The observed results over a typical rural station (Panchgaon) have been corroborated with in situ satellite measurements and attributed to the local meteorological and surrounding anthropogenic activities that are found to modulate the effects due to the Diwali celebration.

Measurement Site Description

The study site, Panchgaon (28.31°N, 76.90°E, 285 m above mean sea level), Haryana State, is a rural location, situated around 50 km from Delhi. This site is surrounded, in the northeast direction, by two cities, namely, Gurgaon (∼24 km) and Manesar (∼9.5 km) which possess several small- and large-scale industries,

Fig. 1 Map showing the observation location and sampling site

the study site receives pollution whenever the wind blows in the northeast sector. Its exact geographic location (indicated by donut symbol), and the Amity University Haryana campus along with the monitoring site (shown with asterisk symbol) are shown in Fig. 1. It is about 5 km away from the Delhi–Jaipur National Highway (NH8) in the northeast (NE) direction, and is enveloped by Aravalli hillocks of average elevation of about 200 m. Thus, the experimental site has complex topography with valley-like terrain. The site receives pollution due to traffic, particularly during nighttime when the heavy vehicles ply on the NH road. Added, the complex wind pattern induced by the surrounding orography often affects the pollution flow at the study region. Further, the building-construction activities within the campus influence the observations. It is also observed that the site is influenced by the Thar Desert, located in the northeast direction, and receives dust pollution through long-range transport process. Thus, although the site is primarily a rural station with sparse residential buildings, population, and vegetation fields, it poses sporadic pollution due to the abovementioned natural and anthropogenic activities.

Material and Methodology

Regular and continuous observations of black carbon (BC) mass concentration measurements using a seven-beam Aethalometer (Magee Scientific Inc. USA, Model AE-42) have been in progress in the campus of Amity University Haryana, Panchgaon (Manesar–Gurgaon) almost from the beginning of 2015 under a collaborative program with Aryabhatta Research Institute for Observational Sciences

(ARIES), Nainital and Indian Institute of Tropical Meteorology (IITM) Delhi Unit, New Delhi. This instrument is fully automatic and uses a continuous filtration of ambient aerosols. Atmospheric air is pumped through an inlet at the desired flow rate (about 4 LPM in the present study), which impinges on a quartz micro fiber strip. A light beam from a high intensity LED lamp is transmitted through the sample deposit on the filter strip, at 880 nm. The instrument measures BC mass concentrations in the wavelength range of 370–950 nm. The measurement of the attenuation of light beam is linearly proportional to the amount of BC deposited on filter strip. Observations were recorded at the time base of 5 min interval. More details of the instrument, measurement and data analysis procedure can be found in Sumit et al. (2011 and references therein). In the present study, an absorption efficiency value corresponding to the environment of sampling station is used to determine the BC mass concentrations as suggested by Hansen et al. (1984, 2007) and Weingartner et al. (2003). The BC mass concentration is calculated from the rate of change of attenuation (ATN). The loading effect that relates the tape advancement with change in ATN has been taken into account in the calculation of BC mass concentration by following the correction algorithm suggested by Virkkula et al. (2007) and Park et al. (2010). In the absence of scattering coefficient data, the corrected attenuation coefficient can be expressed by

$$b_{\mathrm{ATN}}\ (\text{corrected}) = (1 + k * \mathrm{ATN}) * b_{\mathrm{ATN}}\ (\text{Aethalometer}) \tag{1}$$

where k is an empirically derived constant. The corrected aerosol BC mass concentration is calculated as follows:

$$\begin{aligned} \mathrm{BC}\ (\text{corrected}) &= b_{\mathrm{ATN}}\ (\text{corrected})/\sigma_{\mathrm{ATN}} \\ &= (1 + k * \mathrm{ATN}) * \mathrm{BC}\ (\text{Aethalometer}) \end{aligned} \tag{2}$$

The value of k varies depending on sampling location, season, aerosol composition, and age of the aerosols (Hansen et al. 1984, 2007; Weingartner et al. 2003). The uncertainty involved in the concentration was estimated to be about 10%. The conversion of attenuation absorption coefficient into BC mass concentration is done using appropriate absorption efficiency values which vary with wavelength.

In addition to the above-described principal equipment (Multispectral Aethalometer), other two ancillary instruments that have been operated in synchronization with it include (i) TSI Model 3321 Aerodynamic Particle Sizer which provides mass concentration of aerosols at 52 size bins, from which the PM_1, $PM_{2.5}$, and PM_{10} have been derived, and (ii) Kestrel Model 4500NV Weather and Environmental monitor for the measurement of ambient wind, temperature, and relative humidity. The concurrent satellite observations from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) and NOAA-HYSPLIT air-mass back-trajectory model results have also been utilized for attributing the observed aerosol features during the festive period. All the above datasets, archived simultaneously, for the period of pre-, during, and post-Diwali 2015 have been analyzed and the results are discussed in the sections to follow.

Results and Discussion

Diurnal Variation of BC Mass Concentration

The hour-by-hour variations in BC mass concentration observed during pre-, during, and post-Diwali period are shown plotted in Fig. 2. One common feature that can be noted from the figure is that the diurnal variation shows bimodal distribution in BC aerosol mass concentration with one peak around the morning hours and the other around night hours with a broad minimum around noon hours. Normally, we expect higher concentrations on 11 and 12 and gradually coming to the normal values from 13 onwards. But the lower BC values observed on Diwali days may be due to different reasons such as filter loading effect, inlet air flow disturbances arose due to insects' movement caused by strong winds or toxic gases released into the air by the fireworks. Proper observations could not be recorded on November 14, 2015 due to the abovementioned problems. However, the spectral variation of BC mass concentration yielded interesting results which have been enumerated in Figs. 3 and 4.

The high-resolution data (5-min interval) of BC equivalent (BCE) mass concentration observed at seven-wavelengths of Aethalometer are plotted in Fig. 3. Significant variations in wavelength dependency in concentration, especially at UV wavelength of 370 nm, are very clear from the figure. In order to bring out different

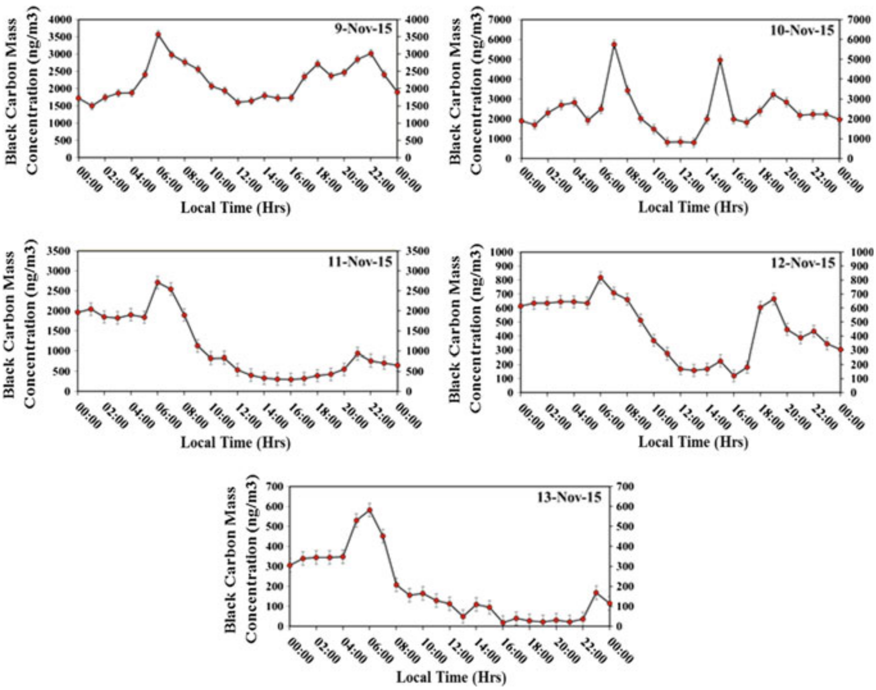

Fig. 2 Day-to-day variation in surface-level BC mass concentration observed during November 09–13, 2015 encompassing the Diwali days of November 11 and 12, 2015

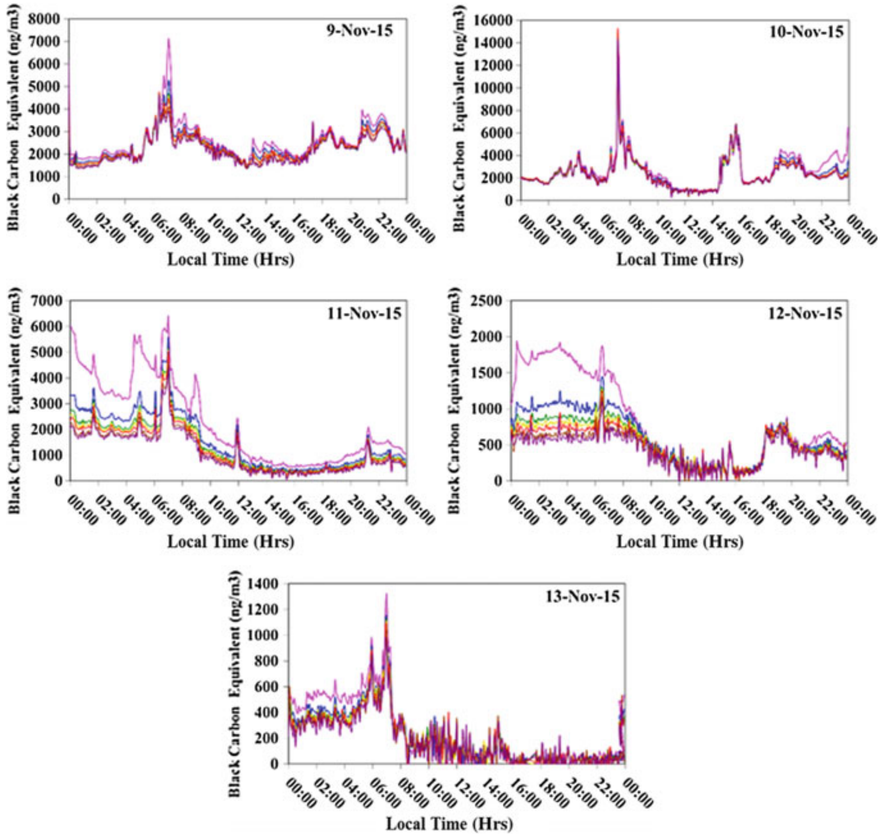

Fig. 3 High spectral resolution BCE mass concentration on November 09, 10, 11, 12, and 13, 2015. The prominent variation of BCE mass on Diwali days may be noted

sources and their time variation of the observed BC mass, concentrations at specific wavelengths (370, 590, and 880 nm) have been displayed on each observation day in Fig. 4.

It can be clearly seen from the figure that there is an interesting day- to-day variation in the signatures of BCE concentrations, particularly on core Diwali days of November 11 and 12, 2015. As suggested in the literature (Andreae and Gelelencser 2006; Moosmuller et al. 2011), the BCE concentration at 370 nm indicates the presence of aromatic organic compounds and fire/smoke aerosols [organic carbon (OC), optically known as brown carbon (BrC)], while those at 590 nm (Yellow Carbon, YC), and 880 nm (Black Carbon, BC) indicate the presence of biomass burning aerosols and fossil fuel combustion aerosols, respectively. It can be seen from Figs. 3 and 4 that BCE at 370 and 590 nm are prominent on core Diwali days (November 11 and 12, 2015) as compared to remaining days. Thus, the results of the present study are consistent and indicative

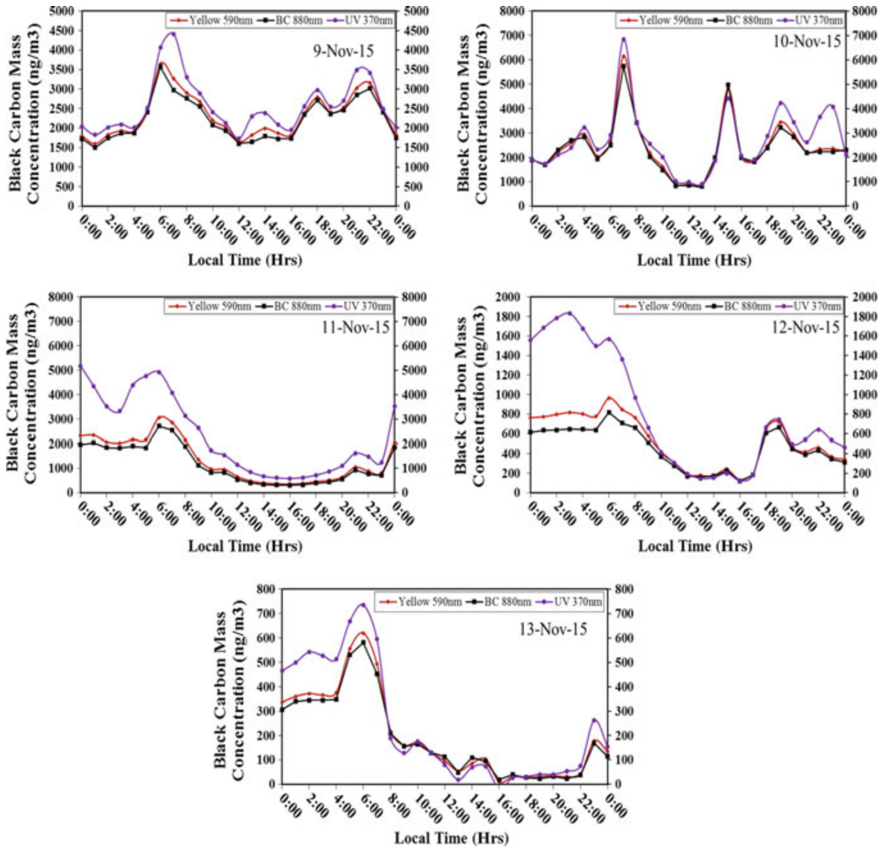

Fig. 4 BC equivalent mass concentration observed at UV (370 nm), *yellow* (590 nm) and NIR (880 nm) wavelengths of the Aethalometer

of the presence of fire/smoke and organic compounds in the fireworks. This is further corroborated with the results shown in Fig. 5.

The wavelength dependence of aerosol absorption is usually parameterized by an empirical relationship as proportional to $\lambda^{-\alpha}$, where λ is wavelength of light and α is absorption angstrom exponent (AAE). Hence, another indicator of the BC source, as suggested by Formenti et al. (2003) and Schnaiter et al. (2003) could be the slope of the AAE. This spectral dependence is described by using the following equation:

$$\alpha(\lambda) = -[(d\ln(b_{abs}(\lambda))/(d\ln(\lambda))] \tag{3}$$

This parameter is not fundamental and for aerosols depends not only on properties of bulk matter, but also on particle morphology and size (Moosmuller et al. 2011). For BC the value of AAE is close to one, whereas it was more than 2 for BrC (Bergstrom et al. 2002; Kirchstetter et al. 2004). Such a plot showing the relative comparison between the slopes of AAE observed on different days during the study

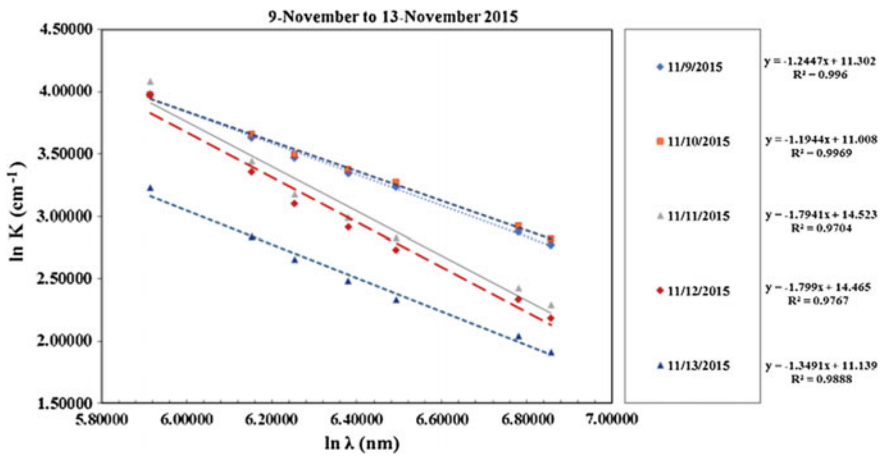

Fig. 5 Daily variation of AAE from November 09–13, 2015. Higher values of slopes indicative of smoke and aromatic organic compounds on core Diwali days (November 11 and 12, 2015) may be noted

period is shown in Fig. 5. Relatively higher slopes around 1.79 may be noted on 11 and 12 as compared to such values observed on remaining days. This clearly implies the method by which the sources can be identified from multispectral BCE observations.

Influence on Columnar AOD and ASD

The columnar aerosol optical depth (AOD), which is atmospheric extinction due to aerosol particles, measured using a Microtops-II multi-wavelength solar radiometer (Solar Light Co., USA), has been studied during the festive period. By evolving linear least squares fit between AOD and λ (in µm) on log-log scale over the spectral range of the radiometer, the slope and intercept of the regression line yield α and β, respectively. The methodology followed for estimating AOD from solar irradiance estimations, and retrieval of Angstrom Exponent (α) and turbidity coefficient (β) from spectral dependence of AOD has been explained in our earlier publications (Devara et al. 1996, 2001; Sumit et al. 2011; Pawar et al. 2015). The size exponent, α (representative of aerosol size distribution) and β (representative of aerosol loading) have been estimated for pre-, during, and post-Diwali period. In other words, alpha is an indicator of fraction of fine-mode aerosols (radii $\leq$ 1 µm) to coarse-mode aerosols (radii > 1 µm) while the β (equals AOD at 1 µm), is a measure of columnar aerosol loading. If α value close to or less than 1.0, then the coarse-mode aerosol particles dominate in the atmosphere, and if it is greater than 1.5 µm, the fine-mode (radii $\leq$ 1 µm) dominates in the atmosphere. Generally, α has a value between 0.5 and 2.5 while β value varies from 0.0 to 0.5 (Iqbal 1983). Thus, the value of $\beta < 0.1$ indicates clean atmosphere while $\beta > 0.1$

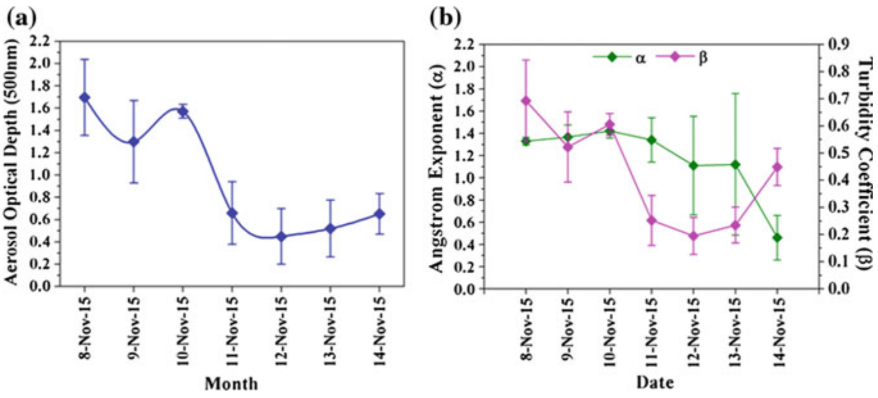

Fig. 6 **a** Variations in AOD at 500 nm wavelength during and around the Diwali period. **b** Day-to-day variation in α and β during and around the Diwali period

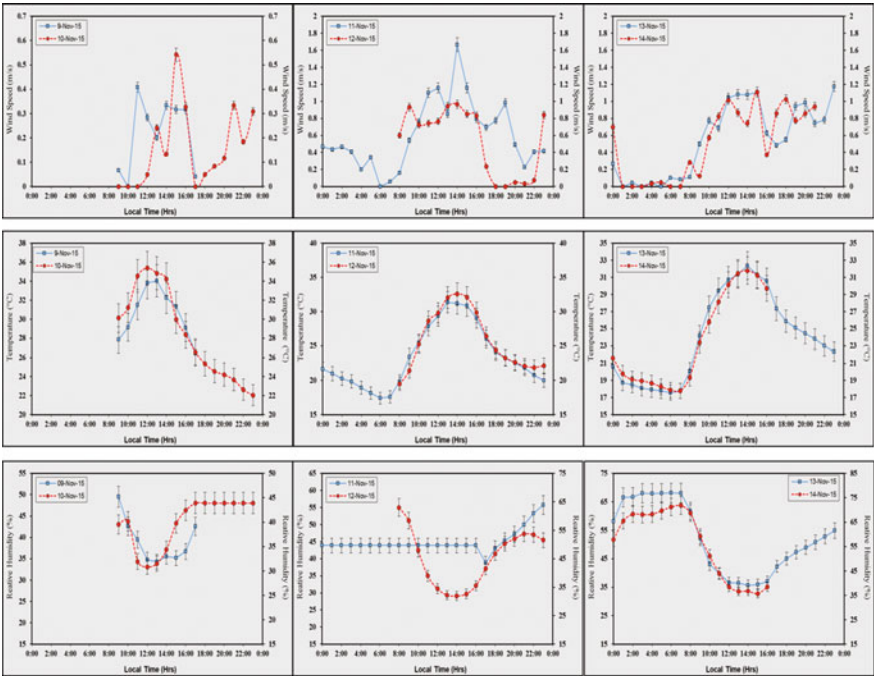

Fig. 7 Diurnal variation of local ambient meteorological parameters recorded at AUH on all the days during the study period

depicts turbid atmosphere. Figure 6a, b display the variations in AOD at 500 nm wavelength and corresponding α and β observed during and around the Diwali period. The greater value of AOD on 10th may be due to the pre-Diwali activity whereas the decrease in AOD on both 11th and 12th is considered to be due to stronger wind speed on those days, as displayed in Fig. 7. Similar feature can be noted in the variation of β as shown in Fig. 6b. Moreover, the higher values of α on 10th and slight drop in its value on 11th and 12th implies abundance of fine-mode particles induced by the Diwali activity.

Influence of Local Meteorology

Figure 7 shows the variations in ambient wind speed, temperature, and relative humidity, observed in synchronization with the operation of Aethalometer and Aerodynamic Particle Sizer. It is interesting to note that the wind speeds were low (about 0.6 m s^{-1}) on the initial two days of the measurement program and thereafter, they became strong, touching up to 2 m s^{-1}. These strong winds on the festive and post-festive days may have diluted the BC mass concentration values. The constant relative humidity on November 11, 2015 may have also contributed to the low BC mass concentration values on that day.

Morphology of Particulate Matter (PM_1, $PM_{2.5}$, and PM_{10})

Figure 8 portrays diurnal variation of PM_1 (particles of diameter up to 1 μm), $PM_{2.5}$ (particles of diameter up to 2.5 μm), and PM_{10} (particles of diameter up to 10 μm) during November 09–14, 2015. The bottommost frame depicts the daily mean values of PM_1, $PM_{2.5}$, and PM_{10}. Similar to the variations in BC, PM also shows two peaks, one in the morning hours (around 0800 h) and the other in the evening hours (commencing from around 2000 h). Subsequently, these two peaks merge into one broad peak, persisting almost throughout the night. The minimum density during afternoon hours is seen on all the days as that of BC. This feature is considered to be due to lifting of local day-time boundary-layer (mixing height) allowing more space for the pollutants to disperse. The observed increase in BC and PM during nighttime is due to the combined effect of anthropogenic activity and nocturnal shallower boundary-layer, which results in reduction in the ventilation coefficient and accumulation of aerosols near the surface (Safai et al. 2014). As per the definition, PM_{10} density would be the highest and PM_1 would be the lowest and $PM_{2.5}$ concentration would lie in between these two. One interesting feature that can be visualized on all the days of the study period is the narrow spacing between the variations in $PM_{2.5}$ and PM_{10}. More the closeness between these curves indirectly indicates the abundance of $PM_{2.5}$ due to growth of particles in the study region. This also provides a clue about the composition of the particles whether they are of scattering or absorbing type, which is very important information to infer their radiative forcing capability in the study region. The aerodynamic particle sizer employed in the present study measures concentration of aerosol particles of diameter ranging between 0.5 and 20 μm, in 52 size channels. The particle density, in each size bin of the instrument, on all the six days during the study period is shown plotted in Fig. 9. The noteworthy point from all the frames is that the particle density is the highest on November 11, 2015. Moreover, the spectrum is relatively

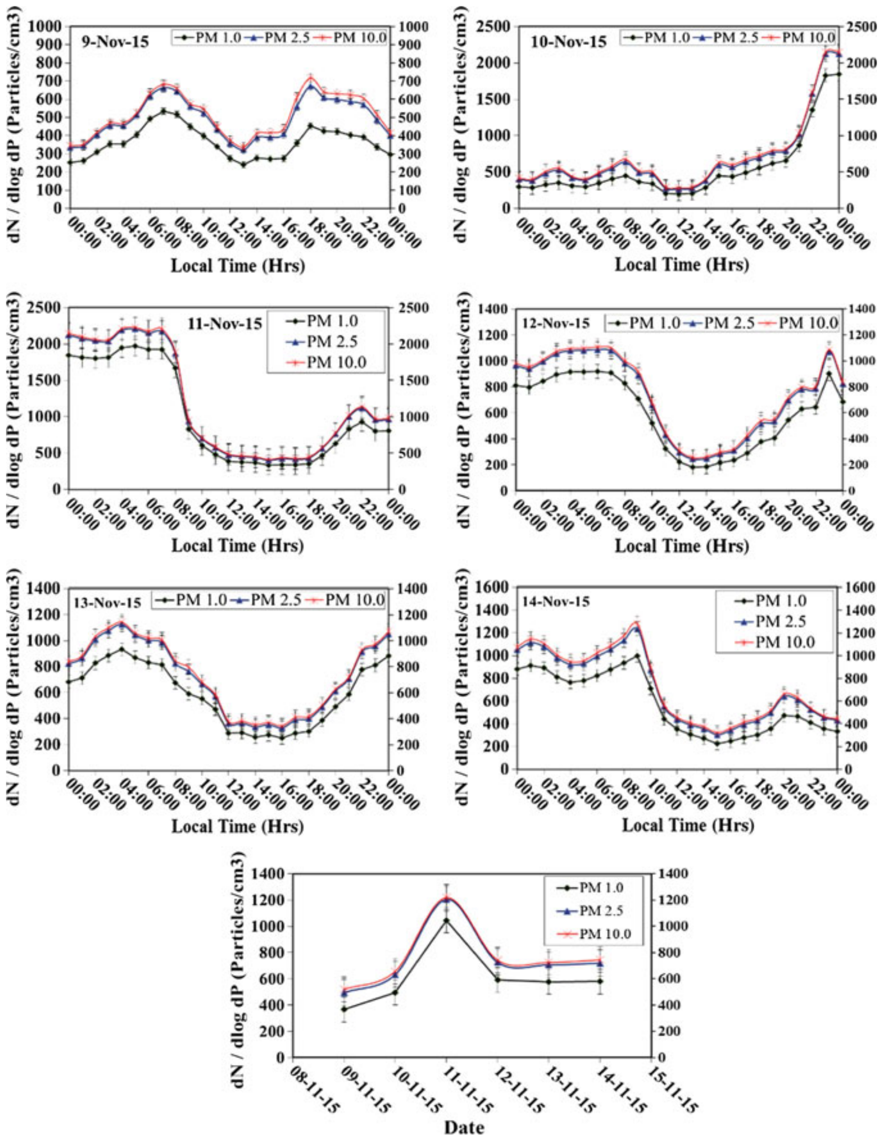

Fig. 8 Daily mean variations of PM_1, $PM_{2.5}$, and PM_{10} density (particles per cubic centimeter) observed during November 09–14, 2015, covering the core Diwali (November 11 and 12, 2015) and control days (November 09, 10, 13, and 14, 2015)

narrow and most of the particles confined to the size bins between 0.54 and 3.53 nm, which indicates abundance of fine-mode aerosol fraction, which is consistent (Safai et al. 2014).

It can be clearly seen from Table 1 that the density of PM is higher by more than double during the festive period as compared to those observed on control days.

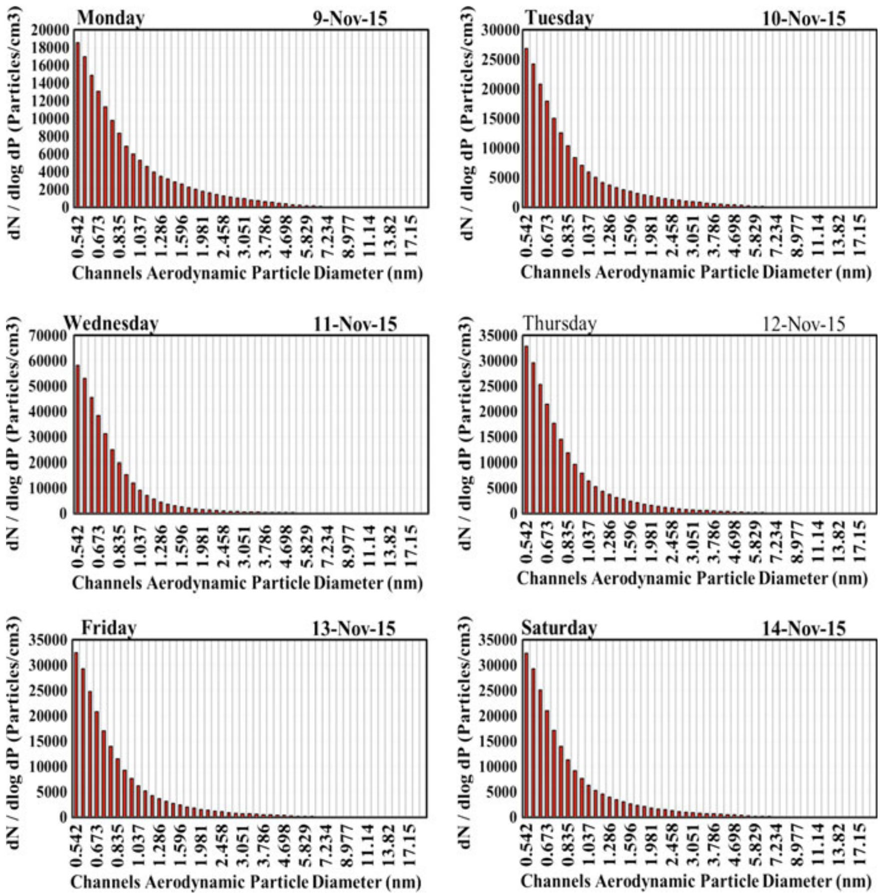

Fig. 9 Size-segregated PM density observed with aerodynamic particle sizer during January 09–14, 2015

Table 1 Daily mean mass concentrations of PM_1, $PM_{2.5}$, and PM_{10} for all the six days of the study period

Date	*d*N/*d*log*d*p concentration (particles/cm^3)		
	PM_1	$PM_{2.5}$	PM_{110}
11/9/2015	366.95	496.73	519.26
11/10/2015	496.73	634.88	657.09
11/11/2015	1045.75	1204.34	1219.84
11/12/2015	592.66	725.16	742.84
11/13/2015	578.40	725.16	725.93
11/14/2015	578.90	720.90	744.39

Satellite Measurements

The CALIPSO satellite over pass [satellite swath and space-time cross-sections of aerosol vertical feature mask (VFM)] available for January 12, 2015 (Diwali day) is shown in Fig. 10.

The area encircled in the frame represents the observation site and its surroundings. It is clear from the VFM plot that the satellite captured the smoke (black

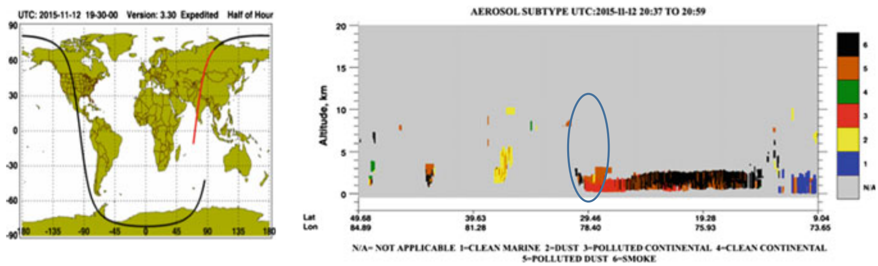

Fig. 10 CALIPSO satellite swath and aerosol vertical feature recorded on November 12, 2015

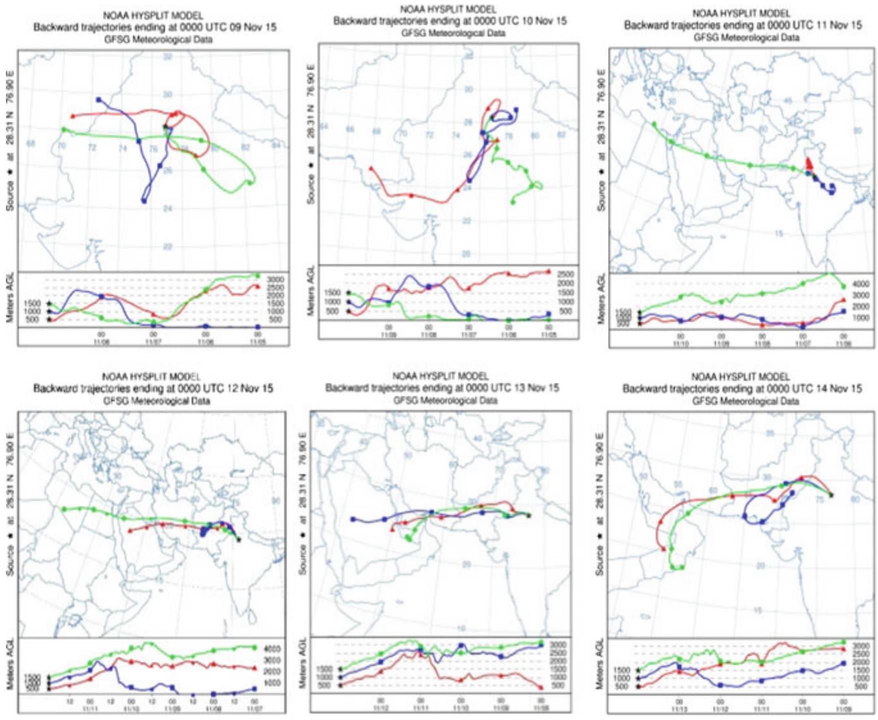

Fig. 11 5-day air-mass back trajectories, obtained at three height levels of 500 m (*red*), 100 m (*blue*) and 1500 m (*green*), using the NOAA-HYSPLIT model for the study period

color), polluted dust (brown color), and polluted continental dust (red color) on November 12, 2015, which is consistent with the activities observed during Diwali festival.

Air-Mass Back Trajectories

In order to investigate the contribution from trans-boundary pollution, through short- and long-range transport phenomenon, the NOAA-HYSPLIT model results are shown in Fig. 11. It can be seen from the figure that the continental air-mass from all the height levels considered in the present study contributes to the pollution at the observation site on the pre-festival days. On Diwali day, the air-mass from 500 and 1000 m levels are of land-origin while the air-mass at 1500 m level comes all the way from gulf countries to the observation site. During the post-festive days, the air-mass from all the three levels are from Arab countries. Thus, the pollution over Panchgaon on Diwali day and on subsequent days involves contribution of air-mass from long distance.

Summary

A study has been carried out at Amity University Haryana (AUH), Panchgaon-Manesar-Gurgaon, to examine the impact of the recent Diwali festival of 2015 on the air quality over the site. For this purpose, a seven-beam Aethalometer, Aerodynamic Particle Sizer, a Multi-wavelength Solar Radiometer, Weather and Environmental Monitor, CALIPSO satellite imageries, and HYSPLIT model results have been used. The results revealed the fire/smoke and soot aerosol sources responsible for the BC mass concentration, enhancement in PM_1, $PM_{2.5}$, and PM_{10} during the festive period. The radiometric measurements revealed fluctuating AOD due to local wind variations and Angstrom exponent implying abundance of fine-mode particles induced by the festive activity. The results have been explained with the help of concurrent satellite, trajectory model and surface meteorological parameters. Considering the influence of different pollutants at different toxic levels on human health, biomarkers need to be developed that help setting up of permissible respiratory levels for human health. Mitigation/remedial measures by discouraging the burning of fireworks on the occasions of celebrations are suggested. Pollution-free fireworks are available but they are very costly and cannot fulfill the demand. Therefore, in some countries, in order to avoid effects to human health and ecosystems, traditional fireworks are replaced with laser shows. Such methods may be considered for the benefit of human health and safety of our Planet Earth.

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The CALIPSO data were acquired (http://www.calipso.larc.nasa.gov/products/lidar/browseimages/products). The authors also appreciate the assistance from Tanojit Paul and Shubhansh Tiwari of AUH in the analysis of data. The insightful comments and valuable suggestions by the anonymous reviewers are thankfully acknowledged.

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Decolorization of Reactive Yellow 17 Dye Using *Aspergillus tamarii*

Anuradha Singh, Arpita Ghosh and Manisha Ghosh Dastidar

Abstract Decolorization of a reactive yellow 17 dye (Molecular formula: $C_{20}H_{20}K_2N_4O_{12}S_3$) using growing *Aspergillus tamarii* was studied in a batch bioreactor. The study was performed up to 90 h at optimized pH 5 for maximum growth of *A. tamarii*. The decolorization and biomass concentration decreased from 58.8 to 6% and from 2.37 to 0.74 g/L, respectively, with increasing initial concentration of dye from 100 to 1000 mg/L. The chemical oxygen demand (COD) after decolorization was found to be decreased from 37.2 to 16% with increasing dye concentration from 100 to 1000 mg/L. Further, desorption study was performed with acidic eluants and the desorbed biomass was reused for decolorization which was compared with that obtained using dead biomass.

Keywords *Aspergillus tamarii* · Reactive yellow 17 dye · Batch bioreactor
Color removal · COD

Introduction

Dyes are colored substances which are used in textile, paper, plastic food, tanneries, paints, and electroplating industries. Effluents generated from these industries have high COD (chemical oxygen demand), BOD (biochemical oxygen demand), suspended solids, biodegradable organics, and pathogenic bacteria (Ranjusha et al. 2010). Effluents also contain residual dyes, which are discharged to the environment directly by most of the textile industries without giving adequate treatment to

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the wastewater. This wastewater causes huge damage to the environment and also affects the aquatic life. Therefore, there is a need of treatment of wastewater before discharging to the environment (Ghosh et al. 2016a, b). Various treatment techniques are available such as membrane filtration, reverse osmosis, ion exchange, fenton reagents, ozonation, photochemical, and activated carbon. However, these techniques are not eco friendly as they result in production of huge amount of secondary pollutants in the form of sludge (containing toxic chemicals) which ultimately lead to handling and disposal problems. Physical and chemical treatment technologies are not very successful in removal of dissolved salts and traces of metals and costly owing to use of large amount of chemicals, resins, etc. (Nigam et al. 1996; Ranjusha et al. 2010). Alternatively, biological treatment is environment friendly, low energy and cost-effective technology, and no secondary pollutant is generated. Microorganisms such as algae, bacteria, and fungi have high efficiency to remove different dyes from aqueous solutions (Ghosh et al. 2015a, b; Ranjusha et al. 2010; Aksu and Tezer 2005). In the present study, fungi were used for decolorization because it is efficient and environment friendly.

Materials and Methods

Reactive yellow 17 dye: Reactive yellow 17 dye was used in the present study, which was soluble in water. The chemical structure of reactive yellow 17 dye is shown in Fig. 1 (http://www.worlddyevariety.com/reactive-dye/reactive-yellow-17.html). This dye was collected from the Department of Textile Technology of Indian Institute of Technology Delhi, India.

Microorganism and media preparation: The fungal strain (*Aspergillus tamarii*) was isolated previously in laboratory from the sludge of a textile industry (Ghosh et al. 2014) and was used in the present study. *A. tamarii* was grown in 250 mL Erlenmeyer flasks with 100 mL of culture media. The composition of culture media is as follows: Glucose—10 g/L; Yeast extract—5.0 g/L; Di-potassium phosphate (K_2HPO_4)—0.5 g/L; Magnesium sulfate ($MgSO_4$)—0.1 g/L; Ammonium nitrate (NH_4NO_3)—0.5 g/L, and Sodium chloride (NaCl)—1 g/L (Ranjusha et al. 2010). It was observed that the natural initial pH of the media was 6.2. The initial pH of synthetic dye solution was adjusted by using 1(N) HCl (hydrochloric acid) or NaOH

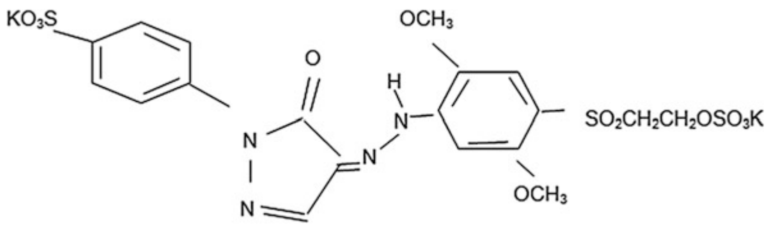

Fig. 1 Structure of reactive yellow 17

(sodium hydroxide) as per the requirement (Ranjusha et al. 2010; Ghosh et al. 2014). The experiments were conducted using sterile culture media containing synthetic dye solution inoculated with *A. tamarii* and incubated at 27 °C and 110 rpm to maintain conditions favorable for the growth of microorganism. The studies were carried out for a period of 90 h. The dye solution was scanned for peak absorbance from 300 to 900 nm range (Robinson et al. 2001; Namdhari et al. 2012). The maximum absorbance (λ_{max}) was observed at 406.8 nm by UV–visible spectrophotometer (Systronics). This absorbance was used for calculation of percentage of decolorization after decolorization experiment (Olukanni et al. 2006).

$$\%\text{Decolorization} = \{(C_0 - C_1)/C_0\} \times 100$$

where,

C_0 initial concentration of dye (mg/L)
C_1 residual concentration of dye (mg/L) after decolorization study.

Decolorization at different initial concentrations of dye: Decolorization study was conducted using solution of different initial concentrations (100–1000 mg/L) of dye at pH: 5 which is optimum for maximum growth of *A. tamarii*. It was observed earlier that maximum growth of *A. tamarii was* obtained at optimized pH: 5 (Ghosh et al. 2014). The biomass was collected after each experiment. The dry weight of biomass was analysed through weight balance machine.

The Chemical oxygen demand (COD) is an important parameter to evaluate the total oxidizable substances in wastewater. The COD values of dye solutions of (100–1000 mg/L initial concentration) were estimated by using dichromate reflux protocol (standard method) given by American Public Health Association (APHA 1989; Ranjusha et al. 2010).

Desorption study and reuse of desorbed biomass: The biomass after decolorization, was collected and dried. Study on desorption of biomass (after decolorization) was performed using acidic eluant (such as H_2SO_4, HCl at different normalities). The pH values of acidic eluants at different normalities (0.5(N) H_2SO_4, 1(N) H_2SO_4, 0.5(N)HCl, and 1(N)HCl) were found to be 1.1, 0.85, 0.86, and 0.66, respectively. For desorption study, initially the biomass was dipped in distilled water followed by different normalities of H_2SO_4 and HCl for 60 min and placed in shaker at 110 rpm. Then, the desorbed biomass was mechanically grinded with water. All the solutions were collected, centrifuged and the absorbances were determined by using UV–visible spectrophotometer. The biomass after desorption was reused for decolorization of synthetic dye solution. Further, fresh biomass was prepared in the absence of dye and was dried. Study on decolorization using desorbed biomass was compared with decolorization using fresh dead biomass in batch modes. The desorbed biomass and fresh dead biomass were added in synthetic dye solution of 100 mg/L in conical flasks separately and placed in shaker at 110 rpm for 60 min. The solutions were centrifuged and the %decolorization was determined by using UV–visible spectrophotometer.

Scanning Electron Microscopic (SEM) Analysis: The SEM analysis of fungal biomass was done to examine the surface of the cells before and after dye decolorization (Ghosh et al. 2014; Ranjusha et al. 2010). The samples for SEM were mounted on the stainless steel stub by coating a thin layer of gold under vacuum in order to improve the quality of micrographs.

Results and Discussion

Decolorization at Different Initial Concentrations of Dye

Figure 2 shows the effect of initial concentration of dye (100–1000 mg/L) with time on decolorization at pH: 5 (optimum for the maximum growth rate of microorganism). With increasing time from 0 to 90 h, it was observed that % decolorization was initially increased up to 70 h for 100 mg/L dye solution. After 70 h, no improvement was observed in %decolorization. It was found that 100 mg/L dye concentration shows maximum decolorization 58.8% as compared to other concentrations (such as 250, 500, 1000 mg/L) of the dye. Decolorization was found to be 58.8, 27, 11, and 6% at 100, 250, 500, and 1000 mg/L dye solution. It is indicated that dye at higher concentration is toxic to the cell growth. Previously, it was reported that *Aspergillus* species removed color 62.6, 69.8, and 87% separately from Reactive Black, Reactive Red, and Remazol Black B dyes solutions at 100 mg/L, respectively (Ramya et al. 2007; Ranjusha et al. 2010). In present case, it is 58.8% color removal and is near to the decolorization value of Reactive black dye as referenced above. The COD after decolorization was found to be decreased from 37.2 to 16% with increasing dye concentration from 100 to 1000 mg/L.

In previous study, maximum biomass concentration was reported as 5.2 g/L in the absence of dye (Ghosh et al. 2014). Figure 3 shows rapid decrease in the biomass concentration from 5.2 to 2.37 g/L with increasing dye concentration from

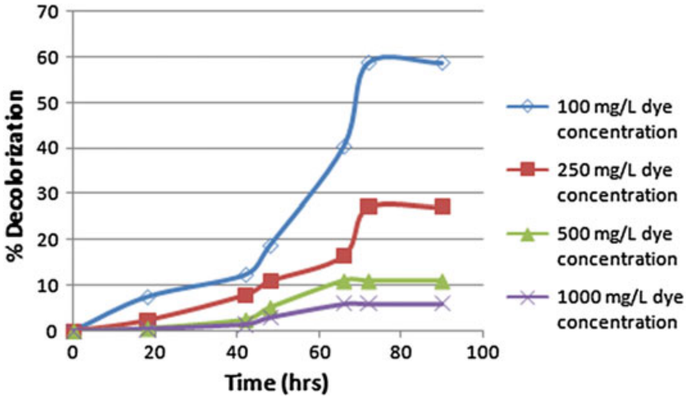

Fig. 2 Decolorization with time at different initial concentration of dye

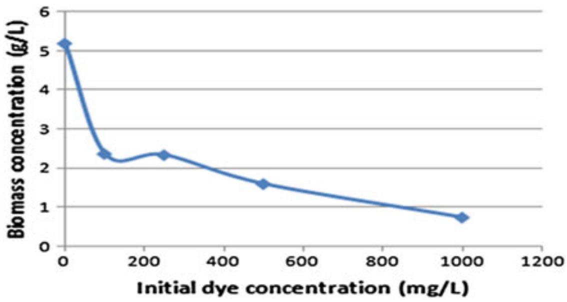

Fig. 3 Effect of initial dye concentration on biomass concentration

Table 1 Dye removed through desorption

S. No.	Eluting agents	Dye removed through desorption (mg/L)
1	Distilled water	0.6
2	*Sulphuric acid (H_2SO_4)*	
	0.5 N	0.055
	1 N	0.065
3	*Hydrochloric acid (HCl)*	
	0.5 N	0.066
	1 N	0.048
4	Mechanical destruction	0.043
	Total	0.877

0 to 100 mg/L. Further increase in the dye concentration from 100 to 1000 mg/L, biomass concentration was decreased from 2.37 to 0.74 g/L. The lower biomass concentration at higher dye concentration is due to the toxicity effect on the growth of microorganism.

Desorption Study and Reuse of Desorbed Biomass

Table 1 shows maximum dye (0.6 mg/L) with distilled water. Loosely bound dye molecules on biomass may be removed using distilled water. Maximum desorption of dye was observed using 1(N) of eluting agents. No significant increase in desorption of color was observed with increased contact time of the biosorbent and the eluting agent. Dye desorbed at different normalities (0.5(N) H_2SO_4, 1(N) H_2SO_4, 0.5(N)HCl, and 1(N)HCl) was found to be 0.055, 0.065, 0.066, and 0.048 mg/L, respectively. The strongly bound dye on cell surface of the biomass has been removed by acidic elutants. The removed Dye was observed to be 0.043 mg/L, after mechanical destruction of the cell. Total 0.877 mg/L dye was observed to be desorbed from biomass in different steps mentioned below. Maximum dye removed in decolorization experiments was 58.8 mg/L by growing biomass using 100 mg/L dye solution. Very less amount of dye desorbed indicates color destruction by the acidic eluants.

The percentage decolorization by using desorbed biomass was 7.3%. The percentage decolorization using growing biomass was observed to be 58.8%. Percentage decolorization by using desorbed biomass has been observed to be low as compared to using living microorganisms because living fungal biomass involves both biosorption and bioaccumulation processes. However, decolorization using desorbed biomass involves only adsorption on the surface of the biomass. The percentage decolorization by using dead biomass was 15.1%. This indicates maximum decolorization of dye was due to color accumulation inside the fungal cell.

SEM Analysis

In the absence of dye, smooth shape of cell was observed (Fig. 4). The shape of cell appears to be distorted when organism was grown (Fig. 5) in the presence of dye. During decolorization morphological changes of the cells have taken place.

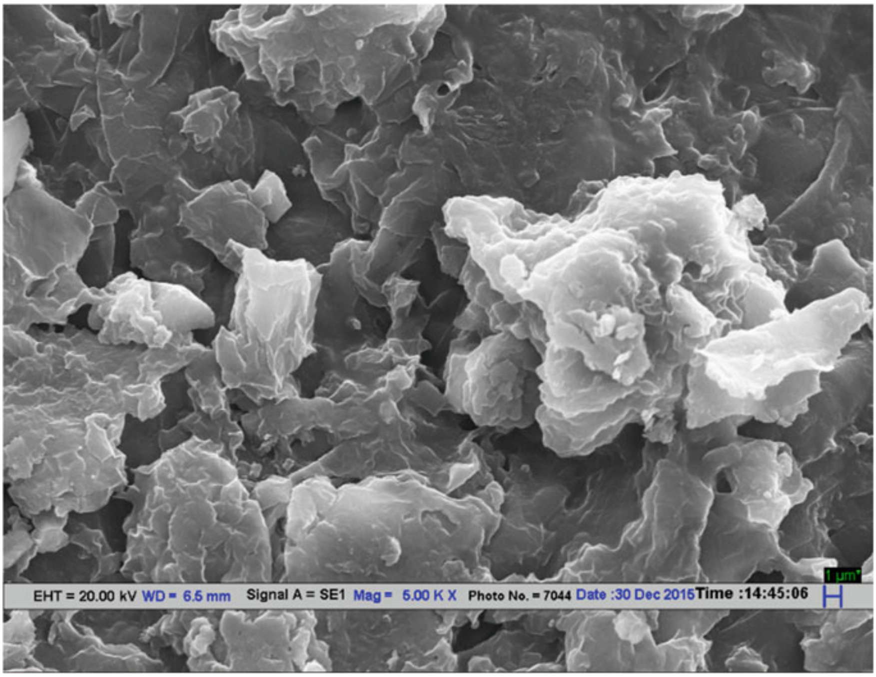

Fig. 4 SEM analysis before biosorption of dye

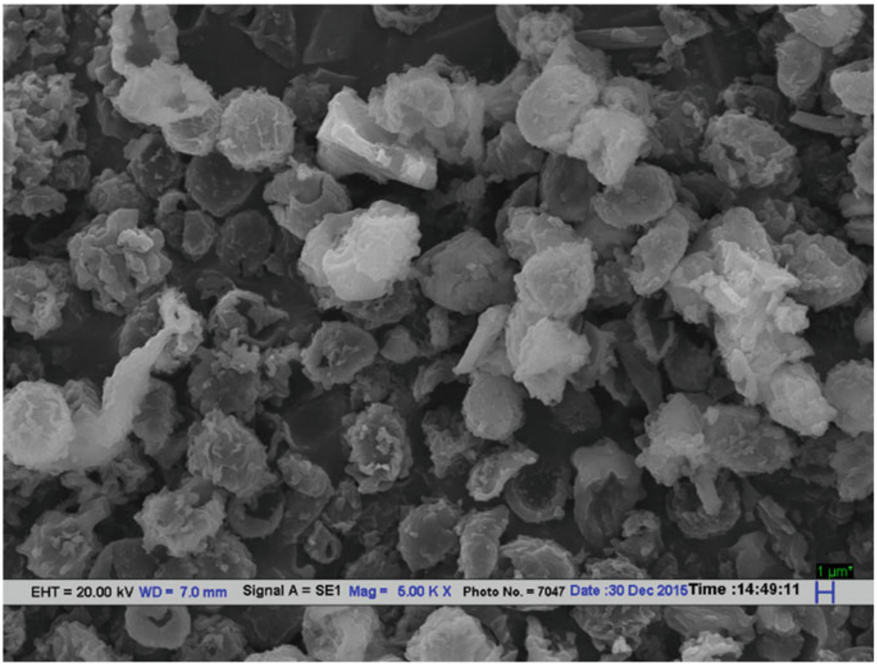

Fig. 5 SEM analysis after biosorption of dye

Conclusion

Aspergillus tamarii was isolated from the sludge of textile industry, has the ability to grow in the presence of dye and is effective in removing Reactive yellow 17 dye. The growth of the microorganism and color removal depends on initial dye concentration and contact time. The growing microorganism was efficient to decolorize the dye solutions at higher concentrations. The decolorization, COD, and biomass were decreased with increasing the concentration of dye. Also, the decolorization of dye by *A. tamarii* was indicated by SEM analysis. The reuse potential of biomass after desorption can minimize the sludge generation and make the process cost-effective.

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Discovery of the Helium Rare Gas in Saugor Division, Southern Ganga Basin, Bundelkhand Region, MP, India

Arun K. Shandilya

Abstract The discovery of the helium rare gas in the wells in Saugor Division, southern Ganga Basin region has been done in Sagar District. The stable isotopic analyses were carried out for the gas samples collected from the 50 tube wells in Sagar and Damoh District of MP. The discovery of the rare gas helium in hydrocarbon rich zone in the tube wells in agricultural field at Garhakota, Rahatgarh, Bina, Banda and Sagar Tahsils, of District and Batiyagarh, Patharia, Jabera, tahsils in Damoh District of MP is a unique finding in rocks of the Vindhyan Super Group, in the history of Earth Science in India. The depth of tube wells varying from 300 to 750 ft. On the basis of geochemical analysis, it is remarkable to note that average values of helium contents varies from 0.34 to 0.732% along with the 72–99% of methane and ethane, and minor amount of oxygen, nitrogen, and CO_2 gases in the hydrocarbon rich zone are recorded during the geochemical and stable isotope analysis. It has been found in the stable isotope δ C^{13} value, the values for the methane is −43.6 to −54.9‰ w.r.t. PDB. For the Ethane gas it is −24.9 to −26.4‰ w.r.t. PDB in the gas samples collected in the saturated sodium chloride solution in the glass bottles at various sites in Sagar and Damoh District. The occurrence of rare helium gas in the Hydrocarbon rich zone was reported for the first time in January, 2007 from the tube wells of Sagar District, which were geochemically and isotopically stable, analysed in the labs of KDMIPE Dehradun and NGRI Hydrabad. The gaseous hydrocarbon analysis shows the presence of moderate to low concentration of methane (C1) 1 to 104 ppb, Ethane (C2) −1 to 14 ppb, Propane (C3) 1 to 10 ppb, i-Butane (i C4) 1 to 9 ppb, and n Butane (n C4) 1 to 8 ppb in the soil samples collected from different locations. The result of the adsorbed soil gas and stable isotopic analysis of Ethane gas in these samples have δ C^{13} value ranging from −24.9‰ w.r.t. PDB and −26.9‰ w.r.t. PDB, and these are indicative that the gas is of thermogenic origin, which must have been formed at very high temperature and pressure condition in the deeper horizon of the Great Vindhyan sedimentary basin of an early Proterozoic (>600 m.y.) period.

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Keywords Petroliferous · Tube wells · Hydrocarbon gas · Helium gas
Proterozoic · Isotopic · Thermogenic

Introduction

The present studies on the hydrocarbon gas anomalies in the seepages and leakages of natural petroleum rare gas Helium in the agricultural field of Sagar and Damoh district has been done in the hydrocarbon rich zone. These hydrocarbon gases and helium gas escape from the reservoir and migrated to the surface, the secondary porosity in the rocks, sediment and soil, or diffuse into the atmosphere or added in the ground water. These leakages of natural gas is an indication of petroleum gas in the form of oil and gas seep from precursor underground (Fig. 1).

The attempt has been made through the cheaper and faster method of geochemical prospecting, which provides the direct evidence for the presence of petroleum accumulation under ground. The samples of soil, water and gas were collected from the tube wells of agricultural fields located in various villages in the Meerkhedi, Rahatgarh (tahsil) Pipariya–Bhutoli villages in Garhakota tahsils of Sagar and Mahalwara village in Sukha block of Patharia tahsil of Damoh district in the southern fringes of Bundelkhand region in MP. The first time leakage of petroleum gas was reported in 1980 from the Meerkhedi village located on the Sagar to Vidisha road, at about 15 km from the Rahatgarh town. In 1993, the leakage was reported by the author in another tube well at Rahatgarh.

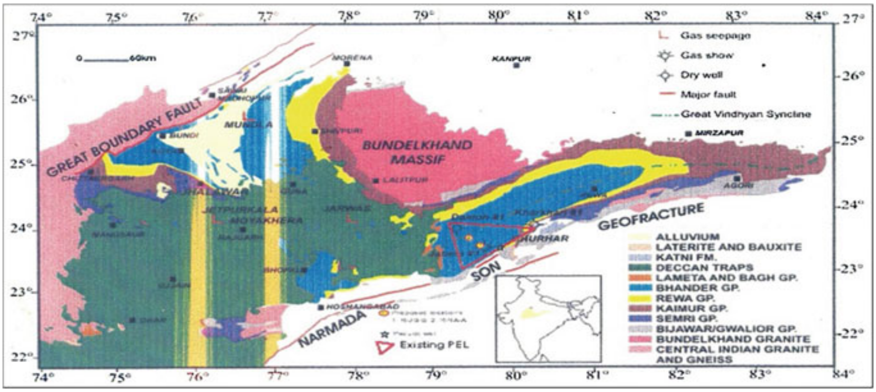
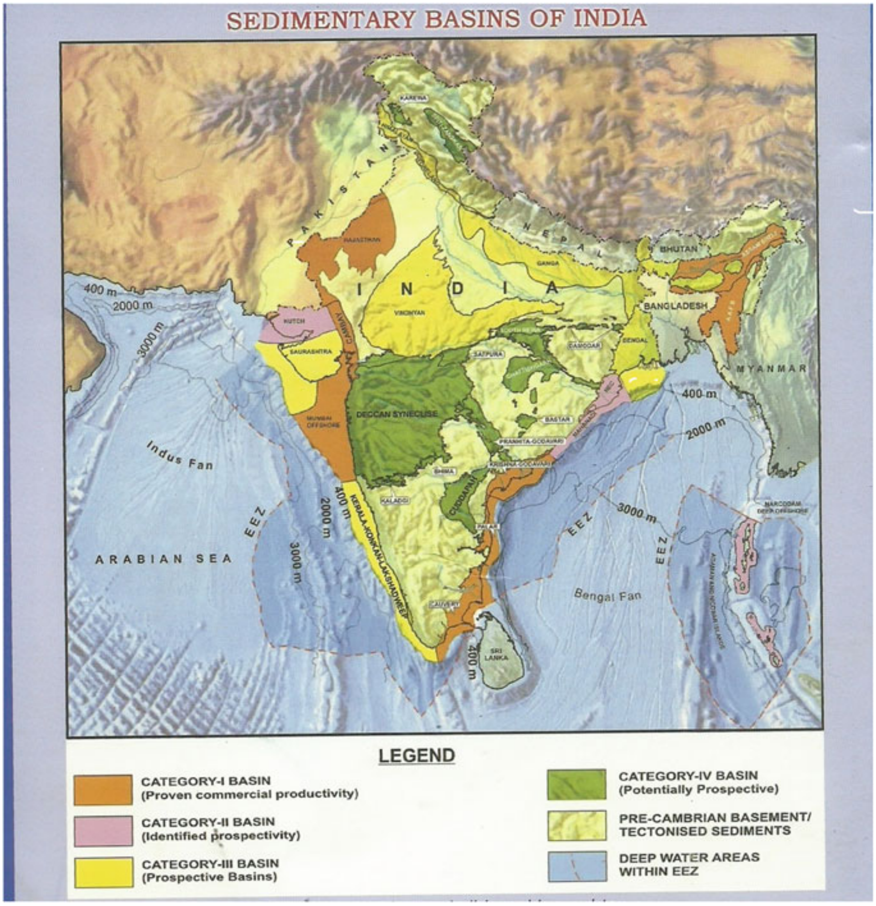


Fig. 1 Geological map of Vindhyan basin showing existing PEL, surface gas seepages, drillied wells, pseudo-well and proposed locations



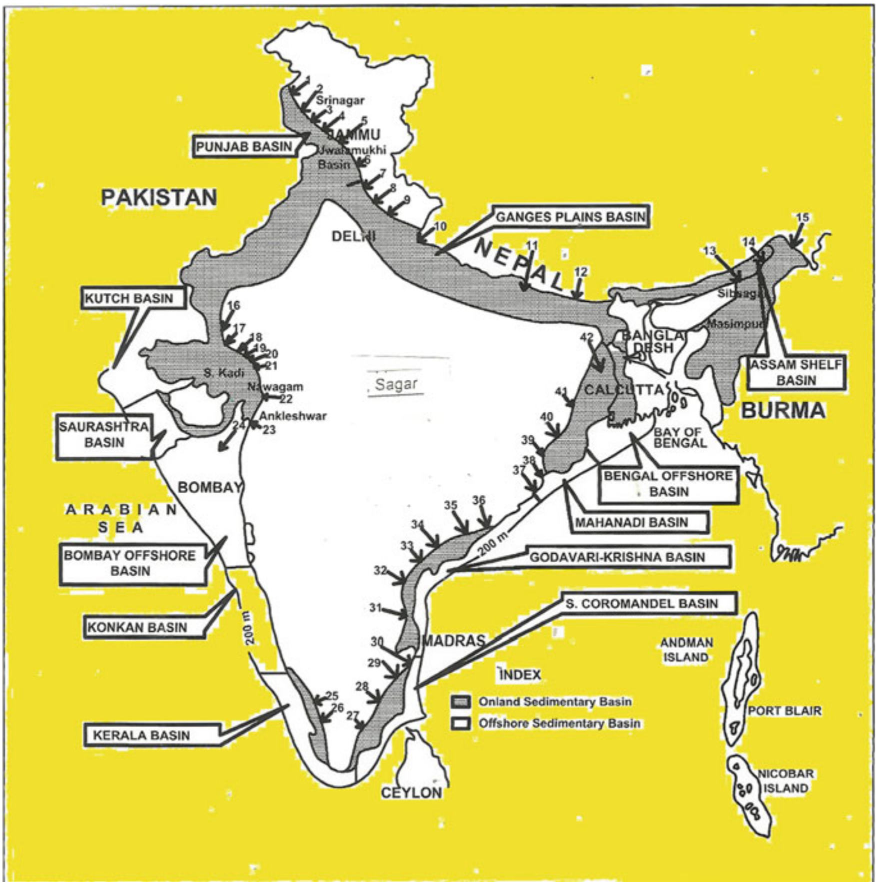
The carbon isotope studies of methane and other gases were done to know whether these petroleum gases are of biogenic or of thermogenic origin. Coleman et al. (1977) in a study on the leakage of gas from the underground storage reservoir showed that isotopic analysis is a reliable technique for differentiating between methane from thermogenic and biogenic source. A useful geochemical method to correlate gases with their source rocks is δ C^{13} determination. The isotopic composition of methane was found to be a more reliable indicator of hydrocarbon reservoir. Shandilya (2007) has reported the occurrence of the petroleum gas in the Sagar District and suggested that these petroleum gases are of thermogenic in origin. Shandilya (2008a, b, c, d) made Discovery of Natural Gas leakages from Bore wells in the rocks of the Vindhyan Super group in Sagar and Damoh Districts, MP and forecasted the reserve of Natural Gas Reserves in Sagar District. Shandilya (2009a, b, c) published an article on GAS IN THE BACKYARD in the BUSINESS INDIA MAGZINE suggesting that this gas is of thermogenic origin. Shandilya (2009a, b, c) has suggested the possibility of Petroleum Gas reserve in Southern Bundelkhand Region, MP. Shandilya and Gajbhiye (2010) made the Discovery of Rare Helium Gas in Sagar District, MP.

Prasanna et al. (2010) conducted the detail investigation of light gaseous hydrocarbon anomalies in the surface soil around Sagar using the geochemical exploration methods for hydrocarbon leakages. The investigation was focused on the detection of absorbed petroleum gases by gas chromatographic method, in Vindhyan basin using composition and ratio of the light hydrocarbons methane, ethane, propane and butane (Fig. 2).

Geology

The present natural gas leakages has been discovered in the dried tube wells, located on the rocks of Sandstone, shale and limestone rocks of the Rewa and Bhander Group of the Vindhyan Super Group as the basement rocks. These petroliferous rocks are overlain by the Lameta bed (late Cretaceous) in the western part of the Pipariya and Bhutoli area in Garhakota tahsil. The western part of the present area is overlain by the rocks of Upper Cretaceous Deccan Trap Basaltic flows, which are intercalated with intertrappean limestone. The area where the leakages of petroleum gas have been discovered is located on the alluvial soil cover. The Deccan Trap Basaltic rocks are exposed in west of the Chinnoua village in Garhakota Tahsil. The dips of the sandstone and shales rocks are 10°–15° toward SE direction. The topography is more or less flat with some low-lying areas near the stream. The geological formation of Sagar area consists of 09 flows of Deccan Trap.

With several intertrappean limestone beds, whole area being underlain to the east and south by the Lameta limestone, which forms the plains and some hills to the south. Western fringe of The Rahatgarh and Meerkhedi areas are covered mostly by the Basaltic flows of Deccan Traps except few inliers of the shale and sandstone rocks of Rewa Group and Bhander Group of the Vindhyan Super Group. The Deccan Trap basalt rocks are mostly covered by the black soil. The Deccan volcanism during late Cretaceous must have generated the proper thermal conditions and acted as a catalyst in triggering Mesozoic hydrocarbon generation processes in the Vindhyan sedimentary basin in Central India (Table 1).



Sl. No.	RIVER	BASIN	Sl. No.	RIVER	BASIN	Sl. No.	RIVER	BASIN
1	Kishanganga	PUNJAB	16	Luni	RAJASTHAN	31	Penneru	KRISHANA - GODAVARI
2	Jhelum		17	Sukri		32	Gundlakamma	
3	Chenab		18	Banas	CAMBAY	33	Krishna	
4	Ravi		19	Saraswah		34	Godavari	
5	Beas		20	Sabarmati		35	Nagavali	
6	Sutlej		21	Mahi		36	Banshadhari	
7	Yamuna	GANGA PLAINS	22	Narmada		37	Rushikulya	MAHANADI
8	Tons		23	Tapti		38	Mahanadi	
9	Ganga		24	Gulf of Khambat	Bombay Offshore	39	Baitarni	
10	Sarda		25	Periyar	KERALA	40	Subarnrekha	BENGAL
11	Gandak		26	Achankovi		41	Damodar	
12	Kosi		27	Valgai	S. COROMANDEL	42	Ganga	
13	Subarnsiri	ASSAM SHELF	28	Kaveri				
14	Brahmaputra		29	Ponnaiyar				
15	Dibang		30	Palar				

Note:-

1. **The base map by Bhagwan Sahay:Pressure regimes in Oil & Gas Exploration**
2. **The west coast reach between Bombay Offshore & Kerala Basin, and Sone & Chambal rivers that are flowing from SW to NE in Ganga basin should also be investigated.**

Fig. 2 Map of India (not to scale) showing petroliferous basins developed along the triangular area of paleocourse of the Indian rivers (JOUR. GEOL. SOC. INDIA, VOL. 85, JUNE 2015)

Table 1 The stratigraphic succession in Sagar District, MP

Age	Formation
Recent sub Recent/quaternaries	Alluvium soil
	Black soil
Upper cretaceous	Deccan trap basalt (with intertrapean limestone)
Lower cretaceous	Lameta formation
Late proterozoic	Bhander (containing the petroleum gas and helium gas)
	Rewa
Vindhyan super group	Kaimur
	Semri
Middle proterozoic Bijawar super group	Phosphastic dolomite
	Dolomite
	Ferrugenous shale
	Ferrugenous sandstone
	Iron formation/BHQ
	Quartzite
	Conglomerate bed
Early proterozoic Bundelkhand granite complex	Quartz reef intrussion
	Pegmatitic intrussion
	Ultramafic intrusive
	Granite intrussive rocks
	Granite gneiss
	Biotite schist
Archean Mehroni super group	Intrussive body
	Dolomitic marble
	Slate
	Ferrugenous formation
	Quartzite
	Schist

(Modified after Rang rajan 1978)

Observation

On the request of authors, the Director Exploration, KDM IPE, ONGC Dehradun and Director, NGRI Hyderabad has sent a team of scientists for the detailed investigation had visited the Piparia–Bhutoli and Rahatgarh and Meerkhedi area and collected the samples of soil, water and gas. The samples were collected from the following localities:

1. Bhu-1: These tube wells fall under the panchayat and P.O. chanauaa tahsil Garhakota district Sagar, MP (part of survey of India toposheet no. 55 m/L). It is accessible by a 3 km Village road from town Garhakota around 45 km East

of Sagar on way to Damoh. The leakage of petroleum gas is reported from 08 tube wells in the month of March 2007.

(a) These bore/tube wells varying in the depth from 260 to 400 ft. with top 60 ft. is of 8″ diam with plastic casing, and rest of well is of 6″ diameter depth 340 ft.) of Shri Bhagwan singh Yadav (lat: 23° 47′ 59.2″N, long: 79° 05′ 29.6″E, Elevation 448 m).

(b) Pip-1: The tube wells (depth 400 ft.) of Sri Asharam Patel S/o Sri Ghappu Patel (lat: 23° 48′ 20″N, long: 79° 50′ 20.7″E, Elevation 450 m).

2. Rah-1: This village is located 40 km west of Sagar on way to Bhopal Road. In the bore well of Shri Leeladhar Tiwari (Tiwari Dhawa: lat: 23° 57′ 15.7″N, long: 79° 25′ 03″E, Elevation 484 m), the tube well is situated on the deccan trap—Vindhyan contact. The leakage of petroleum gas has been reported since 1993.
3. Mee-1: This tube well (lat: 23° 45′ 56″N, long: 78° 18′ 9.6″E, Elevation 440 m) from where gas seepage was occurring belongs to Shri Dhan Singh. The area falls in the toposheet of India No. 55 I/5. This tube well is the eastern extremity of village Meerkhedi, 13 km of Rahatgarh on way to Vidisha. This tube well pouring the petroleum gas sinse 1984 having enormous bubbling in the water. The tube well is located on the contact of daccan tram basalt and vindhyan sand stone (Inlier). The quantity of petroleum gas bublings increase day by day.
4. Mah-1: The leakages of the petroleum gas has been reported since 2009 from this village in Patharia Tahsil of Damoh district. The 378 ft. deep tube well is pouring the water along with the natural petroleum gas and the water which is coming out of the tube well is burning up to 2–3 ft. long flame. In the bore well of Sri Halle singh Lodhi at Mahalwara about 11 km north of Patharia railway station in Damoh District. Is also containing the leakages of petroleum gas in the 378 deep tube well, which was digged in November 2008. The tubewell water getting fire, when light up the matchstick about 1.00 m high flame burning in water. The petroleum gas is also coming out of the tube well when no pumping is done, the leakage of the gas can be easily seen in it.
5. Bat-1: It is located about 25 km from Damoh. In the tube wells the water gives the smell of kerosene/diesel in the month of November–December, 2008 onward. The tube wells are varying in depth from 350 to 400 ft. in the Vindhyan Limestone rocks.
6. Pat-1: In this village the tube well is situated in the inliers of the Vindhyan. Rocks among the Deccan Trap cover, the tube well was digged in 2000, and depth is about 380 ft. It is also pouring the natural petroleum gas as it was reported in November, 2011.
7. SUK-1: In the agricultural field near the Limestone quarry of Narsingh garh Cement (Heidel berg Cement Plant) there is a leakages of petroleum gas along with water. Reported in December, 2009.
8. Man1: A tube well situated in the Deccan trap rocks in Mandi Bamora, depth is 390 ft. digged in May, 2012 also pouring the natural gas along with water. The

flame of 8–10 ft. was observed at the well site in the Public Health Centre at Mandi Bamora. The thickness of the Deccan trap is very low at the site, resting over the rocks of Vindhyan Super Group, in the northern most extend of the Deccan cover.

9. Kon-1: At this village the tube wells are also pouring the gas during the month of November and December and the water is giving the smell of the kerosene in it. It is situated on the rocks of the Vindhyan Super Group.
10. Jhi-1: The tube well is situated on the inlier of the Vindhan rocks. The tube well was digged in Deccan trap rocks, which has overlying the rocks of Vindhyan Super Group. The depth of tube wells are varying from 300 to 400 ft.
11. Ban-1: In this village the leakages of the natural petroleum gas has been reported in March 2012, from a tube well which is about 360 ft. deep. The gas with more speed is coming in the afternoon hour and with bubling sound from the tube well.
12. Gho-1 The Gho-1 falls in the Banda Tahsil of Sagar District. About 25 km from Banda, on the way to Patharia. In this village, there are six (06) tube wells pouring natural gas along with the water. Two hand pump are also leaking this petroleum gas and burning day and night, with the help of the local administration the fire has been controlled since May 7, 2012. The continuous gas leakage has been reported from this village. In the agriculture field of the villagers, the tube wells were digged in different time, but all of them were pouring the natural gas, which is burning 6–8 ft. long flame.

The experiment of the gas leakages was done in some of the old tube wells, in which the natural gas in coming along with water, which is burning, one can say that there is water in burning (\Paani me Aag).

Geochemical Analysis

1. At ONGC Dehradun

The samples were analysed in the geochemical laboratory of KDM IPE Kaulagarh Road, ONGC, Dahradun. The finding of the geochemical analysis of the natural gas, water and soil are as follows (Table 2).

The Oil and Natural Gas Commission Dehradun has concluded with the seepaged gases of Pipariya, Bhatoli and Rahatgarh as predominantly methane (72.14–84% in

Table 2 Geochemical composition of natural gas and stable isotope values

S. No.	Bore well	Chemical composition % (v/v)						Isotopic values (δ C^{13})
		He	O_2		CO_2	C_1	C_{2+}	δ C^{13}
1	Pipariya Bhatoli	0.34	1.6	24.87	0.93	72.14	0.01	−61.5
2	Rahatgarh	0.72	0.65	14.37	0.28	84.00	0.02	−54.0

(After Shandilya 2007)

Pipariya, Bhutoli and 99% in Tiwari Dhaba, Rahatgarh Bore well, and are devoid of higher hydrocarbons. The hydrocarbon gases seem to have predominance of bacterial methane. The pressure of both the seepages is extremely low. As per the owners, the quantity of gas is diminishing day-by-day. The results this time of methane is concerned. Genetically the seepage gases from Pipariya, Bhatoli and Rahatgarh seem to be different from thermogenic gases encountered in exploratory well Jabera-1, drilled by ONGC in Damoh District (MP).

In January 2008, in Bhutoli village further land owner bore the well up to 400 ft. deep, there is huge quantity of natural gas reported to government agencies. In February, 2008 two villagers at Pipariya–Bhutoli have drilled two more tube wells up to the depth of 300–350 ft. about 600–700 m away from the earlier wells in the shales and sandstone rocks of Lower Bhander, they could not get the ground water, but there was leakage of natural gas, which is also giving blue flame.

2. **At NGRI, Hyderabad:**

The samples of petroleum gas, soil and water were also collected by the scientists Dr. A.M. Dayal, Dr. Ravi Srivastava, and Dr. D.J. Patil of NGRI Hyderabad along with the author on May 4–5, 2008. The detail geochemical and stable isotopic studies of the natural petroleum gas, soil and water sample has been done in the Laboratories of NGRI (Tables 3 and 4).

The presence of the ethane gas in both the Localities, and $\delta\ C^{13}$ value in the range of −0.249 and −26.4‰ w.r.t. PDB indicate the thermogenic source of these gases. On the basis of the geochemical and stable isotopic studies of the natural petroleum gas, soil and water suggest that the samples of the Piparia–Bhutoli–Rahatgarh–Meerkhedi of Sagar District containing 72–99% of methane, 0.34–0.742% of Helium, along with the oxygen, carbon dioxide and Nitrogen gases. The stable isotopic $\delta\ C^{13}$ value in the range varying from −43.6‰ w.r.t PDB for methane −24.66‰ w.r.t PDB for ethane at Piparia–Bhutoli to −54.9‰ w.r.t PDB for methane and per mil w.r.t PDB for at Rahatgarh are indicative of the THERMOGENIC origin and also that methane is associated with oil. Bernard (1978) suggested a genetic diagram by correlating (C1/C2 + C3) ratio with $\delta\ C^{13}$ 1 concentration of methane to

Table 3 Stable isotopic value of hydrocarbon gas in Sagar District, MP, India

Location	Name of petroleum gas	Stable isotopic value $\delta\ C^{13}$
Piparia–Bhutoli	Methane	−43.6‰ w.r.t. PDB
	Ethane	−24.6‰ w.r.t. PDB
Rahatgarh–Meerkhedi	Methane	−54.9‰ w.r.t. PDB
	Ethane	−26.4‰ w.r.t. PDB

(After Shandilya 2008)

Table 4 The absorbed soil hydrocarbon gas concentration in Sagar District, MP

	C1	C2	C3	*i* C4	*n* C4	$\sum C3^{+}$
Minimum	1	1	1	1	1	1

classify natural gas types. Molecular ratio C1/C2 + C3 less than 50 are typical for the thermogenic hydrocarbon gases with δ C^{13} values between −30 and −55% (PDB). This suggests that most of the samples fall in the thermogenic range.

The adsorbed soil gas result indicates the presence of methane, ethane, propane and butane in Sagar District, MP. The adsorbed soil gas and carbon isotope studies suggest that these seeped hydrocarbons are of thermogenic origin and petroliferous in nature and indicate the area is warm for hydrocarbon exploration area.

Conclusion

In my opinion the natural petroleum and helium gas are containing the higher amount of Methane (72–99%), and remarkable content 0.34–0.742% of Helium, and minor amount of oxygen, nitrogen and carbon dioxide, it suggests that it must have been formed at higher temperature condition at deeper horizon in the Pre-Cambrian Vindhyan sedimentary basin (Proterozoic in age). The reservoir must be lying below the ground at least 500 m or more deep level. The present leakages of natural gas releasing through many hairline cracks/fracture and feather joints in the sandstone, shales and limestone rocks of the Rewa and Bhander group rocks of the Vindhyan Super Group.

As per the geochemical and stable isotopic studies of Gas samples analysed at NGRI; it found out the methane and ethane gases. The presence of ethane gas collected from the abovementioned localities and the δ C^{13} stable isotopic value in the range of −24.9 to −26.9‰ w.r.t. PDB indicative of the Thermogenic sources.

Acknowledgements The authors are thankful to the Director, NGRI and Dr. A.M. Dayal Asstt. Director of NGRI Hyderabad, and the Director, KDMIPE, ONGC, Dehradun for the Geochemical and Stable isotopic analysis of the various samples. The author is highly thankful for the critical comments and valuable suggestions on this manuscript by Prof. R.P. Tiwari Vice chancellor, Dr. H.S.G. University, Sagar and Prof. P.S. Saklani, Ex, Vice Chancellor, HNB Garhwal University, Srinagar Garhwal and Prof. S.P. Banarjee and Prof. K.S Pitre, Department of Chemistry, Dr. Hari Singh Gour University, Sagar, MP.

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How Soil Texture Affects the Organic Carbon Load in the Mangrove Ecosystem? A Case Study from Bhitarkanika, Odisha

Kakoli Banerjee, Gobinda Bal and Abhijit Mitra

Abstract We analysed the inter-relationship between soil texture and organic carbon (OC) in 12 stations of Bhitarkanika mangrove ecosystem. Our first-order analysis reflects a significant positive correlation of silt and clay with OC ($r_{\text{silt} \times \text{organic carbon}} = 0.90$; $p < 0.01$ and $r_{\text{clay} \times \text{organic carbon}} = 0.84$; $p < 0.01$). However, in case of sand, a significant negative correlation is visualized with OC ($r = -0.89$; $p < 0.01$). The results indicate that OC forms a coating over silt and clay particles on the basis of principle of cohesion, but this cohesive force is not visible in case of sand particles. The overall analysis suggests the need of coastal vegetation conservation in the Bhitarkanika area as their decomposition products lead to the formation of organic carbon that serve as important nutrient for the growth and survival of the mangrove vegetation in the study area.

Keywords Bhitarkanika mangrove ecosystem · Soil texture
Soil organic carbon (SOC)

Introduction

Mangrove ecosystem is a storehouse of rich floral and faunal biodiversity with endemic adaptation having great ecological and economical significance. The product of biodiversity is the basic need for growing human populations. Among the biodiversity rich regions, the coastal marine ecosystems are one of the most productive, biologically diverse and significantly valuable areas. Hence, they are also called as, "heart of ocean". They produce high detritus and particulate organic

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matter and release as nutritious food for various organisms. Some other usefulness of mangroves are fuel, energy, health, medicine, food, fertilizer and many other industrial products. The important biogeochemical services of mangroves include the entrapment of sediments and pollutants, filtering of nutrients, remineralization of organic and inorganic matter, and export of organic matter (Alongi et al. 1992). But as a result of climate change and unplanned developmental activities, the mangrove forests are suffering from its degradation.

The ongoing physical, chemical, biological and geological processes change the dead organisms, detritus and riverine organic materials, etc. into particulate matter and enrich the adjacent aquatic ecosystems. These processes also include the supply of inorganic and organic substances from river run-off, resuspension of previously deposited sediments production and breakdown of biological materials, and physico-chemical adsorption-desorption processes related to redox reactions near water-sediment boundary (Feeby et al. 1986). Salinity of soil depicts the geographical feature and position of the ecosystem (Banerjee et al. 2012). The salinity of soil is also dependent upon the amount of fresh water discharge (Mitra et al. 2011). High amount of anthropogenic sewage discharge increase the pH of soil in mangrove (Banerjee et al. 2012). The climate, geomorphology, tidal range, fresh water input, physico-chemical properties and biological factors, etc. together control the nutrient status, productivity and biodiversity of mangroves. The mangrove sediments of Bhitarkanika were Pleistocene deposits comprising clay, sand, silt and 'kankar', with reddish brown cemented pebbles and gravels due to high degree of oxidation (Banerjee and Rao 1990). Benthic zones near continental shelf act as closed vessels, which wells up nutrient between adjacent terrestrial land mass and ocean. Mangrove largely constitutes fertile estuary with rich source of nutrients having detritus-based food web. The vegetation forms a direct source of food for insects, crustaceans, invertebrate and vertebrates. Most of the productions from mangroves get transferred to other trophic levels by means of litter fall and detritus pathway.

In biological point of view, mangrove ecosystem is primarily a source of organic matter and nutrients, which also acts as sink for organic carbon, sediments and pollutants over a long period of time (Kristensen et al. 2008). Mangrove sediments characterized by high organic matter serve as organic substrates for microbial communities (Alongi 1998). Thus, the ecosystems play a vital role in the biogeochemistry of contaminants present in the tropical coastal areas (Dittmar and Lara 2001) and hence they have remarkable potential to store nutrients (Dwivedi and Padmakumar 1983). The nutrient fluctuation of a mangrove ecosystem is an important function in terms of biogeochemical cycling of elements in the coastal zone (Jennerjahn and Ittekot 2002). The sediments of mangrove play a pivotal role in nutrient biogeochemical processes, both as a source and sink for nutrients and organic matter. Sediments are characteristically rich in organic matter but low in nutrient quality. The nutrient and organic matters dynamics in the high salinity coastal wetlands also depends upon the river run-off, anthropogenic discharges and allochthonous (mangrove litter, phytoplankton and benthic algae) (Hedges and Keil 1995; Hedges et al. 1997; Harji et al. 2010). The fate of this detritus is recycling within or outwelling from the mangrove forest in dissolved micro-particulate and macro-particulate forms (Kristensen et al. 2000). The decomposing mangrove litter is a function of input and export by tides and run-off. The mean residence time of the detritus vary between 58 and 252 days in mangrove basin and 40–91 days for fringe and riverine forests (Twilley et al. 1986). Decomposition rates increase with humidity, temperature, oxygen availability and composition of the organic matter (Kathiresan 2000).

With this background, the present paper aims to study the physical properties of soil such as soil temperature, soil pH, soil salinity and soil texture in mangrove areas and find the correlation of soil characteristics with the soil organic carbon in the study area.

Materials and Methods

Study Area

The Bhitarkanika mangrove forest is situated in the Rajnagar sub-division of Kendrapara district, Odisha. The Bhitarkanika estuary is formed by the major rivers such as Brahmani, Baitarani and Subarnarekha, Dhamara, Maipura, Patsala, Hansua and Hansina. The rivers have formed many islands namely Kalibhanjadian, Wheelers group, Bagulidian, Manakudian and Udabali with dense mangroves and black alluvial soil with sand, silt, clay and kankar. The climate of the area is tropical humid experiencing mainly three seasons (summer, rainy and winter). The summer starts from mid February and end in mid June with April as the hottest month of the year. The occasional rain and cyclones occur in the end of the summer. The rainy season starts with the influence of southwest monsoon, with maximum amount of rainfall. The winter starts from November, and continues up to February. January is the coldest month. The maximum and minimum temperature ranges between 10 and 45 °C. The average annual rainfall is 1200 mm. Field studies were conducted at 12 different locations of Bhitarkanika Wildlife Sanctuary (Fig. 1 and Table 1).

Sampling Techniques

The soil samples were collected randomly from selected locations of mangrove area located in east coast of India in the months of June–July 2015. The soil samples were taken using soil corer, at depth of 0–10 cm from the top, kept in chill condition (i.e. ice box) and brought to the laboratory. In laboratory, the soil samples were air dried, homogenized and passed through a 2 mm mesh sieve to remove the stone pieces and large root particles. The composite soil sample was used for detail

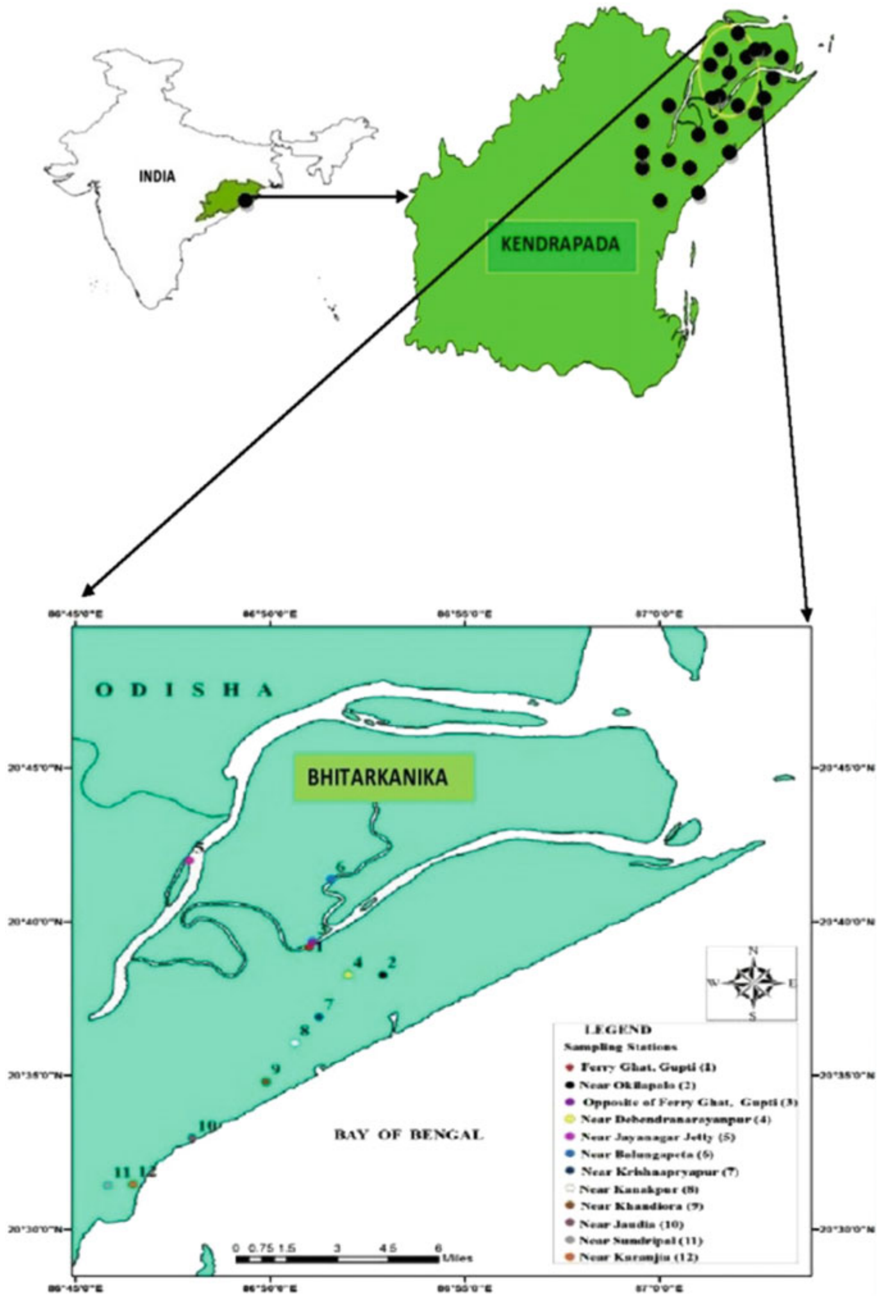


Fig. 1 Map of sampling sites

Table 1 Sampling site coordinates with description

S. No.	Name of the stations	Coordinates latitude longitude		Major activity
1	Ferry Ghat, Gupti	20° 39′ 09.80″N	86° 51′ 01.07″E	Transport and tourist
2	Near Okilapalo	20° 38′ 15.71″N	86° 52′ 53.15″E	Transport and agriculture
3	Opposite of Gupti	20° 39′ 20.83″N	86° 51′ 05.54″E	Transport and tourist
4	Near Debendranarayanpur	20° 38′ 15.92″N	86° 51′ 59.79″E	Sewage discharge
5	Near Jayanagar Jetty	20° 41′ 58.51″N	86° 47′ 55.02″E	Transport and tourist
6	Near Balungapeta	20° 41′ 22.57″N	86° 51′ 33.19″E	Agriculture
7	Near Krishnapryapur	20° 36′ 53.95″N	86° 51′ 15.47″E	Tourist and agriculture
8	Near Kanakpur	20° 36′ 02.33″N	86° 50′ 38.38″E	Agriculture
9	Near Khandiora	20° 34′ 47.42″N	86° 49′ 53.73″E	Agriculture
10	Near Jaudia	20° 32′ 58.04″N	86° 47′ 59.40″E	Agriculture and aquaculture
11	Near Sundripal	20° 31′ 25.29″N	86° 45′ 49.29″E	Agriculture and aquaculture
12	Near Karanjia	20° 31′ 27.71″N	86° 46′ 28.05″E	Agriculture and aquaculture

analysis of soil salinity, pH, temperature, soil texture and organic carbon through standard methods.

Analysis of Soil Parameters

The soil temperature was measured by using digital thermometer (SIGMA) by dipping it in the soil directly, and five readings were taken and the average soil temperature reading was taken as final. The soil pH was measured by using digital pH metre (SYSTRONICS), and similar process was repeated with five readings and the average was calculated as final. Soil salinity was determined by measuring the electrical conductivity with the help of a conductivity metre. Soil texture was measured by the Hydrometer method (Gee and Bauder 1986). Soil Organic Carbon of the samples were analysed by the standard titration method (Walkley and Black 1934). The data collected were expressed as Mean ± standard deviation. In order to find out the difference between the physico-chemical parameters of soil in mangrove areas ANOVA analysis was computed using SPSS 13.1. Correlation coefficients were computed in order to find out the inter-relationship between soil physical properties and soil organic carbon.

Results and Discussion

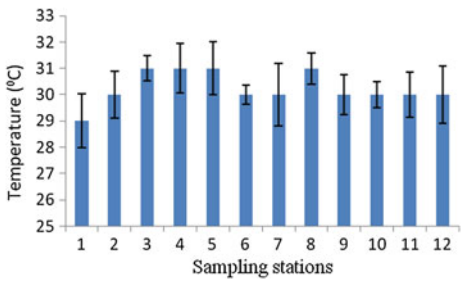
The biological stability of soil organic carbon (SOC) is influenced by the chemical structure of SOC and the existence of various mechanisms of protection offered by soil minerals and their spatial arrangement within the soil matrix (Baldock and Skjemstad 2000). The degree of physical protection of SOC is mainly a factor of soil texture, specific mineral surface area and soil mineralogy. However, other soil parameters (e.g. water holding capacity, pH, porosity) can act as rate modifiers in attaining the protective capacity, set by the mineral matrix of the soil (Krull et al. 2001). The results of the present research programme are discussed under separate headings.

Soil Temperature, Soil pH and Soil Salinity

The soil temperature, salinity and pH are the major essential parameters which are generally influenced by the intensity of solar radiation, evaporation, insulation, freshwater influx and cooling. The average soil temperature varied spatially in the study area depending on the location and sampling time (Fig. 2). The maximum soil temperature recorded in study area was 31.2 ± 0.94 °C at station 4 and minimum of 29.9 ± 1.03 °C in station 1 with an average temperature of 30.87 ± 0.90 °C. Soil studied during present work showed swamp-mud in the study area, being typical characteristic of a mangrove ecosystem in a tropical ecosystem. Moreover the specific heat capacity of vegetated land is 0.83 J/g. This is the reason why the mangrove areas are cooler providing shade from radiation and also through the cooling effect of water from leaves.

The soil pH fluctuation is not very high between stations with little bit acidic nature which may be due to presence of sulphuric acid. The average soil pH recorded in the study area is 6.82 ± 0.45. The maximum soil pH was recorded 7.28 ± 0.86 in station 5 and minimum of 6.34 ± 0.62 in station 12 (Fig. 3). The pH of soil showed more acidic in the study area as the mangrove environment is

Fig. 2 Graph showing variation in temperature at the sampling sites



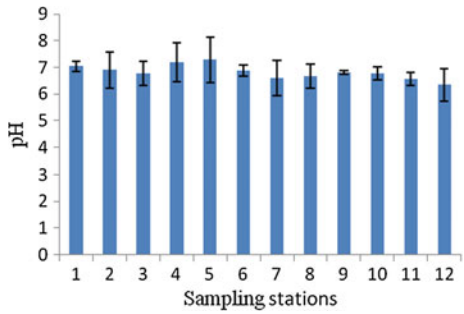


Fig. 3 Graph showing variation in pH at the sampling sites

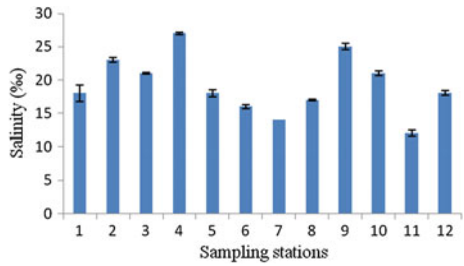


Fig. 4 Graph showing variation in salinity at the sampling sites

subjected to change into addition of organic substances by mangrove flora and fauna. Level of carbonates and bicarbonates is also dependent on the location of the forest (Chaudhary and Bhattacharya 1984; Williams 1987; Bhosale 1990). The pH of the mangrove sites is also hampered by addition of domestic waste along with freshwater influx in rainy season which might have resulted in lowering of pH at station 12, the station being located in the fringe area of Bhitarkanika mangrove ecosystem (Nair et al. 1984; Hossain et al. 1988). The organic acids released from the mangrove vegetation may have driven the pH of soil to lower value. Similar studies have also been found by Banerjee et al. (2012), while working for the Sundarban mangrove ecosystem. The low value of pH indicates acidic condition of mangrove soil which may be due to the oxidation of ferrous sulphate ($FeSO_4$) and ferric sulphide (FeS) to sulphuric acid (H_2SO_4) (Holmer et al. 1994).

The average soil salinity was found to be 19.17 ± 0.37‰ with maximum soil salinity in station 4 (27.0 ± 0.21‰) and minimum in station 11 (12 ± 0.27‰) (Fig. 4). The soil salinity reflects the geophysical features of the ecosystem. It is also an indicator of dilution caused by run-off, stream discharge, barrage discharge and other anthropogenic activity. Relatively low soil salinity at station 11 may be due to the effect of discharge by the Bramhani, Baitarani, Hansua and Maipura rivers to the Bay of Bengal. Similar results have also been reported by (Saisastry and Chandramohan 1990; Vijayalaksmi et al. 1993; Senthilkumar et al. 2002 and

Banerjee et al. 2012) while working in the Godavari estuary, Gulf of Kachchh, Bellar estuary and Sundarban estuaries, respectively.

Soil Texture

The architecture of the soil mineral matrix refers to the arrangement of pores and soil particles. Almost all organic carbon in soil is located within pores between mineral grains either as discrete particles or as molecules adsorbed onto the surfaces of mineral particles. Soil architecture can influence the biological stability of organic materials through its effects on water and oxygen availability, entrapment and isolation from decomposers, and through the dynamics of soil aggregation. Soil texture is a single most important physical property of the soil and alone provides status of water flow potential, water holding capacity, fertility potential and suitability for many urban uses (Chaudhuri and Choudhury 1994; Sarkar et al. 1999). In the present study, the soil texture has been measured in term of sand, silt and clay at all the sampling points in the study area. The values of sand, silt and clay ranged from 14.0 ± 0.56% to 62.0 ± 0.65%, 13.0 ± 0.34% to 45.0 ± 0.44% and 25 ± 0.13% to 49.0 ± 0.38% with an average value of 25.83 ± 0.48%, 34.25 ± 0.41% and 39.9 ± 0.32%, respectively, (Figs. 5, 6 and 7). The values of sand, silt and clay varied as per the order clay (39.9 ± 0.32%) > silt (34.25 ± 0.41%) > sand (25.83 ± 0.48%) in the mangrove area. This is mainly due to the difference in soil susceptibility erosion (erodibility) based on texture. A soil with high percentage of sand, silt and clay particles (mangrove area) has greater erodibility. Under the same conditions, the high silt and clay domination in texture in the mangrove areas may be attributed to the winnowing activity of sediment transported system through the rivers flowing in the Bhitarkanika estuaries.

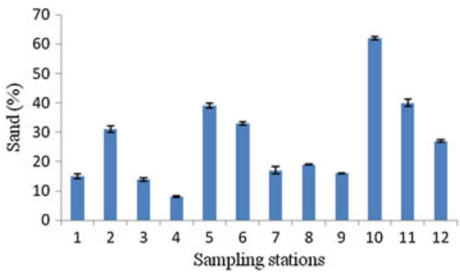


Fig. 5 Graph showing variation in sand percentage at the sampling sites

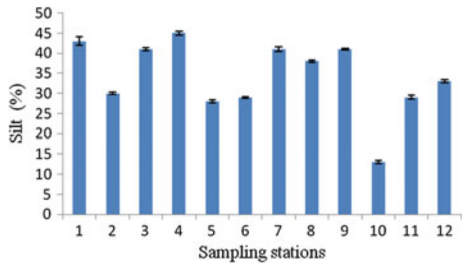


Fig. 6 Graph showing variation in silt percentage at the sampling sites

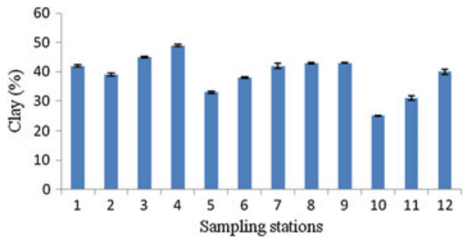


Fig. 7 Graph showing variation in clay percentage at the sampling sites

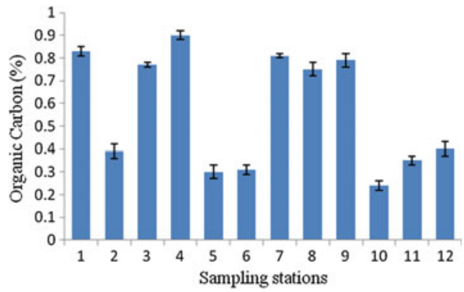


Fig. 8 Graph showing variation in organic carbon percentage at the sampling sites

Soil Organic Carbon

Soil organic carbon (SOC) refers to the carbon in soils associated with the products of living organisms. It is a heterogeneous mixture of simple and complex organic carbon compound, which can be divided into different pools that serve many functions to soil ecosystems. SOC is of fundamental importance to soil health and fertility namely chemical, physical and biological. It is also a part of the global carbon cycle, and the global SOC pool is twice as large as that in the atmosphere and nearly three times that of the vegetation biomass carbon pool. Soil organic carbon study is almost important from sequestration or storage of carbon in soil which is considered as a strategy for mitigating climate change. The average soil organic carbon in the study area was measured as $0.57 \pm 0.09\%$ with maximum value ($0.90 \pm 0.07\%$) at station 4 and minimum value ($0.24 \pm 0.07\%$) at station 10, respectively. This may be due to the presence of dense mangrove forest, diverse microorganisms and the riverine outfalls at the study sites (Fig. 8).

Table 2 Inter-relationship between soil physico-chemical parameters and organic carbon

	Temperature	pH	Salinity	Sand	Silt	Clay	Organic carbon
Temperature	1						
pH	−0.07	1					
Salinity	0.18	0.46	1				
Sand	−0.08	−0.09	−0.27	1			
Silt	0.03	0.10	0.21	−0.99	1		
Clay	0.17	0.11	0.39	−0.97	0.93	1	
Organic Carbon	−0.009	0.11	0.32	−0.90	0.91	0.84	1

Table 3 ANOVA computed to show variation among the study sites

Soil parameters	F_{cal}	F_{crit}	P value	Average values in mangrove area
Temperature	7.46	4.30	<0.05	30.87 ± 0.90 °C
pH	109.95	4.30	<0.01	6.82 ± 0.45
Salinity	0.52	4.30	<0.1	19.17 ± 0.37‰
Sand	94.68	4.30	<0.01	25.83 ± 0.48%
Silt	124.71	4.30	<0.01	34.25 ± 0.41%
Clay	230.51	4.30	<0.01	39.9 ± 0.32%
Organic carbon	25.71	4.30	<0.01	0.57 ± 0.09%

It is generally assumed that there is a positive correlation between clay content and preservation of SOC as documented in studies by Ladd et al. (1985), Schimel et al. (1985a, b), Spain (1990), Feller et al. (1991), Amato and Ladd (1992), and summarized by Oades (1989). Recent studies by Schjønning et al. (1999) and Thomsen et al. (1999) reported differences in the rate of degradability of soil carbon which was strongly correlated with water holding capacity and volumetric water content. In the present study, correlation coefficient computed between the soil parameters and SOC has also revealed a similar result (Table 2) at 1% level of significance. To analyze the spatial variation in the soil parameters ANOVA was computed between the stations that also showed significant variation in soil parameters (Table 3). This proves that our results are at par with the studies done by the earlier workers.

Conclusion

The study is extremely relevant from the point of view of mangrove growth and coastal vegetation and its substituent carbon storage. The present study is unique in itself as very few studies have been done on the comparative analysis of soil organic carbon, soil texture and soil properties in this mangrove ecosystem of Odisha. The present study also focuses on the quantity and quality of vegetation associated with variation in biogeochemical cycling in soil. Soil texture as revealed from the study contains high percentage of clay and silt in mangrove areas and has a greater cohesivity which is an important aspect from carbon storage point of view. Such study of soil physico-chemical properties in the mangrove areas highlights the physical foundation of every ecosystem for nutrient retention to ensure better tree performance for biodiversity conservation. Management action plan should be formulated for afforestation programme considering the parameters that have pronounced difference between the habitats. Hence in the management action plan parameters like organic carbon must be given priority for plantation programme. To elaborate more lucidly, substratum with less organic carbon may be carpeted with *Suaeda*, *Salicornia*, *Ipomoea* sp., etc. whose requirement of organic carbon is much less compared to true mangrove species.

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Part IV
Water Quality Assessment

Recent Developments in Defluoridation of Drinking Water in India

Swati Dubey, Madhu Agarwal and A.B. Gupta

Abstract Presence of high fluorides in groundwater has caused systemic fluorosis to become an endemic problem in many countries of the developing world, namely, India, Sri Lanka and many African nations. It is a conclusive fact that higher concentration of fluoride (beyond 1.5 mg/L) can cause teeth mottling and still higher concentrations may lead to different major health hazards including skeletal and neurological problems. The fluoride level in water in India ranges from 2 to 29 ppm, whereas the permissible level in drinking water according to WHO standard is 1.5 ppm and BIS 10500 permits only 1 ppm fluoride in drinking water. Various defluoridation techniques in India have been developed for maintaining the concentration of fluoride in water up to the permissible limit like Nalgonda Technique, reverse osmosis, activated alumina adsorption, Bio-F process, etc. Nalgonda Technique involves addition of Aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation, sedimentation, filtration and disinfection and the acceptable limit of water of 1 mg/l has been achieved. Defluoridation using activated alumina as adsorbent is not cost-effective. Hence, development of community-based defluoridation unit is needed with a technique which is cost-effective, technologically simple in operation while being able to keep the fluoride level in permissible limit. The paper critically discusses the recent developments in various defluoridation processes, identifies the pertinent gaps in them and offers plausible solutions by summarizing the ongoing research at MNIT Jaipur in order to obviate these gaps through appropriate technological interventions.

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Introduction

Fluorosis is the major health problem in 24 countries, including India, which lie in the geographical fluoride belt. Fluoride, above a threshold concentration, has been demonstrated to be toxic. Excessive consumption of fluorides for a long period in various forms results in deleterious effects on different tissues of the body such as teeth (dental fluorosis), bone (skeletal fluorosis) and soft tissues (non-skeletal fluorosis) (Barnett et al. 1968; Shekhar et al. 2012). It is a conclusive fact that higher concentration of fluoride (beyond 1.5 mg/L) can cause teeth mottling and still higher concentrations may lead to different major health hazards including skeletal and neurological problems (Sachan et al. 2014).

Dental fluorosis is characterized by staining, pitting and mottling of the dental enamel. However, much higher concentrations (approximately 4 mg/L) and long-time exposure can lead to crippling skeletal fluorosis and osteoporosis (Yakub and Soboyejo 2013). The highest fluoride concentration ever found in natural water was 2800 mg/L, recorded in Lake Nakuru in the Rift valley in Kenya (Kumar and Gopal 2000).

Various fluorosis mitigation programmes have been carried out worldwide through technological interventions involving a host of defluoridation technologies. In India, Government of India has set up National Drinking Water Mission to provide safe drinking water to its people and to combat fluorosis problem (Vaish and Vaish 2000), under which many subprogrammes have been initiated as described below:

- Project SARITA (Durgapur, Rajasthan) (Vaish and Vaish 2000): A pilot project (Fluorosis Mitigation Programme by defluoridation using Nalgonda based drum sets and Activated Alumina filters along with community awareness activities) was launched by SARITA in four villages of Dungarpur district of Rajasthan under the sponsorship of UNICEF.
- Sachetana Plus: Fluoride Mitigation Project (Mythri et al. 2012): BAIF Institute for Rural Development, Karnataka (BIRD-K), a nonprofit organization based in Tumkur District started a programme on fluoride mitigation through rainwater harvesting in 1996.
- Fluorosis mitigation project at Sonbhadra, UP (Gautam and Tripathi 2009): Peoples' Science Institute (PSI) in association with Banwasi Seva Ashram (BSA) began a programme of fluoride testing and fluorosis mitigation in Sonbhadra district in September 2004. Major components included health assessment, water quality monitoring, public awareness programmes, nutritional interventions, etc.

- Fluorosis Mitigation In Nuapada District, Orissa: Peoples' Science Institute (PSI) along with Sahbhagi Vikash Abhiyan (SVA) launched a fluorosis mitigation programme in four districts (Nuapada, Kalahandi, Bolangir, and Burger) of western Orissa in 2005.
- Fluorosis mitigation project in Dear District, MP: Water Aid (UK), Vasudha Vikas Sansthan, Dhar and People's Science Institute, Dehradun initiated a fluorosis mitigation programme in November 2008 in Dhar District, MP.
- Mitigation of Fluorosis in Nalgonda District Villages (Narayana et al. 2004): Sai Oral Health Foundation assisted by the Government of Andhra Pradesh, had adopted a strategy of providing low fluoride water in affected villages (Anthampet and Batlapally) in Nalgonda district through the use of bone char based domestic defluoridators and rainwater harvesting systems.
- Integrated Fluorosis Mitigation, Madhya Pradesh: National Environmental Engineering Research Institute (NEERI) in association with UNICEF, Regional Medical Research Center for Tribals (ICMR) and Public Health Engineering Department, Govt. of Madhya Pradesh launched Integrated Fluorosis Mitigation project in two districts (Jhabua and Dhar) based on interventions which included water dilution and defluoridation and nutritional supplements in both schools and communities.
- The state Government of Rajasthan through PHED is implementing the project of Fluoride Mitigation called Rajasthan Integrated Fluoride Mitigation Program (RIFMP) for all districts of Rajasthan. Phase-I of this programme aims to cover all villages/habitations where sources of drinking water are having fluoride concentration >5 ppm. All villages/habitations having drinking water source >1.5 ppm fluoride are being covered in II (3–5 ppm) and III Phases (1.5–3 ppm) of the programme. Presently, Nalgonda technique has been banned in RIFMP due to the reports of high residual aluminium in the treated water.
- National Rural Drinking Water Program (NRDWP): It was launched by Govt. of India in 2009 with a goal to provide every rural person with adequate safe water for drinking, cooking and other domestic basic needs on a sustainable basis.

With a view to resolve the problem of water scarcity and high fluoride concentration in drinking water, the Government of Gujarat has identified a few long term schemes. Some of the schemes, based on the import of surface water are Dharoi Reservoir Dependent Scheme, Sabarmati River Dependent Scheme and Narmada Canal Dependent Scheme (Piddennavar and Pushpanjali 2013).

Various defluoridation techniques in India have been developed for maintaining the concentration of fluoride in water up to the permissible limit like Nalgonda Technique, reverse osmosis, adsorption using activated alumina, Bio-F process, etc. They all have their applications and limitations for the treatment of water on a community scale.

Defluoridation Techniques

Defluoridation refers to methods of water treatment that reduce the concentration of fluoride in the water, normally, in order to make it safe for human consumption. Methods for defluoridation can be broadly divided into two main groups: adsorption and precipitation. Adsorption methods remove the fluoride by physical surface adsorption or ion exchange.

Nalgonda Technique

One of the most popular precipitation processes is the Nalgonda technique, which is a means of fluoride removal that depends on the flocculation, sedimentation and filtration of fluoride with the addition of aluminium sulphate or aluminium chloride and lime. Nalgonda Technique is preferred at all levels because of its low price and ease of handling (Dahi et al. 1996). Aluminium salt may be added as aluminium sulphate or aluminium chloride or a combination of these two, which is decided based on their original concentration in the water. The dose of aluminium salt increases with increase in the fluoride and alkalinity levels of raw water.

Aluminium sulphate ($Al_2(SO_4)_3.18H_2O$) is added to the water to acts as a flocculent. Though aluminium sulphate is commonly used in general water treatment as a flocculent, the amounts used in defluoridation are much higher (150 mg/mgF or 1000 mg/L or almost 20 times the normal dose used for coagulation). As is typical with flocculation processes, the water must be thoroughly stirred to ensure dispersal of the flocculating agent. Because the reaction results in an excess of H^+ ions, Lime ($Ca(OH)_2$) is added to the water during the process to help maintain a neutral pH and hasten the settling of the sediment. The amount of lime added is typically 5% (by mass) of the aluminium sulphate added, empirically 1/20th that of the dose of aluminium salt. Lime facilitates forming dense floc for rapid setting. Bleaching powder is added to the raw water at the rate of 3 mg/L for disinfection. The chemical reactions involved in the process are shown below:

$$\begin{aligned} 2Al_2(SO_4)_3.18H_2O + NaF + 9Na_2CO_3 &\rightarrow \left[5Al(OH)_3.Al(OH)_2F\right] \\ &+ 9Na_2SO_4 + NaHCO_3 + 8CO_2 + 45H_2O \end{aligned} \tag{1}$$

$$\begin{aligned} 3Al_2(SO_4)_3.18H_2O + NaF + 17NaHCO_3 &\rightarrow \left[5Al(OH)_3.Al(OH)_2F\right] \\ &+ 9Na_2SO_4 + 17CO_2 + 18H_2O \end{aligned} \tag{2}$$

Other aluminium containing compounds are also used for defluoridation of water. Recently, polyaluminium chloride (PACl) has gained interest as a defluoridating agent. Polyaluminium chlorides are synthetic polymers dissolved in water. They react to form insoluble aluminium poly-hydroxides which precipitate in big volumetric flocs. The flocs absorb suspended pollutants in the water which are precipitated with the PAC and can together be easily removed. PACl can be used as a flocculant for all types of water treatment, drinking water, industrial waste water, urban waste water and in the paper industry. Against the conventional use of aluminium sulphate (alum) it is showing distinct advantages. Highly charged polymer chain polymerization of aluminium ions and colloidal particles in water with high efficiency and power in and bridging flocculation function, can effectively remove the water turbidity, colour, heavy metals and trace organic compounds. The Nalgonda Defluoridation process that uses high dosages of alum varying from 145 to 1600 mg/L leading to the formation of stable colloidal aluminium/microflocs, can increase turbidity because of high colloidal aluminium residuals.

The major drawback with this process is that, it can give rise to a large number of dissolved complexes such as aluminium fluoride and aluminium hydroxyl fluoride complexes in treated water due to the presence of *aqua-complex aluminium ions formed during alum hydrolysis reactions and they have high charge to radius ratio*. Concentrations of as aluminium fluoride and aluminium hydroxyl fluoride complexes depend on the nature of the aluminium hydroxide precipitates/alumina surfaces, pH, fluoride content and temperature. Chowdhury et al. (1991) investigated hydrous aluminium oxide colloids produced by hydrolyzing aluminium sulphate at 98 °C and initial SEM studies showed that the colloidal particles were spherical, with an average diameter of 0.5 ± 0.1 μm at pH of 7.8. Such particle sizes are difficult to remove through plain settling practiced in the Nalgonda process. During this process, slight variations in pH, high fluoride concentrations and high alum dosages can also affect the coagulation process, causing the formation of stable colloidal aluminium/microflocs that will increase turbidity and cause *high aluminium residuals* (George et al. 2009). They render moderate to high quantities of aluminium in output water, which is objectionable. Driscoll and Letterman (1988) suggested that approximately 11% of aluminium inputs remained in the treated water as residual aluminium. The overall residual aluminium in the treated water would be due to both dissolved and colloidal aluminium present in it. The WHO standards and BIS 10500 (1991) permit only 0.2 mg/L as a safe limit of aluminium in drinking water, which is generally much lower than actual concentration of aluminium, treated by the above method (Selvapathy and Arjunan 1995; Berube and Brule 1994; Berkowitz et al. 2005).

A theoretical model, NALD-2, was developed by George et al. (2009) to study for interactions of fluoride and aluminium in the alum-based Nalgonda Defluoridation Process that can predict the extent of defluoridation as well as concentrations of dissolved and colloidal aluminium in the treated water with respect to changes in pH, alum dosage and initial fluoride concentrations. This model represents the defluoridation mechanism taking into account the charged behaviour of the amphoteric aluminium hydroxide colloids, available charged site densities and fluoride complexion reactions (Weng et al. 2002). Colloidal aluminium concentration is a function of alum dosage and pH of the water (Sanjuan and Michard 1987). The NALD-2 model helps in predicting alum dosages for minimum residual aluminium in alum treated water, as the fluoride removal is dependent on the available charged sites on the aluminium hydroxide particles (NEERI 2007).

The basic assumptions in the development of the NALD-2 model simulator are described as follows:

The overall residual aluminium in the treated water is due to the presence of colloidal and dissolved forms of aluminium (Parthasarathy et al. 1986). The dissolved aluminium in the defluoridated water consists of aluminium fluoride complexes such as AlF^{2+}, AlF^{2+}, AlF^{4-}, AlF^{2-} and $AlF_6{}^{3-}$ aluminium hydroxyl fluorides like $AlOHF^{+}$, $Al(OH)_2F_2{}^{-}$, free Al^{3+}; and hydroxides like $AlOH_2{}^{+}$, $Al(OH)_2^{+}$, $Al(OH)_4^{-}$ and $Al_2(OH)_2^{2+}$, etc., and their concentrations depend on the pH, alum and fluoride concentrations.

The particulate forms of aluminium that precipitate from the hydrolysis reaction consist of neutral forms like AlF_3^0, $AlOHF_2^0$, and monomeric $Al(OH)_3^0$ as well as polymeric aluminium hydroxide $Aln(OH)_{3n}{}^0$ species. Defluoridation occurs due to fluoride complexing with protonated sites on

$Aln(OH)_{3n}^0$ species and precipitates in its complexed form $Aln(OH)_{3n-1}F^0$.

The colloidal forms of aluminium in the suspension are stable charged colloidal precipitates $Aln(OH)_{3n-1}^{+}$ and $Aln(OH)_{3n-1}O^{-}$ that do not participate in the fluoride complexion reactions and remain in the treated water (Stumm et al. 1970).

The model equation that describe for total dissolved aluminium in the treated water including all dissolved species is described as:

$$\{Al_D\} = \{Al^{3+}\} + \{AlF^{2+}\} + \{AlF^{2+}\} + \{AlF^{4-}\} + \{AlF_5^{2-}\} + \{AlF_{63-}\} + \{AlOHF^{+}\} + \{Al(OH)_2F_2^{-}\} + \{AlOH_2^{+}\} + \{Al(OH)_2^{+}\} + \{Al(OH)_4^{-}\} + 2\left\{Al_2(OH)_2^{2+}\right\}$$

The most important application of Nalgonda Process Simulator (NALD-2) is for prediction of concentrations of various aluminium fluoride complexes (AI-F, AI-OH, AIOH-F), precipitated fluoride, residual fluoride in free and complexed forms; and dissolved, colloidal and precipitated forms of aluminium in treated water. It also demonstrates the effect of alum dosage, pH and initial fluoride concentrations, etc., on these species concentrations, defluoridation process efficiency and can determine optimal conditions for minimum residual aluminium. NALD-2 model simulator can help in finding the optimum conditions and these findings are of high practical significance in not only providing a comprehensive knowledge base of aluminium fluoride interactions in the area of defluoridation but also pave the way for developing simulation tools for prediction of residual aluminium in alum-based defluoridation and conventional water treatment processes. This also may find applications in optimizing process parameters for the treatment of certain industrial wastewaters that contain high concentrations of fluoride.

Thus, an alternative technology is required to fulfill the need for large quantity of safe drinking water with permissible limit of aluminium and fluoride. The ongoing research at MNIT, Jaipur is focused on developing methods with permissible limit of aluminium and fluoride in alum treated waters and applicable for small to large communities alike. For higher throughput, Nalgonda process, which is a batch process, has been operated in a continuous mode and to keep both residual aluminium and fluoride in drinking water under permissible limit, it is integrated with Micro filtration membranes for quicker and efficient removal of Alumino-fluoro complexes (Al-F). Effective removal of residual Al-F complexes was expected to achieve, as the sizes of these particles are in micrometer range (≈2 μm) (George et al. 2005) thereby causing almost no suspensions and very low aluminium in output water. A 0.25 μm membrane was used by Srinivasan et al. (2000) to differentiate the colloidal aluminium from the dissolved forms. Thus, in our laboratory studies, we have used a 0.2 μm commercial membrane as well as a membrane obtained from IIT Delhi and integrated these with Nalgonda treated water as a post treatment. The initial results are highly encouraging with both residual fluoride as well as residual aluminium being brought within acceptable limits after filtration (CCDU 2015).

Adsorption on Activated Alumina

Several adsorbent materials have been tested in an attempt to identify an efficient and economical defluoridating material (Sneha et al. 2012; George et al. 2010). Activated alumina (AA) has been extensively studied for years for fluoride removal from drinking water. Defluoridation processes based on AA have been used at both community and domestic levels. Ghorai and Pant (2004, 2005) have found that removal was the result of ion exchange as well as adsorption processes. The fundamental interfa-cial properties of aluminium hydroxide are the protonation of surface hydroxyl groups resulting in the development of surface charge (Goldberg et al. 1996; Grahame 1955). At solution pH values below 6 the surface of AA has a positive charge and thus a great capacity for fluoride adsorption. In the neutral pH range the affinity of the surface for fluoride is much lower, limiting the practical applications of AA. Adsorption of fluoride onto AA depends on various factors such as raw water characteristics as well as AA grade, particle size, flow rate and adsorbent depth. If the bed depth is decreased, even though the other conditions are maintained constant, concentration of the solute in treated water will rise sharply from the time the effluent is first discharged from the adsorber.

The major drawback of the process is that alumina begins to leach aluminium and its fluoride complexes below pH 6 and poses severe threats to human health, as aluminium and its fluoride complexes are thought to cause Alzheimer's disease and other health complications (Todorovic and Milonjovic 2004; George et al. 2009). Recent attempts to increase the uptake capacity of AA with manganese/manganese oxides (Tripathy and Raichur 2008; Teng et al. 2009; Alemu et al. 2014), magnesium (Maliyekkal et al. 2008) and iron hydroxide/AA mixtures (Biswas et al. 2007) appear to have been successful. Adsorbent bed regeneration is an important operation which strongly influences the economical performance of adsorption processes. Any innovative technique that can reduce the cost of the regeneration operation can contribute to making column bed adsorption more efficient and more attrac-tive (Lounici et al. 2001). Several regeneration methods for an activated alumina column saturated with fluoride ions have been reported in the literature (Barbier and Mazounie 1984; Schoeman 2009).

Defluoridation using activated alumina needs thousands of defluoridation units to treat large volume of water, for large Indian population. The activated alumina-based defluoridation process is considered favourable for removal of fluoride, but recent research has found that identification of the optimum uptake capacity for alumina is essential so that fluoride adsorption is not offset by the aluminium dissolution mechanism on the alumina surface in presence of high fluorides (Miller et al. 1984; Kvech and Edwards 2002). Agarwal et al. (1999) reported that the treated water from activated alumina defluoridation process has moderately high residual aluminium ranging from 0.16 to 0.45 mg/L. Besides activated alumina-based plants, the Rajasthan government has installed many defluoridation units based on Bio-F process, that involves a base of hydroxyapatite, which is impregnated with alum for carrying out defluoridation. In a recent study, community level defluoridation plants based on Bio-F process were investigated for their defluoridation potential and residual aluminium concentration in treated water was monitored at Nagaur and Jodhpur districts in Rajasthan, India. A total of 38 groundwater samples were collected from various community level Bio-Filter® media based defluoridation plants in fluoride rich villages of the study area. The fluoride removal efficiency of plants operated in Nagaur lied between 88 and 100%, while, those in Jodhpur showed 97 to 100% removal. The presence of residual aluminium in treated water was found to be in trace concentrations (Yadav et al. 2015).

The activated alumina and Bio-F technique-based adsorption for fluoride removal also have their field problems related to requirement of frequent recharging. Also, the flow rate is governed by the minimum contact period required that results in low volumetric capacity of treatment thus limiting their application for larger communities.

Ongoing research at MNIT Jaipur has indicated a high potential of using HAP impregnated with alum for defluoridation (Mondal and George 2015). The Mg-HAP adsorbent developed for fluoride removal from aqueous solution has very good potential for defluoridation with a capacity of 1.4 mg/g. Fluoride removal of 92.34% was achieved with 10 g/L, and equilibrium was reached in 180 min. It was observed that increasing the amount of adsorbent and contact time increases the percentage of removal initially; however, gradually, it attains equilibrium and becomes constant. The adsorption capacity of Mg-HAP is not affected by pH of the medium. Calcium leaching in the solution was only observed at highly alkaline pH (9 and 10). Other anions such as nitrate and chloride did not affect the process significantly; however, the presence of bicarbonate, sulphate and phosphate ions lowered the defluoridation capacity. Adsorption pattern follows Langmuir isotherm the best and the rate of reaction followed pseudo-second-order kinetics and the sorption of fluoride ion on Mg-HAP was shown to occur through intraparticle diffusion pattern. The understanding gained from the results can be further applied for designing of adsorption systems for defluoridation of water for both domestic and community-based applications.

Other Processes for Defluoridation

Electrocoagulation

Electrocoagulation (EC) has been demonstrated as an effective process for defluoridation by researchers (Hu et al. 2003; Emamjomeh and Sivakumar 2006). Production of less waste sludge by the EC process might replace the conventional chemical coagulation (Emamjomeh et al. 2011). Recent work at MNIT Jaipur on electrochemical process for defluoridation has indicated a good efficiency for the removal of F and Al simultaneously using Al electrodes under 230 V DC regulated power supply (Sinha et al. 2012, 2015). Results obtained from the experiments revealed that more the detention time, more is the fluoride removal. Also charge loading and effluent fluoride concentration does not hold a linear relationship. Charge loading was found to be a critical parameter in defluoridation experiments, as increase in charge loading initially decreases the fluoride concentration in the effluent but after a critical point the decrease in fluoride concentration is insignificant. Electrocoagulation process also combats the major drawback of Nalgonda and Activated Alumina process as it renders lesser aluminium in the effluent. In the work done by Sinha et al. (2015), the electrocoagulation (EC) process was used for fluoride removal. It was found that aluminium content in water increases with an increase in the energy input. Therefore, experiments were optimized for a minimum energy input to achieve the target value (0.7 mg/L) of fluoride in resultant water. The experimental investigations revealed that use of bentonite clay as coagulant in clariflocculation brings down the aluminium concentration of water below the WHO guideline.

Reverse Osmosis

In reverse osmosis, the hydraulic pressure is exerted on one side of the semi permeable membrane which forces the water across the membrane leaving the salts behind. The relative size of the pollutants left behind depends on the pressure exerted on the membrane. In electrodialysis, the membranes allow the ions to pass but not the water. The driving force is an electric current which carries the ions through the membranes (Majewska-Nowak et al. 2015). The removal of fluoride in the reverse osmosis process has been reported to vary from 45 to 90% as the pH of the water is raised from 5.5 to 7. The membranes are very sensitive to pH and temperature.

The economics of the approach also deserves evaluation under specific circumstances. The units are also subject to chemical attacks, plugging, fouling by particulate matter, and concentrated and large quantity of wastes. The waste volumes are even larger than the ion exchange process. Sometimes, the pre-treatment requirements are extensive. Some of the major disadvantages of reverse osmosis process are it removes all the ions present in water. Since though some minerals are essential for proper growth, therefore, remineralization is required after treatment. The process is expensive in comparison to other options. The water becomes acidic and needs pH correction and lots of water gets wasted as brine (Kumar and Gopal 2000).

Conclusion

Fluorosis is an important public health problem in India. Drinking water is the main source of ingestion of fluoride. The various manifestations of chronic fluoride toxicity are mild to severe dental fluorosis, skeletal fluorosis, crippling fluorosis and systemic fluorosis, where visceral organs are involved. Though not life threatening, this disease causes impairment of dental aesthetics, derangement of skeletal system which results in compromised quality of life. There is no cure to the disease and prevention is the only solution. The first and foremost preventive measure is drinking fluoride-safe water. This can be accomplished by defluoridation of fluoride-contaminated drinking water. Defluoridation should be taken up where there is no alternate source of safe drinking water.

The activation alumina and Bio-F technique-based adsorption for fluoride removal also have their field problems related to requirement of frequent recharging. Also, the flow rate is governed by the minimum contact period required that results in low volumetric capacity of treatment thus limiting their application for larger communities. At MNIT, Jaipur that Nalgonda process which is batch process is made continuous and to keep both residual aluminium and fluoride in drinking water under permissible limit it is integrated with Micro and/or ultra filtration membranes for quicker and efficient removal of Alumino-fluoro complexes (Al-F). Work on electrochemical process and a low cost Bio-F process has also shown a great promise and we are hopeful of providing acceptable field solutions for defluoridation in near future.

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Water Quality Assessment and Correlation Study of Physico-Chemical Parameters of Sukinda Chromite Mining Area, Odisha, India

R.K. Tiwary, Binu Kumari and D.B. Singh

Abstract The Sukinda Chromite Valley of Odisha state is endowed with the highest reserve of chromite ore in India and produces 98% of the chromite ore of the country. Cr (VI) is a highly toxic form of chromium metal being used in different industries like leather tanning, electroplating, dye and pigment. Due to open cast mining process in Sukinda chromite valley, huge quantity of over burden dump (OB) are being generated and during rainy season Cr (VI) leached from the OB dump and contaminate the ground water as well as surface water of the surrounding area. Different water samples were collected from mines, surface water and groundwater and analyzed for their physico-chemical properties including heavy metals and Cr (VI). The result shows that at some locations, the total Cr and Cr (VI) concentration exceeded the permissible limit of 0.05 mg/L as per Indian water quality standards, despite mine water treatment at mine sites. The concentration of total Cr in mine water ranged from 0.32 to 1.46 mg/L before treatment and between 0.02 and 0.42 mg/L after treatment. Total chromium for surface water varied from 0.04 to 0.38 mg/L and for groundwater varied from 0.001 to 0.678 mg/L which exceeds the permissible limit of 0.1 mg/L for inland surface water. Cr (VI) content in these water samples also exceeds the permissible limit of 0.05 mg/L. Pearson's correlation analysis revealed that the Cr exhibited a significant positive correlation with pH (0.688), temperature (0.428), Total hardness (0.568) and sulphate (0.686). Cr (VI) also showed the similar results with total chromium.

Keywords Hexavalent chromium · Correlation study · Heavy metals
Contamination

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Introduction

The Sukinda Valley in Jajpur district of Odisha is one of the largest chromite and nickel producing mining area of India and is greatly contributing in supplying India's chromite ore demand (Rao et al. 2003). An increasing demand for chromite ores as resulted in an increase in chromite ore production. The extraction of chromite ore has mostly been carried out by open-cast mining process. During mining process, the chromite ore as well as the waste rock material are dumped in the mining area without considering the environmental aspects that causing the damage to the topography as well as contaminating the surface water bodies (Dhakate and Singh 2008). The overburden (OB) dump around the mine contaminates the groundwater as well as surface water sources by leaching of Cr (VI) and other impurities (Tiwary et al. 1995). Increased open cast mining has caused environmental degradation from loss of forest cover, decreases in floral and faunal diversity (Mishra and Sahu 2013), water table depletion, and surface and groundwater quality deterioration (Mohanty and Patra 2011; Tiwary et al. 2005). The major environmental problem in Sukinda Valley is the contamination of Damsal Nalla which is a tributary of the River Brahmani. It is the only local source of drinking water for local people. Chromium is one of the most highly soluble metal pollutants having a wide range of uses in the metals and chemical industries. Because of its carcinogenic (Mancuso 1951; Mancuso and Heuper 1951; Ono 1988; Waterhouse 1975; Yassi and Nieboer 1988), and teratogenic (Abbasi and Soni 1984) characteristics, it has become a serious health concern. It is known to cause various health problems like skin rashes, respiratory problems, liver damage, and weakened immune systems. According to the world health organization (WHO) and bureau of indian standards (BIS), the maximum allowable limit for total Cr or Cr (VI) is 0.05 mg/L. Water contaminated with high concentrations of metals, sulphide minerals, dissolved solids or salts can negatively affect on surface water quality, aquatic ecosystems and groundwater quality (Lottermoser 2012). The present study was carried out to determine the chromium content of three different water streams- chromite mine waste water, Damsal Nala and ground water to know the current status and to examine correlation to determine whether steps taken for environmental pollution control measures will be effective. Pearson's correlation coefficient (r) values of the physico-chemical parameters were determined using statistical package for social sciences (SPSS version16).

Materials and Methods

Study Area

The Sukinda Valley is surrounded by the Daitari and the Mahagiri hills. The study area comprises of the entire Sukinda chromite mining area consisting of 14 chromite mines of different mine owners. The study area lies between latitude 21°−21° 05′N and longitude 85° 40′–85° 53′E.

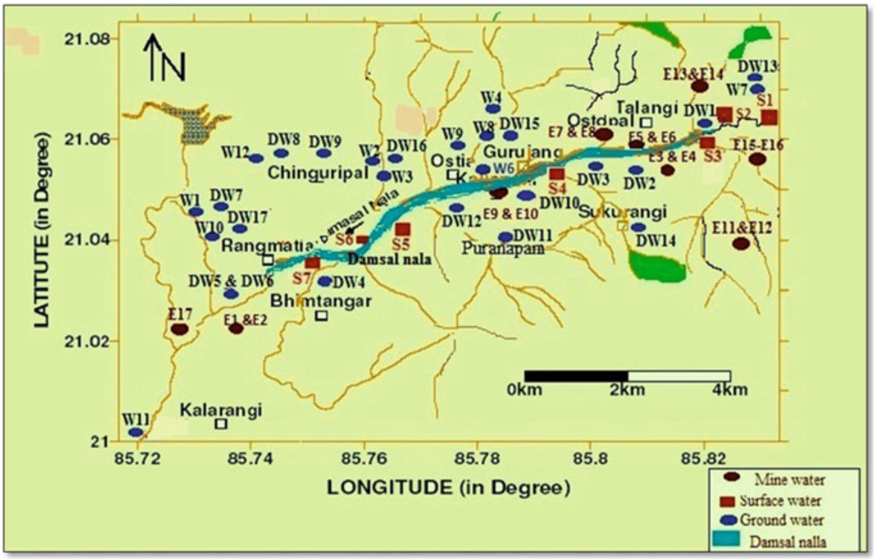

Fig. 1 Location map of water sampling in Sukinda chromite mine area

Sample Collection

Seventeen Mine water (Inlet and Outlet), 10 surface water (Damsal Nala and the Brahmani river), and 31 ground water (hand pump and dug wells) samples were collected in post monsoon season during the year 2008–2009 (Fig. 1). Water collection, storage and analysis of different physico-chemical parameters of water were carried out as per APHA (2005). Dissolved Oxygen (DO) was analyzed immediately after sampling by Winkler's method (APHA 2005). Other parameters such as total hardness (TH), total suspended solids (TSS), total dissolved solids (TDS), alkalinity, chloride (Cl^{-}) and sulphate (SO_4^{-2}) were analyzed in the laboratory using standard methods (APHA 2005). Cr (VI) was estimated spectrophotometrically using 1, 5-diphenyl carbazide in acidic medium (APHA 2005).

Results and Discussion

Mine Water Quality

The TSS of the mine water varied between 14 and 84 mg/L, TDS varied between 146 and 313 mg/L, TH varied from 155 to 308 mg/L and alkalinity varied from 67 to 234 mg/L. All the values were within the specified limit (WHO 1984). Anions like chloride of mine water varied from 12.306 to 33.41 mg/L whereas sulphate

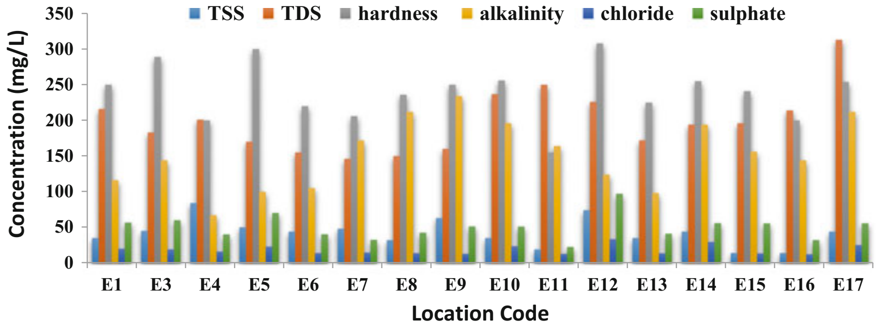

Fig. 2 Physico-chemical analysis of chromite mine water sample

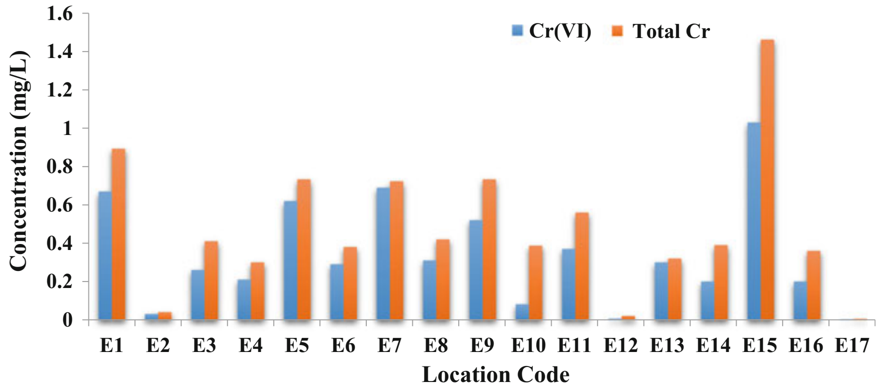

Fig. 3 Concentration of Cr and Cr (VI) in inlet and outlet mine water samples

varied from 22.45 to 97.1 mg/L (Fig. 2). The value of Cr (VI) for Inlet mine water varies from 0.26 to 1.027 mg/L with maximum concentration at E15 while for outlet mine water is 0.006 to 0.31 mg/L. Total chromium for Inlet and Outlet mine water varies from 0.32 to 1.46 to 0.02–0.42 mg/L respectively (Fig. 3).

Metal contents of the water samples were analyzed by ICPMS following the method of APHA.

The analytical result shows that the concentration level of Total Cr and Nickel were found in higher concentrations in inlet and outlet of mine water treatment plant and mine discharge water. Other metal like manganese (Mn) varies from 0.014 to 0.220 mg/L, Iron ranging between 0.089 and 4.920 mg/L, Ni ranges between 0.016 and 0.382 mg/L, Sodium (Na) varies from 2.053 to 4.831 mg/L, Magnesium (Mg) from 18.267 to 49.831 mg/L, Potassium (K) from 0.498 to 1.591 mg/L and Calcium (Ca) varies from 5.034 to 7.505 mg/L. Concentration of Fe was higher than the permissible limits while all other heavy metals were found within the prescribed limits. Water samples collected from the outlets of the treatments plants exhibit lower values of Cr (VI) Fig. (4).

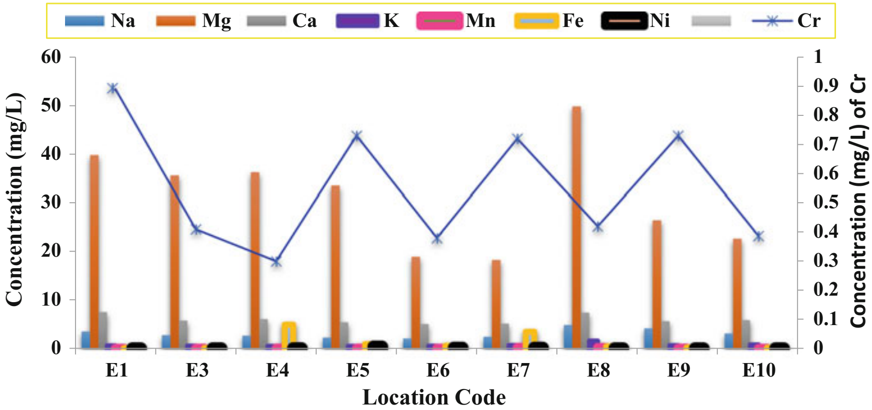

Fig. 4 Heavy metal concentration in mine water at different locations

Surface Water Quality

The physico-chemical analysis of surface water showed the TDS ranged between 49 and 174 mg/l within the specified limit (WHO 1984). A similar result was observed in previous study (Dhakate and Singh 2008). The TSS of surface water (Damsal Nala) varied from 24 to 92 mg/L where all these values crossed the specified limit (BIS 1991). The DO content of the Damsal Nala ranged from 6.5 to 7.6 mg/L. Figure 6 shows that the Cr (VI) of the Damsal Nala vary between 0.003 and 0.28 mg/l with the maximum concentration at S6, exceeding the permissible limits of 0.05 mg/l for drinking water limit. Heavy metal analysis shows higher concentration of total chromium in surface water exceeding the prescribed limits. Total Cr is also found to be exceeded the prescribed limit (BIS 1981), with maximum concentration (0.38) again at sampling location S6. This water should not be used for domestic purpose (Figs. 5 and 6).

Statistical Analysis

Correlation analysis of the Cr with physico-chemical parameters was performed using SPSS software, version 16. The result shows that there are positive correlations between temperature versus pH (0.201), and temperature versus TDS (0.510) while the negative correlation between temperature with DO (−0.890). There is a significant positive correlation between hardness and sulphate (0.661), TSS versus Chloride (0.676). Non-significant positive correlation was found between Temperature versus TDS, hardness versus Cr (VI) (0.547) and hardness versus Total Cr (0.568). Again pH was positively correlated with TSS (0.569), Sulphate

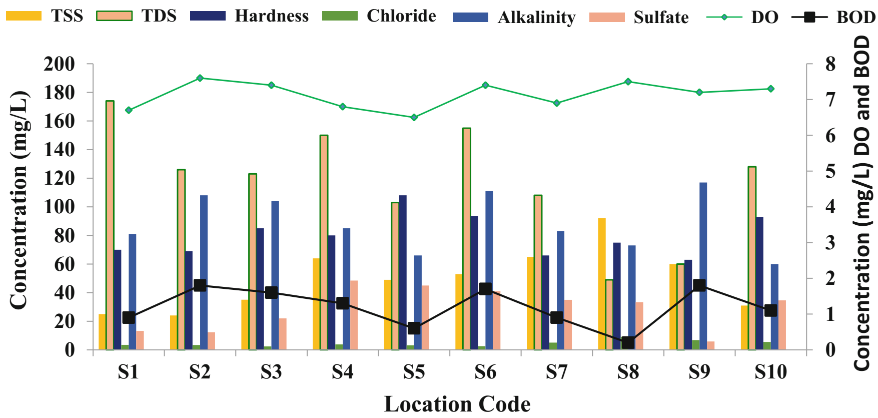

Fig. 5 Physico-chemical analysis of surface water sample (Damsal nalla)

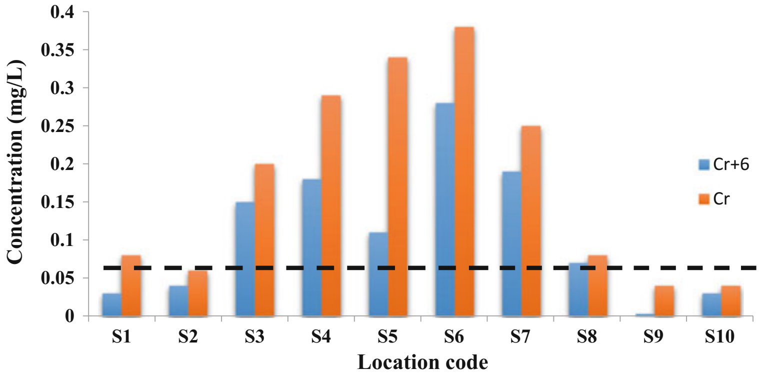

Fig. 6 Concentration of Cr and Cr (VI) in surface water sample, Sukinda chromite mines, India

(0.614) and Cr (VI) (0.514). (Non-significant positive correlation was also observed between Total Cr and hardness (0.568) and Cr versus TDS (0.317). Similar type of result was observed in the previous study (Khatoon et al. 2013). The correlation analysis also revealed that the Cr exhibited a significant positive correlation with pH (0.688), Sulphate (0.686) and Cr (VI) (0.837). Cr (VI) also showed the similar results with total chromium (Table 1). Khatoon et al. (2013) found the similar results. A significant negative correlation was found between TDS and Cl^- (−0.789) and Temp and DO (−0.890). The inverse relationship between Temperature and DO is a natural process as warmer water becomes more easily saturated with oxygen and holds less DO (Pejman et al. 2009).

Table 1 Correlation matrix for physico-chemical parameter of surface water samples of Sukinda chromite mine

Parameters	Temp	pH	DO	BOD	TSS	TDS	Hardness	Chloride	Alkalinity	Sulphate	Cr (VI)	Total Cr
Temp	1	0.201	−0.890**	−0.107	−0.194	0.510	0.351	−0.461	−0.285	0.325	0.446	0.428
pH		1	−0.208	−0.004	0.569	−0.199	0.409	−0.013	0.108	0.614	0.514	0.688*
DO			1	0.390	0.012	−0.265	−0.226	0.248	0.452	−0.331	−0.540	−0.339
BOD				1	−0.464	0.291	−0.195	−0.475	0.831**	−0.415	−0.289	0.034
TSS					1	−0.640*	−0.129	0.676*	−0.108	0.404	0.210	0.160
TDS						1	0.205	−0.789**	0.008	0.153	0.071	0.317
Hardness							1	−0.386	−0.418	0.661*	0.547	0.568
Chloride								1	−0.252	−0.115	−0.404	−0.589
Alkalinity									1	−0.522	−0.275	0.067
Sulphate										1	0.695*	0.686*
Cr (VI)											1	0.837**
Total Cr												1

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

Ground Water Quality

The TSS of ground water samples varied between 14 and 86 mg/l, with maximum concentration at W12 and alkalinity varied from 12 to 304 mg/L with maximum concentration was observed at DW17 which cross the specified limit (BIS 1991). Other water quality parameters like TDS, hardness, chloride and sulphate varied from 38 to 345 mg/L, 14 to 214 mg/L, 1.57 to 96.98 mg/L and from nil to 21.54 mg/L respectively. All the values were found within permissible limits (BIS 1991) (Fig. 7). Concentration of Cr (VI) in water samples ranged from non-detectable to 0.10 mg/L with maximum concentration at (DW1); total Cr varied from 0.001 to 678 mg/L, with the maximum concentration at DW10. Samples collected from the dug open wells (W) have lower concentrations of physico-chemical parameters like TSS, TDS, hardness, alkalinity, Cl^- and SO_4^{-2} (Fig. 7), and lower concentrations of Cr (VI), from non-detectable to 0.01 mg/L (Fig. 8). The concentration of Iron is found to be present in higher ranges in most of the samples. The value ranges between 0.046 and 2.930 mg/l, which is above the desirable limit of 0.3 mg/L. Other heavy metals were found well within the prescribed limits for drinking water. Heavy metal concentrations in open wells were found below the safe limits for drinking water quality (IS: 10500). Cr (VI) was also found below the permissible limit. Variation in Cr (VI) and Total Cr in hand pump and dug wells of the region is shown in Fig. 8 which clearly indicate the presence of Cr (VI) above the threshold limit values in some of the samples collected from the tube well of sampling site, DW1 and DW4, and same trend is observed for the Total Cr. The concentration of Cu was within the permissible limit (<0.05 mg/l as per Indian Standards) (Fig. 9).

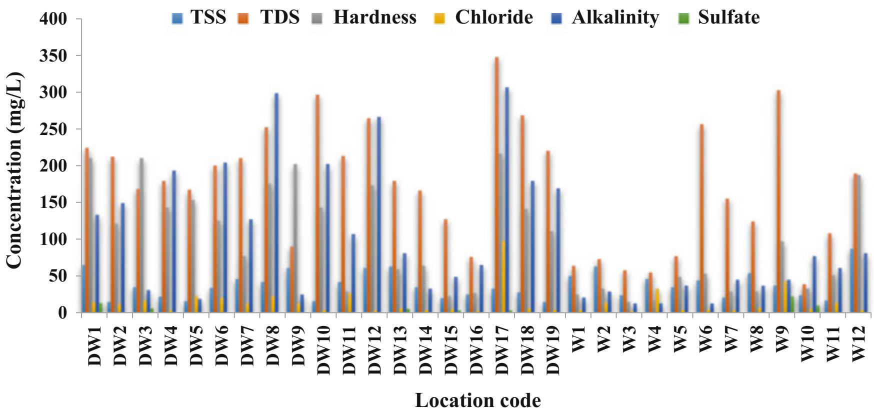

Fig. 7 Physico-chemical analysis of ground water sample

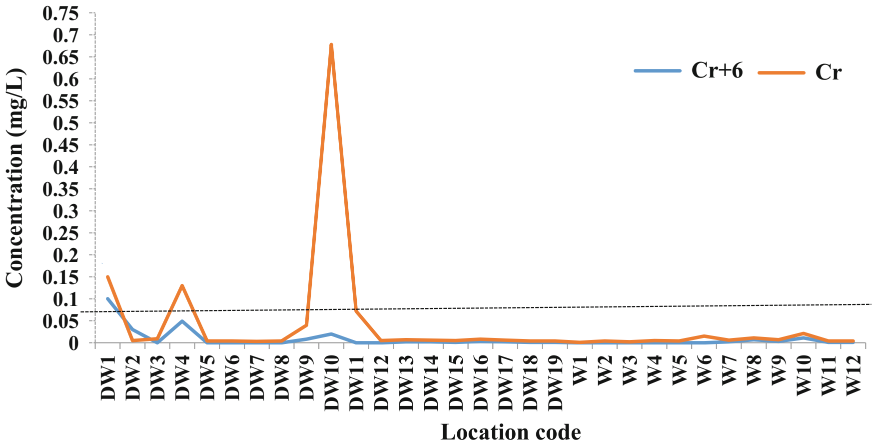

Fig. 8 Concentration of total Cr and Cr (VI) in ground water sample

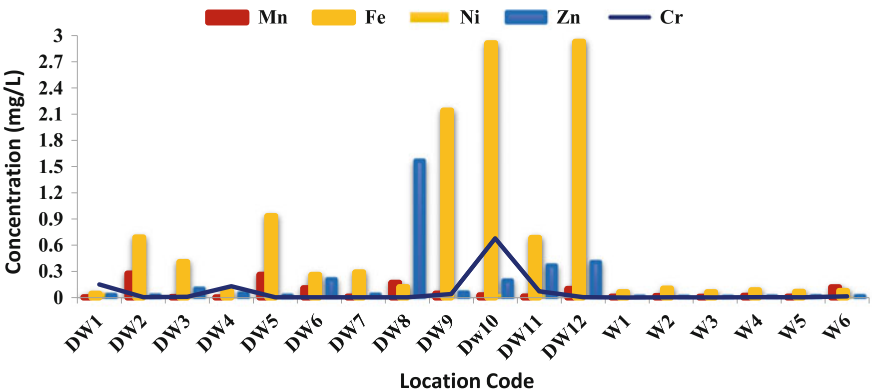

Fig. 9 Heavy meal concentration in ground water samples

Contour Analysis

Contour analysis has been carried out for few elevated and toxic heavy metals in the Groundwater of Sukinda region. It is useful for the Sukinda chromite mining area to identify the potential region of severe pollution in terms of Cr (VI). Contour maps have been plotted for pH, TDS, Cr (VI), Total Cr, Fe, Mn and Ni and are shown in Figs. 10, 11, 12, 13, 14, 15 and 16. Figure 11 shows that maximum number of sampling sites with high TDS is located in and around the mining area. It also extends towards the North and Northeast direction of the study area, covering the region of trans- Damsal nalla. Contour maps for the pH (Fig. 10) exhibited low pH at the sampling site W3 followed W2 and W4. Hexavalent chromium is known for

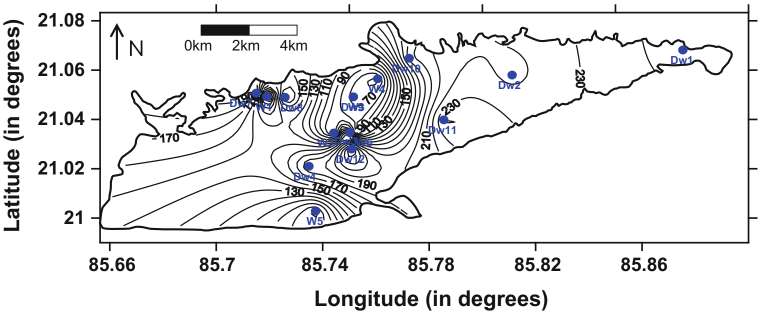

Fig. 10 Contour map for pH

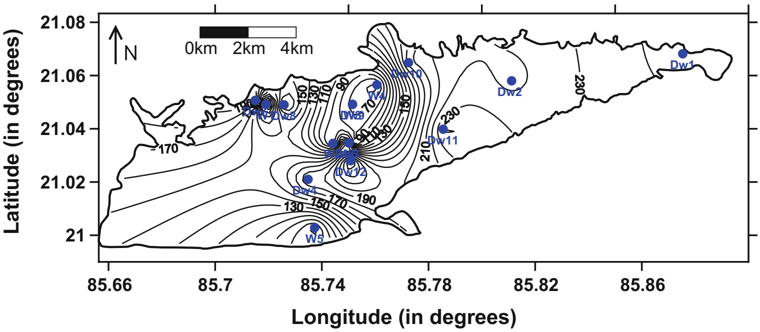

Fig. 11 Contour map for TDS

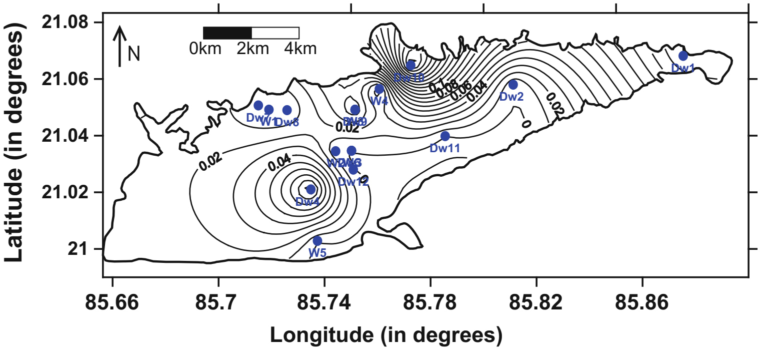

Fig. 12 Contour map for Cr (VI)

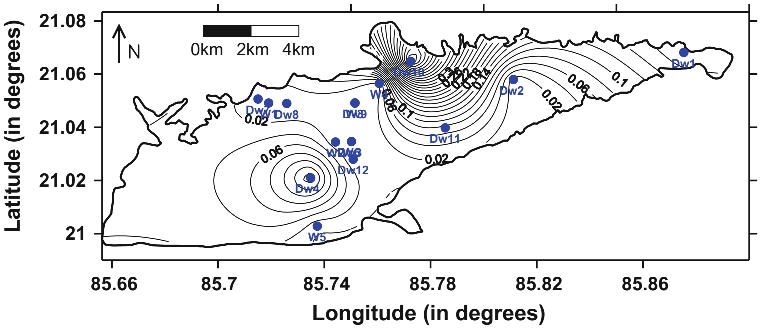

Fig. 13 Contour map for Total Cr

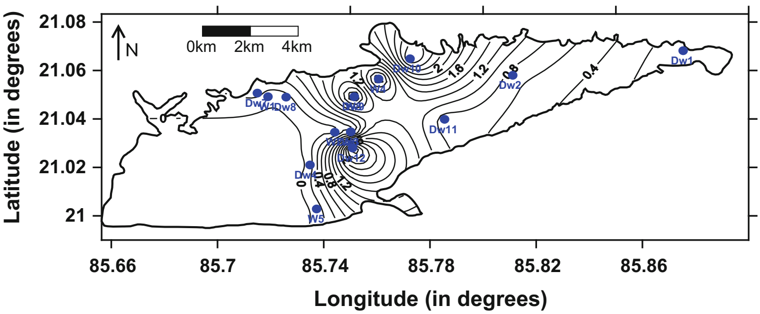

Fig. 14 Contour map for Fe

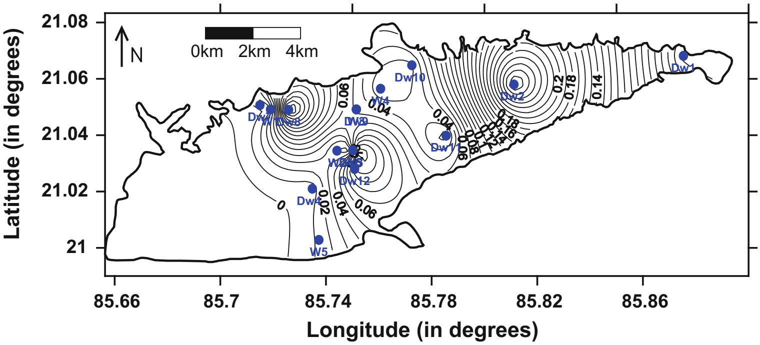

Fig. 15 Contour map for Mn

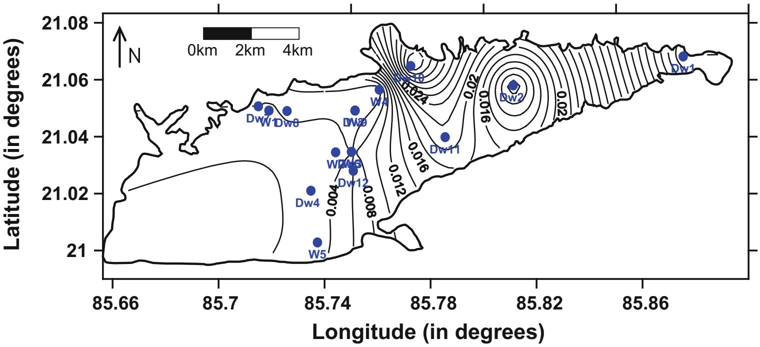

Fig. 16 Contour map for Ni

its extreme toxicity and contour graph plotted of the study area (Fig. 12) shows that the sampling site DW1 and DW4 which falls in the cis Damsal nalla or South side of the Damsal nalla were affected due the presence of high concentration of hexavalent chromium. The contour map clearly indicates the enrichment of chromium in various parts of Sukinda Chromite mining area. Isopleths for the total chromium is shown in Fig. 13 exhibits similar trend and also shows same contour lines as that of hexavalent chromium. Maximum concentration of total chromium was observed in the villages in North and Northeastern region of the study area, in and around DW1, DW4 and DW10. Contour maps for Fe, Mn and Ni are shown in Figs. 14, 15 and 16, depicting that the groundwater in the Northern region covering the sampling site DW1, DW10, W3, DW12, is contaminated with high concentration of Fe. Whereas isopleth drawn for Mn is found to be concentrated at the sampling site DW2, DW5, DW6, DW8 and DW12 and isopleth for Ni is concentrated mainly around DW1 and DW10 indicating that the ground water collected from these areas to be polluted with Mn and Ni.

Conclusion

The results of the present investigation concludes that chromite mine waste water before treatment (E1, E3, E5, E7, E9, E11, E13 and E15) exhibited poor water quality being contaminated with Cr and Cr (VI), which has led to the contamination of some water resources at the discharge point. All the mines use $FeSO_4$ treatment process for reduction of Cr (VI) to Cr (III) but some mines might not be following the method properly, resulting in very little Cr removal. Outlet mine water sample i.e., E4, E6, E8, E14 and E16 exceeded the permissible Cr (VI) limits of 0.1 mg/L for inland surface water. This has led to Cr contamination of some water resources including ground and surface water. Damsla Nala is the primary source of drinking water of this region and as a consequence of mining activity it is highly contaminated with Cr (VI). At sites S3-S7, Cr (VI) is elevated (0.11–0.28 mg/L), but the levels decrease with distance, and by the time the Damsal Nala travels 10 km and meets the Brahmani River, hexavalent chromium is found within permissible limits (S9 = 0.003, S10 = 0.03). Although dug wells had acceptable concentrations of Cr (VI), two tube wells (DW1 and DW4) had concentration of Cr (VI) higher than permissible limits and the wells cannot be used for drinking water. Contour map for Cr (VI) and Cr also confirm that maximum concentration lies in the vicinity of DW1, DW4 and DW10 which is surrounded by mining activities which needs to be managed properly. All the chromite mines are situated at a distance of 2–3 km of the river. During the rainy season, Leaching from the OB dumps and surface run off from the mining area drain easily into the river and become the source of Cr (VI) in the river. High level of some parameters in groundwater indicating the unsuitability of most of these water samples for potable purposes. Similarly, Damsal nala was also unfit for drinking purpose due to high concentration of total Chromium especially in the mining area.

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Water Quality Assessment of a Lentic Water Body Using Remote Sensing: A Case Study

B.K. Purandara, B.S. Jamadar, T. Chandramohan, M.K. Jose and B. Venkatesh

Abstract Water Quality assessment of lakes, rivers, and reservoirs is a key issue for environmental monitoring and management. Lakes are subjected to sudden environmental changes caused by anthropogenic activities due to their multiple uses (agriculture, fishing, and boating, industrial and water supply). One of the most important issues in lake water management is water quality. Water quality assessments are being carried out using conventional methods which are very common and accurate, however, have the disadvantage of being expensive and labor-intensive. Further, sampling method and frequency are the major constraints to obtain representative samples. In order to overcome such hurdles in water quality management remote sensing approach has become more user-friendly and quite reliable. Remote sensing approach to water quality assessment is based on the optical bands in the region from blue to near infrared. These data are then used to explore the relation between the reflectance of water bodies and biophysical parameters such as: transparency, chlorophyll concentration (phytoplankton), and the organic and mineral suspended sediments. In the present study, an attempt has been made to understand the water quality characteristics of a lake situated in coastal, Kerala, known as Vembanad lake (a Ramsar site in south India) using Landsat-TM data. A relationship between Landsat-TM bands and suspended sediment concentration has been arrived at and compared with the field monitored data. It is noticed that TM bands such as TM5, TM6, and TM7 show higher correlation with observed data than bands 1, 2, and 3.

Keywords Water quality · Remote sensing · Suspended sediments

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Introduction

There is no specific definition for Lakes in India. The term "Lake" is used loosely to represent various types of water bodies–natural, man-made and ephemeral including wetlands. Many lakes are categorized as wetlands, while reporting under Ramsar Convention. Lakes may be manmade or natural. Most of the lakes in the tropics and coastal belts are natural. However, the environmental status and ecological conditions of lentic bodies (particularly lakes) are less discussed in the literature. Though there is a distinction between freshwater lake sand brackish water lakes. The lakes of southern peninsular India are distinct from those of the Himalayan region. In the recent years, in India the water quality of inland water bodies like the rivers, lake sand ponds is assessed to establish their water quality status and pollution level (CPCB 2008). For this, predominantly the conventional water quality assessment methods have been commonly used. The current techniques usually used in the country form on it oring and assessing the quality of water bodies involves in situ measurement and/or the collection of water samples for subsequent laboratory analysis so as to retrieve the chemical, physical and biological characteristics of water that help in assessing its quality.

In the water quality analysis, the use of recent advanced technical tools like the remote sensing and geographical information system is however limited. Though the conventional methods give accurate information about the quality of water at the geographically specific station in the water bodies, but these results are not very helpful in providing a complete picture of the quality of water of the whole water body. Numerous researches done on the assessment of the quality of water using the recent advanced techniques like the remote sensing in integration with Geographical Information System bring to light the limitations associated with conventional methods. The major constraint of current in situ techniques of measuring water quality variables is quite time-consuming; and further, from these methods unable to provide a synoptic view of an individual water body or a set of water bodies across the land scape. It requires excessive traveling, sampling, and expensive laboratory analysis, especially for a large area; thus it is very difficult to report and predict the water quality situation in time. However, in the recent times, remote sensing (RS) techniques for water quality monitoring are accessible and reported to be very efficient. As the pollutants scatter and absorb the incoming solar radiation, the water quality is significantly correlated with the water column's optical characteristics, such as color and transparency, which can be obtained from RS data. Investigations suggest that optical data can provide an alternative means for obtaining relatively low-cost, simultaneous information on surface water quality conditions from numerous lakes, coastal, and oceanic areas. Although the methods to retrieve water quality from RS data might not be as precise as traditional methods, they are time and cost efficient over the large area and can provide the opportunity for regular observation of even very remote regions. Therefore, remote sensing techniques have been widely used in estimating the pollution situation of surface water (Akbar et al. 2012; Naithani 2012; Ritchie and Cooper 2001).

Presently, many satellites with high resolutions have been used in water quality monitoring studies. A number of studies have been carried out to relate water quality parameters such as Chlorphyll-a and suspended sediments with remote sensing data. Further, these observations can be used in various numerical schemes to help characterize the trophic status of an aquatic ecosystem.

However, as stated by earlier researchers, the number of available in situ measurements of water quality characteristics is quite limited both spatially and temporally. It is reported by various researchers that chl-a and SS are optically active water quality parameters in various water bodies and employed digital evaluation and near infrared wavelengths to assess the water quality parameters (e.g., Ritchie et al. 1990; Lathrop 1992; Choubey 1994). However, the previous studies were mostly carried out on the seriously polluted inland water body whereas the slightly polluted water bodies, especially those drinking water sources, have not been taken into consideration. The main reason is that they are of weak optical characteristics and low signal noise ratio. However, these are practically the most important part of the water quality management. Therefore, this is the challenging part for the researchers.

In the recent past, many researchers have used RS and ERDAS Imagine 9.1 Software for water quality assessment and have shown many positive results. Improvement and advancements in sensor technologies, realtime remote monitoring will prove to be an important tool in assessing water quality. While working on the use of hyper spectral RS and ERDAS Imagine 9.1 Software, to assess the water quality in coastal areas and shallow inland lakes of Iowa, USA., it is reported that the integration of RS and ERDAS Imagine 9.1 Software along with in situ water sampling and analysis can simplify and accelerate the procedure for water quality assessment with an acceptable degree of accuracy (Sugumaran et al. 2005).

Study Area

The Vembanad Lake, a Ramsar site is one of the largest coastal wetland ecosystems in south India, covering an area of 24,000 ha and contributes over 50% of the total area of backwaters in the state. This ecosystem has several functions and economic values. The lake's total surface area is spread across three central districts of Kerala, viz., Ernakulum in the north, Kottayam in the east and Alappuzha in the south. It is the lifeline of the area. Nearly 1.6 million people live on the banks of the lake.

This wetland and the surrounding area together form a socio-ecological system supporting the life of the people who live in the villages situated on its banks (Purandara 2008). Vembanad Lake is a transitional ecologically sensitive zone between the marine and terrestrial environments. These are highly productive zones providing feeding and spawning areas for a very large proportion of commercial fish and shellfish. It supports rich fishery resources such as a variety of finfish, shellfish, several species of marine fishes and shrimps. The lake system also supports a highly productive agriculture system in Kuttanad–the “rice bowl of Kerala”—spread over 1,100 km^2 which is a reclaimed portion of the lake.

A large population living in the drainage basin is directly or indirectly dependent upon this wetland ecosystem for their livelihood. Extensive field investigations carried out in the study area, indicated that the lake is used for fishing, mining sand and lime shell deposits, harvesting live clam sand tourism-related activities. Surrounding land mass is used for rice cultivation, plantation crops, housing, tourist resorts, etc. All these water-based activities depend upon the environmental integrity of the Vembanad Lake and its surroundings.

The environmental conditions of the lake ecosystem are undergoing a drastic change due to both hydrological and human interference. This kind of variations in the ecosystem may seriously affect the livelihood of surrounding people. One of the major factors affecting the endogenic system is due to fishery activities such as unscientific fishery practices like the adoption of fishing nets with small mesh size, fishing during high tide especially near estuarine bar mouths and use of destructive methods of catching process.

It is reported that the prime cause of environmental degradation of Vembanad Lake is attributed to reclamation and creation of the Wellington Island, the bunding works in the Kuttanad area for improving agriculture, construction of the Thottapally Spillway to divert floodwaters of Achankovil, Pamba, Manimala, and Meenachil directly to the sea. In addition, Thanneermukkom bund was built to prevent salinity ingress into the Kuttanad agricultural area during summer (Purandara and Dora 1987).

All the above interventions significantly altered the original flow pattern and changed the lake ecology adversely. Figure 1 shows the Vembanad Lake with locations of water sampling for water quality analysis.

Data Collection

The following data products were used for the present study:

1. Surface water quality of Vembanad Lake wetland system collateral data.
2. Landsat-TM Satellite data.

The details of the data products used are described below.

Surface Water Quality of Vembanad Lake

Surface water samples were collected from three different zones as North zone, Central zone and South zone. Each zone having seven stations, with a total number of 21 stations in the entire lake water body. Physic-chemical parameters from all three zones were investigated and their results are used for the analysis of remote sensing data.

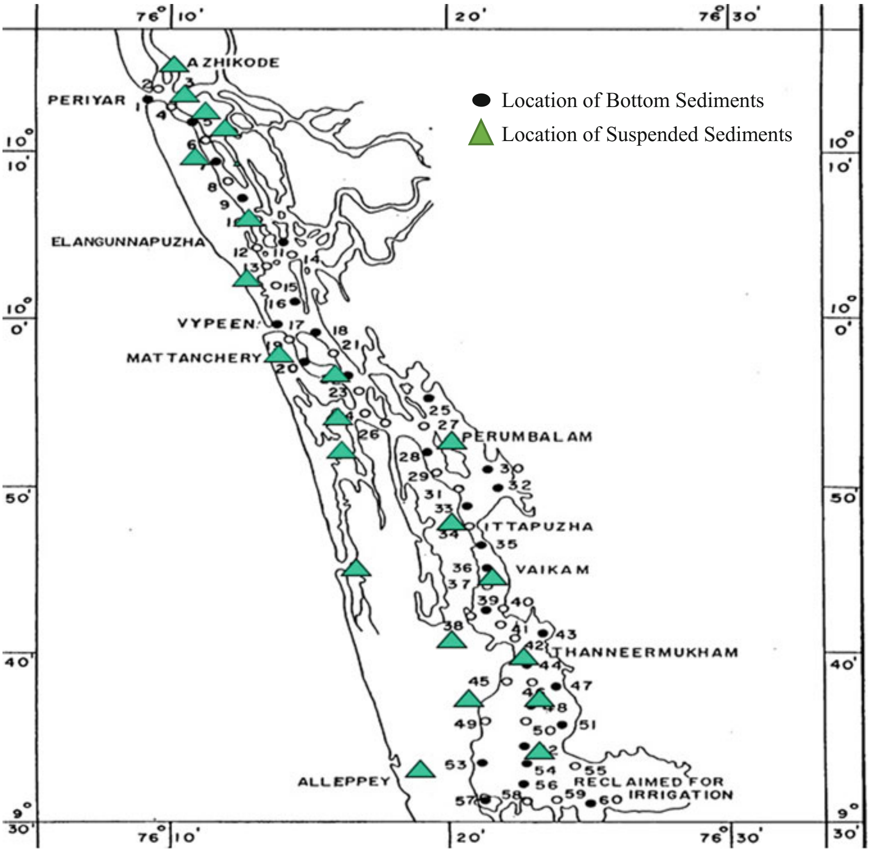

Fig. 1 Vembanad Lake with sampling locations (bottom sediments and suspended sediments)

Landsat-TM Satellite Data

Satellite data is amenable to both visual interpretation and digital analysis. Landsat thematic mapper (TM) data for two cloud-free dates, one during pre-monsoon and the other during post-monsoon, were acquired for the study. The TM images were precision corrected by radiometric and geometric means. The data pertaining to spectral bands were used to retrieve water quality characteristics of the lake. The DN values were extracted with the help of ERDAS Imagine 9.1 software. The DN values for each TM band for the water sampling location on each date were extracted, after radiometric calibration, atmospheric correction, and radiometric rectification, and employed in the current study. With help of DN values indices were generated. The correlation values are taken for both ground truth and Remote

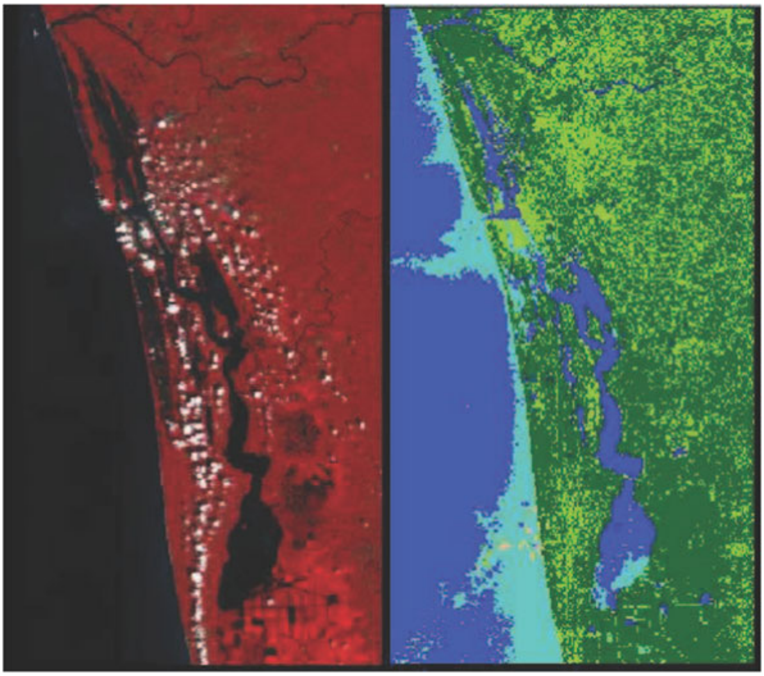

Fig. 2 An overview of Vembanad Lake (extracted from the satellite data)

sensing data. Suspended sediment was recorded from 7-Stations only throughout the lake. The data pertaining to different spectral bands were used to retrieve water quality characteristics of the Vembanad Lake (Fig. 2).

Results and Discussion

Turbidity and Suspended sediments are the two important and striking characteristics used to understand the physical status of a water body. Turbidity of water is mainly caused by suspended particles such as clay, silts, finely divided organic and inorganic matters, plankton and other microscopic organisms. Seasonal variation of turbidity follows monsoon → pre-monsoon → post-monsoon. Inflow of eroded materials due to high rain causes the water to be highly turbid in monsoon. In order to assess the water quality status, image processing software, viz. ERDAS 9.1 was employed. In remote sensing, one of the most convincing approaches of analysis is by developing derivative indices which may be used effectively to improve the predictive characteristics of various band data (Thiam and Eastman 1999; Sudheer et al. 2006). These indices are normally derived by arithmetic manipulations of

Table 1 Details of various derivative indices considered in the study

Index	Band combination and form
IND1	(TM1 + TM2 + TM3)/3
IND2	TM1/TM2
IND3	TM1/TM3
IND4	TM2/TM3
IND5	(TM5 + TM7)/2
IND6	(TM4 + TM5 + TM7)/3
IND7	(TM1 − TM3)/(TM1 + TM3)

Table 2 Correlation matrix of absolute variance of derivative indices with water quality parameters

Correlation matrix of absolute variance of derivative indices with water quality parameters								
	IND1	IND2	IND3	IND4	IND5	IND6	IND7	SS
IND1	1.000							
IND2	−0.771	1.000						
IND3	−0.138	0.343	1.000					
IND4	0.355	−0.231	0.826	1.000				
IND5	0.718	−0.315	−0.226	0.064	1.000			
IND6	0.752	−0.389	−0.252	0.079	0.977	1.000		
IND7	−0.028	0.241	0.993	0.879	−0.171	−0.191	1.000	
SS[a]	0.703	−0.349	−0.011	0.272	0.823	0.803	0.069	1.000

[a] *SS* Suspended sediments

different combinations of TM band data. Details pertaining to various derivative indices with band respective band combinations are shown in Table 1.

The correlation matrix of absolute variance of Derivative indices with water quality parameters are presented in Table 2.

The correlation matrix of absolute variation was computed using statistical software SPSS. The sign of the correlation may be related to the magnitude of the DN values in individual bands and the arithmetic operation but can be ignored since the interest here is on the strength of the relationship between the variables. It appears that a linear combination of four bands (with $R = -0.349, -0.011, 0.272, 0.069$) may not result in an accurate model for SS when linearly regressed. However, other combinations of these bands (as in IND1, IND5, IND6) have good potential for retrieving the SS information ($R = 0.703, 0.823, 0.803$).

The results also show the indices IND2 and IND3 have relatively less potential to ground truth. It is evident that the absolute variation provides a better picture of the strength of relationship among the variables.

The correlation matrix between the absolute variance of TM bands and the water quality parameters is presented in Table 3. TM band combinations of TM5, TM6,

Table 3 Correlation (R) matrix of absolute variance of TM bands and water quality parameters

Correlation (R) matrix of absolute variance of TM bands and water quality parameter								
	TM1	TM2	TM3	TM4	TM5	TM6	TM7	SS
TM1	1.000							
TM2	0.962	1.000						
TM3	0.557	0.697	1.000					
TM4	0.623	0.675	0.760	1.000				
TM5	0.577	0.564	0.655	0.827	1.000			
TM6	0.611	0.58	0.617	0.807	0.997	1.000		
TM7	0.592	0.554	0.595	0.826	0.994	0.997	1.000	
SS	0.574	0.547	0.415	0.658	0.821	0.835	0.831	1.000

Table 4 Comparison of observed and estimated (based on regression equations) suspended sediments

Stations	Observed SSC (mg/l)	Average DN values (x)	Regression equation (y)	Estimated SSC using regression equation	% error
1	155	(TM1) 145.42	$0.916x-1.8459$	131.35	15.25
2	79	(TM2) 112.57	$0.552x+29.618$	91.76	16.15
3	141	(TM3) 229.143	$0.4402x+14.114$	114.94	18.48
4	76	(TM4) 154.143	$0.5339x+1.02$	83.31	9.60
5	49	(TM5) 85.57	$0.6874x+11.203$	52.28	6.60
6	114	(TM6) 169.43	$0.6564x-7.0497$	103.99	8.70
7	139	(TM7) 199.57	$0.6489x-1.8356$	127.66	8.15

and TM7 or a combination TM4, TM5, TM6, and TM7 is significant in retrieving SS information from remote sensing data. A significant observation is that the data for bands TM1, TM2, and TM3 are not sensitive to SS, and hence the incorporation of DNs from these bands in modeling SS would only increase the model complexity.

The regression values have been generated by comparing with the Ground truth i.e. Suspended sediments to the TM data. Each TM band is used to generate correlation equation and regression values with respect to suspended solids. Table 4 shows regression equation for TM1, TM2, TM3, TM4, TM5, TM6, and TM7. The visible bands and infrared bands with correlations with ground truth show a significant relationship between Suspended Solids and their DN values in Linear Regression models. The regressions obtained are much correlated with ground details, in all 7-Bands the most realistic results can be obtained by using TM5 with regression value $R^2 = 0.835$, having best fitting equation $Y = 0.6874x + 11.203$.

Summary

The above study highlighted the significance of remote sensing data in analyzing water quality parameters particularly based on suspended sediments. It is noticed that the suspended sediment concentration depends on the reflectance values derived from the remote sensing data. Accordingly, a remote sensing based framework may be developed for the prediction of water quality of different source waters by integrating satellite data and ground-based measurements. Regression equations developed from the results obtained from present investigation is found to be more reliable in the case of TM5, TM6, and TM7. From the study it is observed that the central portion of the Vembanad Lake is more prone to pollution as it is evident from the sediment concentration. Therefore, it is suggested that it is necessary to regularly monitor the water quality in selected locations to help in lake water management.

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Assessment of Water Quality Trends of Khadakwasla Reservoir Using CCME-WQI

Savitri K. Hansda, K.K. Swain, S.P. Vaidya and R.S. Jagtap

Abstract The present paper is based on the water quality studies in Khadakwasla Reservoir done from November 2003 to May 2012. Twenty water quality parameters were analyzed for samples collected from five locations. The analyzed data were subjected to the formulation by Candian Council of Ministers of Environment (CCME) Water Quality Index (WQI). Such assessment by calculation makes it simple, to know the trend of water quality. The physicochemical water quality parameters used for this Index are pH, EC, DO, BOD, COD, Na, K, Ca, Mg, TH, CO_3, HCO_3, TAlk, Cl, SO_4, NO_3–N, PO_4–P, Fe, SiO_2, TDS. The first component of this index F_1 (Scope), i.e., the percentage of Variables (parameters) exceeding the standard(std) permissible limits, ranged from 10 to 30%. The second component, F_2 (Frequency), i.e., percentage failed tests under each failed Variables ranged from 2 to 13%. The third component F_3 (Amplitude) of failed tests ranged from 1 to 32. The values of F_1, F_2, and F_3 showed an increase from 2003 to 2012. Water quality grade ranged from 76 to 94, depicting 2% fair and 98% good water quality samples.

Keywords Khadakwasla reservoir · Physico-chemical parameters Standard limits · Failed tests · F_1 · F_2 · F_3 · WQI · WQ grades

Introduction

Khadakwasla reservoir is a tropical man-made reservoir located in an upstream part of Upper Bhima River basin in Maharashtra India (18º 26 30′N and 73º 28 15′E); it was created by damming the perennial Mutha River in 1964 (Fig. 1).

The reservoir was constructed primarily to supply domestic water to the people of Pune city. It also supplies water to surrounding villages for drinking, irrigation, and small industries. Its right bank canal (112 km) irrigates about 45,000 ha of land

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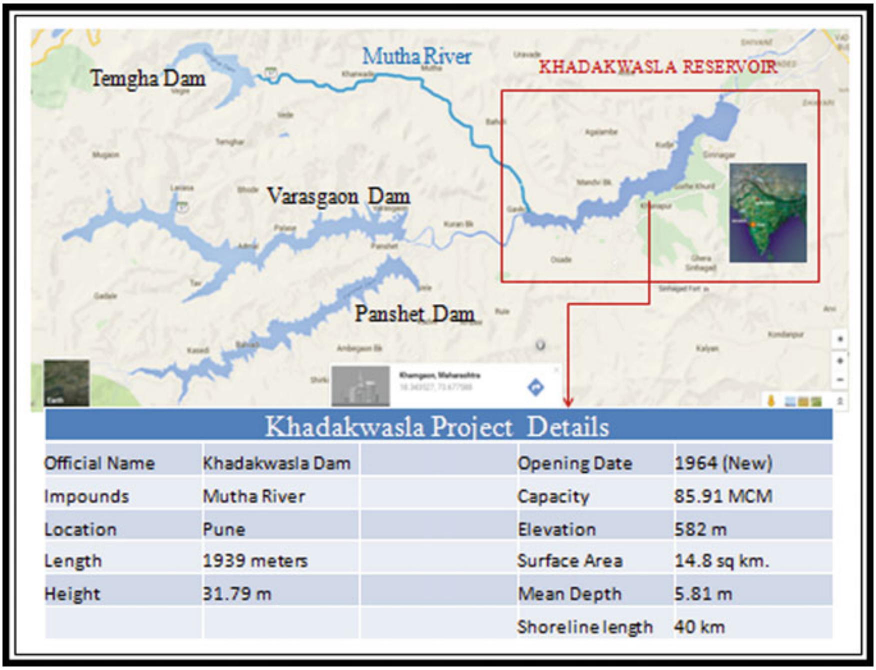

Official Name	Khadakwasla Dam	Opening Date	1964 (New)
Impounds	Mutha River	Capacity	85.91 MCM
Location	Pune	Elevation	582 m
Length	1939 meters	Surface Area	14.8 sq km.
Height	31.79 m	Mean Depth	5.81 m
		Shoreline length	40 km

Fig. 1 Location of Khadakwasla reservoir, Pune

up to 200 km downstream in Pune district. Besides being the source of water supply to Pune city, it is also a Waterman ship Training Center (WTC) used to train the NDA naval cadets and to familiarize them with the naval way of life.

The reservoir is surrounded by villages and agricultural farms. Most of the domestic activities like bathing, washing of clothes, cattle, vehicles are carried out on the banks of reservoir. There is one poultry farm near the right bank and many holiday resorts on both the sides of the reservoir. Just a few kilometers up the road lies Singhagad Fort and the twin dams at Panshet, and Varasgaon. These dams and Temghar discharge into Khadakwasla reservoir.

Continuous assessment of physical, chemical, and biological parameters of water is an essential part of current water quality control programs. The water quality index (WQI) is a well-known method as well as one of the most effective tools for expressing water quality that offers a simple, stable, and reproducible unit of measure and communicates information of water quality to the concerned citizens and policy makers. It thus becomes an important tool for the assessment and management of surface water (Chauhan and Singh 2010).

Introduction to Water Quality (WQ) and Water Quality Index (WQI)

Water Quality is a measure of the condition of water able to sustain healthy ecosystem and human life. It is generally referred by its physical, chemical, and biological characteristics which are compared against a set of standards to assess its compliance. Standards and guidelines are established to know the suitability of water for designated uses such as drinking, recreation, agricultural irrigation, or protection and maintenance of aquatic life. Indian Standards specification (1983) for drinking water quality ensures that public drinking water supplies are as safe as possible. In India, CPCB is responsible for establishing these standards.

Water Quality Index (WQI) is a single numerical expression, like a score or grade, which reflects the composite influence of significant water quality parameters. The Index provides a meaningful and uniform method for assessing the overall quality of a waterbody (lentic/lotic systems), comparing quality conditions at different points in space and time, which is also a measure of water pollution abetment programs. Indices are used for different intended uses of water.

History of Water Quality Index (WQI): An index number system for rating water quality as a tool for evaluating water quality was first started by Horton (1965). Many researchers (e.g., Brown et al. 1970; Prati et al. 1971; Dinius 1972, 1987; Walski and Parker 1974; Landwehr 1979; Dunnette 1979; Bhargava 1983, 1985) developed their own rating scales. The concept of indices to represent gradation in water quality was applied to water quality assessment and monitoring for various designated uses of water by Deininger and Maciunas (1971), Harkins (1974), NSF (2003), Burden et al. (2002), Buyan (2005), Cash et al. (2001). WQI was used as a tool to know the past, present, and future state of the environment in the Vistula and Odra river basins by Brown et al. (1972). Water Quality for British Columbia was reported as BCWQI (1986, 1996) and improved in 1998. Many Indian researchers such as Chauhan and Singh (2010) used it in Evaluation Of Ganga water for drinking purpose. Bagde and Verma (1985) used it in Limnological studies. Tiwari and Manzoor (1988) formulated different indices for different uses of water. Application of Canadian Water Quality Index to PPWB in Alberta was used as a successful Monitoring Program (CCME 1997, 2001, 2003).

CCME-WQI

CCME-WQI has been chosen to assess water quality of Khadakwasla Reservoir because it has great flexibility to compare the analyzed water quality data with any of so many prevailing standards for various water uses.

In 1997, the Water Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment (CCME) decided to review various existing techniques for the calculation of WQIs. Their efforts led to the development of a standardized system i.e. a unified water quality index that has been employed in all parts of Canada for the assessment of water quality (CCME 1997, 2001, 2003).

The CCME-WQI index is based on a combination of three factors F_1, F_2, and F_3:

1. ***F_1*** (***Scope***): The number of variables whose objectives are not met.

$$F_1 = \frac{\text{Number of Failed Variables}}{\text{Total Number of Variables}} \times 100 \quad (1)$$

2. ***F_2 (Frequency)***: Each test under Failed Variables where objectives are not met.

$$F_2 = \frac{\text{Number of Failed Tests}}{\text{Total Number of Tests}} \times 100 \quad (2)$$

3. ***F_3*** (***Amplitude***): The amount by which the objectives are not met. The measure of amplitude is calculated in three steps as given below.

   3(i) "Excursion" is the number of times by which an individual Failed Test is greater than (or less than, when the objective is a minimum).

   (a) When the test value must not exceed the objective value

$$\text{Excursion}_i = \left[\frac{\text{Failed Test Value}_i}{\text{Objective}_j}\right] - 1 \quad (3)$$

   (b) When test value must exceeds/must not fall below the objective.

$$\text{Excursion}_j = \left[\frac{\text{Objective}_j}{\text{Failed value}_i}\right] - 1 \quad (4)$$

   3(ii) The collective amount by which individual tests are out of compliance is calculated by *summing* the *excursions* of individual tests and dividing by the total number of tests. This value is referred to as normalized sum of excursions or "nse", Mathematical formula is:

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{number of tests}}$$

   3(iii) F_3 is then calculated by an asymptotic function that scales the normalized sum of excursions from objectives (nse) as below:

$$F_3 = \frac{\text{nse}}{(\text{nse} * 0.01 + 0.01)} \quad (5)$$

Table 1 CCME-WQI grades, values, and description of water quality

S. No.	Rank	CCME-WQI value	Description
1	Excellent	95–100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels
2	Good	80–94	Water quality is protected with a slight presence of threat or impairment; conditions close to natural or pristine levels
3	Fair	65–79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
4	Marginal	45–64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
5	Poor	0–44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

Then CCME-WQI is calculated by

$$\text{CCME-WQI} = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right] \tag{6}$$

The factor of 1.732 has been introduced to scale the index from 0 to 100. Since the individual index factors can range as high as 100, it means that the vector length can reach a maximum of 173.2 as shown below:

$$\sqrt{100^2 + 100^2 + 100^2} = \sqrt{30000} = 173.205 \tag{7}$$

Thus, the above formulation produces a value between 0 and 100 and gives a numerical value to the state of water quality. Note a zero (0) value signifies very poor water quality, whereas a value close to 100 signifies excellent water quality. The assignment of CCME-WQI values to different categories is somewhat subjective process and also demands expert judgment and public's expectations of water quality. Depending on CCME-WQI value/score, the water quality is ranked in the following five categories (Table 1).

Method

Selection of sampling location: Khadakwasla Reservoir (Fig. 1) catchment area consists of mainly defense campus having wide spread office and quarters, villages, agricultural lands, poultry farm, etc. whose potential pollution effects from the

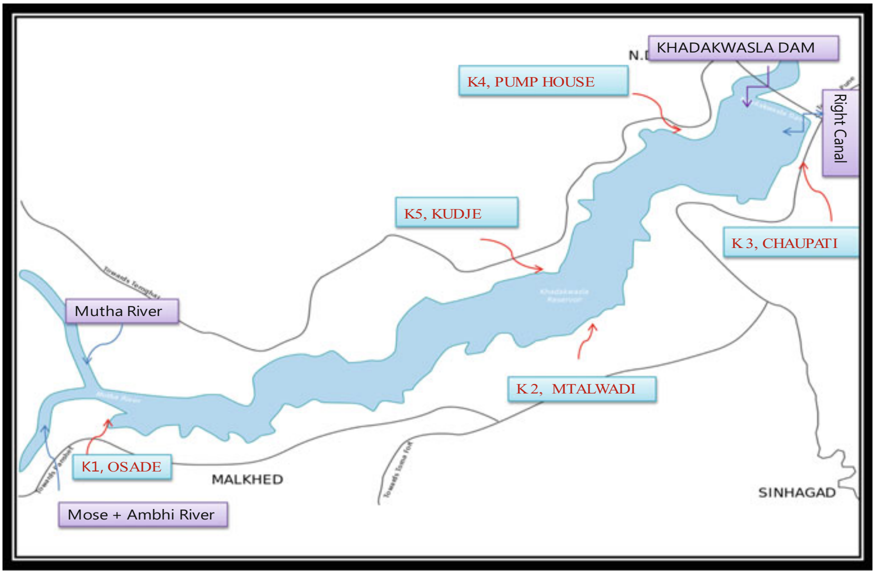

Fig. 2 Five sampling locations in Khadakwasla reservoir, Pune

watershed drains during rains into the common water body, the reservoir. Five sampling locations, K1, K2, K3 on the right bank, K4 and K5 on left bank were selected. K1, K2, and K5 represent Riverine zone and K1 and K4 Lacusterine zone keeping in view the following points:

1. To observe the impact of Anthropogenic Activities on the left and right banks of the reservoir.
2. To observe the water quality at Riverine and Lacusterine zone.
3. To observe the intensity of pollutants in five sampling points.

Water Sample Collection—Surface water from sampling locations were collected in well labeled cleaned polyethylene bottles rinsed by deionized and reservoir water. Analysis of physicochemical parameters is done as per APHA (2005), Standard Methods for the Examination of Water and Waste Water, 21st edition, American Public Health Association, Washington, D.C., USA (Fig. 2).

Result and Discussions

The CCME-WQI was calculated location-wise as mentioned under method above. Tables 2, 3, 4, 5, and 6 are for locations from K1 to K5, respectively. They show statistically analyzed data (field observed and lab determined) for years from 2003 to 2012 for each location. Comparison of 20 physicochemical parameters (Parm)

Table 2 Physicochemical -parameters of sampling location-K1 (Osade) right bank

Parm	pH	Cond	DO	BOD	COD	Na+	K+	Ca++	Mg++	TH	HCO3-	CO3=	TALK	Cl-	SO4=	NO3-N	PO4-P	SiO2	Fe	TDS
Obj	**8.5**	**300**	**5**	**2**	**10**	**250**	**12**	**75**	**200**	**300**	**200**	**200**	**300**	**250**	**150**	**45**	**0.1**	**50**	**0.3**	**500**
2003	7.4	105	4	2.7	18.6	13	0.8	15.6	5.3	60.9	79.3	0	79.3	5	2.1	1.2	1.3	8.8	0.9	78.4
2004	7.9	145	4	3.5	89.9	16.3	3.5	26.5	7.5	83	79.7	0.5	79.7	22.5	7	1.7	1.3	8.7	1.4	99.6
2005	8.4	185	4.1	4.9	26.2	11.4	2.2	27.3	10.5	112	61.6	0	61.6	13.7	15.2	3.8	0.7	1.7	5.6	104
2006	7.5	257	4.1	2	26	16.3	1	38.9	8.7	119	96.6	3.3	99.9	16.2	6.6	0.8	0.3	1.8	1	127
2007	7.7	91.5	6.1	2.2	14.2	16	6.8	37.4	2.7	98.4	51.5	1.3	52.8	23.1	5	0.3	0.2	2.1	0.2	97.2
2008	8.1	182	6.1	7.7	18.4	17.3	1.8	41.7	13.4	159	120	0	120	107	3.7	2.6	0.3	6.2	0.2	243
2009	8.2	212	3	1	13.2	17	2.4	26.2	8.6	94.6	153	0	153	66.5	2.6	0.3	0.3	2.8	1.1	147
2010	8.4	265	3	1.9	26	12.4	3.6	27.6	16.9	139	126	2	128	40.4	15	0.3	0.2	2.9	0.3	151
2011	7.6	112	4.9	0.5	68.6	15.3	2.9	10.4	5.1	46.9	65.2	0	65.2	16.5	5.1	0.4	0.2	35.5	0.4	73.7
2012	7.7	185	4.9	1.2	71.8	18.4	1.9	5	1.9	20.5	62.8	0	62.8	8.7	1.1	0.8	0.5	25.4	0.4	69.8

Table 3 Physicochemical -parameters of sampling location-K2 (Ghore/Matalwadi) right bank

Parm	pH	Cond	DO	BOD	COD	Na+	K+	Ca++	Mg++	TH	HCO3-	CO3=	TALK	Cl-	SO4=	NO3-N	PO4-P	SiO2	Fe	TDS
Obj	**8.5**	**300**	**5**	**2**	**10**	**250**	**12**	**75**	**200**	**300**	**200**	**200**	**300**	**250**	**150**	**45**	**0.1**	**50**	**0.3**	**500**
2003	8.3	90	4.2	4.2	90.2	10.1	1.7	10.9	7.1	54.9	61	0	61	6.5	2.1	0.2	0.1	3	0.1	65.3
2004	9.2	112	4.2	1.9	184	17.2	1.3	28.9	6.3	94.4	81.8	0.3	81.8	30.9	7.5	1.7	0.1	6	0.7	109
2005	8.5	222	4.6	7.4	26.2	11.4	3.9	39.8	9.8	140	74.6	0	74.6	16.2	21.3	5.8	0.5	2.9	7.5	135
2006	8.4	169	4.6	4.8	39.4	10.8	1	29.2	8.7	91.2	84.6	2.6	86.5	13.3	8.8	0.7	0.3	2.9	1	91
2007	7.9	78	5.3	0.6	14.9	14.7	6.3	42.4	2	113	69.1	0	69.1	20.6	5.2	0.4	0.2	1.8	0.3	110
2008	7.8	120	6.5	2.4	17.4	16.5	3.7	38.7	8.3	124	78.9	0	78.9	87.1	3.7	2.4	0.2	4.7	0.5	170
2009	8.1	170	6.5	0.8	11.3	20.9	2.9	55	15.7	202	88.8	1.7	90.5	108	3.5	0.3	0.3	5	0.3	249
2010	7.7	174	8	1.4	13.7	7.7	0.8	23.1	8.6	93.1	66.2	0	66.2	39.8	11.5	0.2	0.1	4.3	0.3	108
2011	7.5	135	6.3	0.1	131	15.8	0.9	20.3	5.3	72.3	76.7	2.5	76.7	26.4	8.4	0.4	0.1	34.3	0.3	90.7
2012	8.5	118	5.5	1.6	59.6	18.7	1.8	6.1	1.5	21.4	62.8	0	62.8	9.2	1.3	0.5	0.4	20.2	0.3	70.9

Table 4 Physicochemical -parameters of sampling location-K3 (Chaupati) right bank

Parm	pH	Cond	DO	BOD	COD	Na+	K+	Ca++	Mg++	TH	HCO3-	CO3=	TALK	Cl-	SO4=	NO3-N	PO4-P	SiO2	Fe	TDS
Obj	**8.5**	**300**	**5**	**2**	**10**	**250**	**12**	**75**	**200**	**300**	**200**	**200**	**300**	**250**	**150**	**45**	**0.1**	**50**	**0.3**	**500**
2003	7.8	100	4.1	2.3	15.8	10	0.7	11	9.8	58.7	73.2	0	73.2	7.8	2.5	0.1	0.1	2.5	0	68.9
2004	8.5	118	4.1	1.8	153	15.2	1.3	24.9	5.4	70.1	67.8	0	67.8	21.2	9.1	2.3	0.1	3	0.7	86.4
2005	8.7	156	4.9	6.7	30.8	12	0.8	39.5	6.6	117	88.2	0	88.2	13.8	9.4	2.8	0.4	1.8	2.9	103
2006	8.6	181	4.9	2.1	17.4	11.7	3.5	23.3	6.6	79.6	71.6	8.5	72.6	16.6	5.9	0.5	0.3	1.8	0.8	84.8
2007	8	74	5.3	2.6	10.3	15	3.4	9.2	1.9	30.4	46.7	0	46.7	18.5	4.9	0.4	0.1	2	0.2	73.8
2008	8.7	101	6.3	0.8	15.4	15.1	1.9	20.5	7.5	82.1	62	0	62	52.3	18	0.2	0.2	5	0.2	126
2009	7.9	88	6.3	0.9	12.8	17.1	1.2	15.7	7.6	70.5	80.3	0	80.3	60.8	3.1	0.6	0.3	2.8	1.1	125
2010	7.7	165	6.7	4.1	13.1	7.4	0.8	26.7	6.2	92	65.4	3	65.4	41.6	8.8	0.2	0.1	4.6	0.4	111
2011	7.6	89	6.6	0.8	24.2	14.3	1	13.6	3.8	41.4	69.5	0	69.5	18.4	4.4	0.4	0.1	35	0.3	70.1
2012	7.7	128	5.8	2.9	66.8	21.1	2	2.3	0.5	7.8	60.3	0	60.3	7.2	1.2	0.6	0.4	25.2	0.3	65.3

Table 5 Physicochemical -parameters of sampling location-K4 (Pump House) left bank

Parm	pH	Cond	DO	BOD	COD	Na+	K+	Ca++	Mg++	TH	HCO3-	CO3=	TALK	Cl-	SO4=	NO3-N	PO4-P	SiO2	Fe	TDS
Obj	**8.5**	**300**	**5**	**2**	**10**	**250**	**12**	**75**	**200**	**300**	**200**	**200**	**300**	**250**	**150**	**45**	**0.1**	**50**	**0.3**	**500**
2003	8.8	120	4	2	21.5	12.4	0.7	14.7	8	69.6	79.3	0	79.3	8.1	2.3	1.5	1.4	8.2	0.3	87.1
2004	8.6	116	4	2.4	118	13.6	1	25.7	5.4	86.1	82	0	82	19.7	15	1.7	0.4	10.8	0.6	91.1
2005	8.7	165	4.9	7.5	27.7	12.6	0.7	23.4	9.8	98.7	82.8	0	82.8	17	6.1	3.3	0.3	1.7	1	96.1
2006	8.9	122	4.9	2.9	34.9	9.8	0.8	23.2	5.2	78.3	95.6	4	99.6	14.6	7.3	0.6	0.3	1.8	0.8	83.1
2007	7.8	72	5.8	0.5	22.9	14.7	7.4	41.9	3.7	110	51.5	0	51.5	18.2	6.1	0.3	0.2	1.8	0.3	109
2008	8.7	114	6.7	3.3	17.4	15.2	1.6	22.9	8.5	92.1	68.7	0	68.7	63.9	2.2	0.2	0.3	5.2	0.2	148
2009	7.8	85	6.7	0.4	18.6	16.9	1.2	16	8.3	72.3	88.4	0	88.4	58.9	2.1	0.3	0.2	2.8	0.2	131
2010	7.8	160	7.1	2.6	28.3	8.6	1.1	23.7	7.4	89.5	62.9	1	62.9	42.8	5	0.2	0.2	4.2	0.4	110
2011	7.8	78	7.1	0.9	115	12.6	1.6	11.6	3.5	36.8	65.9	0	65.9	16.9	5.4	0.4	0.1	35.3	0.3	67
2012	7.9	118	5.5	1.1	68.8	18.1	1.7	4.6	1.9	19.4	57.8	0	57.8	9.4	1.4	1	0.5	23.5	0.4	67.5

Table 6 Physicochemical -parameters of sampling location-K 5 (Kudje) left bank

Parm	pH	Cond	DO	BOD	COD	Na+	K+	Ca++	Mg++	TH	HCO3-	CO3=	TALK	Cl-	SO4=	NO3-N	PO4-P	SiO2	Fe	TDS
Obj	**8.5**	**300**	**5**	**2**	**10**	**250**	**12**	**75**	**200**	**300**	**200**	**200**	**300**	**250**	**150**	**45**	**0.1**	**50**	**0.3**	**500**
2003	8.3	85	4	2.5	7.2	9.4	0.6	8.7	7.1	47.7	51.9	0	51.9	6.5	3.2	0.2	0.2	3.4	0	54.6
2004	9.1	112	4.1	1.3	124	14.3	1	26.5	7.1	82.1	104	0.8	104	18.1	18.5	1.4	1.8	10	0.5	105
2005	8.9	157	4.8	7.8	29.2	11.3	0.8	22.4	8.2	89.6	77.3	0	77.3	14	9.9	2.9	0.9	2	2.7	88.3
2006	8.9	124	4.8	7	25.8	11.1	0.7	24.6	13.9	117	55.5	1.3	55.5	15.2	5.3	0.5	0.3	2	0.5	80.6
2007	7.8	72.7	5.7	1.1	11.9	15.8	7.1	32.8	2.5	89.3	44.7	4	48.6	20.6	5.5	0.4	0.1	2.8	0.3	95.7
2008	8.9	108	7.3	1.5	16.9	16.5	1	22.9	7.3	87.1	65.1	0	65.1	68.4	5.8	0.7	0.2	4.7	0.2	151
2009	7.9	83	7.3	1.5	12.2	22.7	1.3	14.4	9.1	73.6	84.1	0	84.1	45.6	2.1	0.4	0.3	3	0.3	123
2010	7.7	160	5.5	0.8	18.4	7.6	0.5	26.5	5.9	90.5	58.9	1	58.9	40.7	6.1	0.2	0.2	4.5	0.4	109
2011	8.1	78	5.5	0.7	65.5	13.7	1	11.2	3.8	32.7	65.9	0	65.9	15.3	4.8	0.4	0.1	28.8	0.5	67.3
2012	7.9	110	6.1	1.1	62.6	16.2	1.2	4.4	2.2	19.9	55.3	0	55.3	8.2	1.3	0.8	0.4	22.7	0.3	62.2

Table 7 Twenty physicochemical parameters of Khadakwasla reservoir water indicating the minimum, maximum, mean, and standard deviation values compared with Indian Standards

S.L	Parameters	Units	Objectives	Min	Max	Avg	Stdev	% Compliance
1	pH	-	8.5	6.3	9.2	7.7	0.5	90
2	Cond	μS/cm	300	41	265	85.7	37.2	100
3	DO	mg/l	5	3	11.3	7	1.4	93
4	BOD	mg/l	2	0	7.8	1.1	1.4	86
5	COD	mg/l	10	0.8	184.4	18.8	26.7	43
6	Na^+	mg/l	250	3.3	22.7	9.4	4.3	100
7	K^+	mg/l	12	0.1	7.4	1	1	100
8	Ca^{++}	mg/l	75	1.5	55	14.2	8.7	100
9	Mg^{++}	mg/l	200	0	16.9	3.7	2.7	100
10	TH	mg/l	300	7.8	201.8	50.8	28.8	100
11	$HCO3^-$	mg/l	200	5.9	152.9	47.8	21.6	100
12	$CO3^=$	mg/l	200	0	8.5	0.2	0.8	100
13	TALK	mg/l	300	5.9	152.9	48	21.7	100
14	Cl^-	mg/l	250	0.5	108.3	14.6	14	100
15	$SO4^=$	mg/l	150	0	21.3	3.5	2.8	100
16	NO3-N	mg/l	45	0	5.8	0.5	0.6	100
17	PO4-P	mg/l	0.1	0	1.8	0.2	0.2	46
18	SiO2	mg/l	50	0	35.5	2.9	5.5	100
19	Fe	mg/l	0.3	0	7.5	0.4	0.7	59
20	TDS	mg/l	500	19.7	249.3	70.9	29.7	100

with their respective objective values (Obj) as per CPCB, Indian Standard (IS) 10500: 2012 and WHO (2004) guidelines for drinking was done. It is evident that six parameters failed to show 100% compliance. Failed physico-chemical parameters are shown in red color.

Tables 4, 5, 6, 7, and 8 show physicochemical parameters of five sampling Locations K1–K5, 2003–2012.

Table 7 shows the list of 20 water quality parameters considered for CCME-WQI and their ranges for all locations collectively. This table is the overall lookup for whole reservoir water quality when compared with standards for best-designated use for drinking. As detailed in method while computing CCME-WQI each water quality parameter was compared with (IS) to compute excursions, nse, and F_3. It was observed for each location six parameters were showing deviation from their respective objective values (IS). This can be seen in tables from 2 to 6 for locations K1–K5.

Tables 8, 9, 10, 11, and 12 show Failed variables, Excursions, nse, F_1, F_2, F_3, and CCME-WQI for five locations during years 2003–2012.

Table 8 Results of sampling location K1 (Osade) right bank

Years	Total number of variables	Total number failed variables	Total number of tests	Number of failed tests	Excursion	nse	F_1	F_2	F_3	CCME-WQI
2003	20	5	40	8	18.45	0.46	25	13	32	76
2004	20	5	200	28	67.14	0.34	25	3	25	79
2005	20	5	240	29	60.38	0.25	25	2	20	81
2006	20	4	200	15	12.20	0.06	20	2	6	88
2007	20	3	60	5	1.59	0.03	15	5	3	91
2008	20	4	60	5	6.71	0.11	20	7	10	87
2009	20	4	80	9	8.80	0.11	20	5	10	87
2010	20	4	80	10	6.88	0.09	20	5	8	87
2011	20	3	60	5	8.57	0.14	15	5	13	88
2012	20	3	60	6	16.84	0.28	15	5	22	84

Table 9 Results of sampling location K2 (Gore/Matalwadi) right bank

Years	Total number of variables	Total number of failed variables	Total number of tests	Number of failed tests	Excursion	nse	F_1	F_2	F_3	CCME-WQI
2003	20	3	42	4	10.35	0.25	15	7	20	85
2004	20	5	218	24	39.93	0.18	25	2	15	83
2005	20	4	262	18	50.95	0.19	20	2	16	85
2006	20	4	218	23	14.64	0.07	20	2	6	88
2007	20	2	64	5	1.59	0.02	10	3	2	94
2008	20	4	64	6	4.27	0.07	20	6	6	87
2009	20	3	86	10	5.21	0.06	15	3	6	91
2010	20	3	86	6	1.04	0.01	15	3	1	91
2011	20	3	64	9	15.61	0.24	15	5	20	85
2012	20	4	64	4	11.89	0.19	20	6	16	85

Table 10 Results of sampling location K3 (Chaupatti) right bank

Years	Total number of variables	Total number of failed variables	Total number of tests	Number of failed tests	Excursion	nse	F_1	F_2	F_3	CCME-WQI
2003	20	4	42	3	1.18	0.03	20	10	3	87
2004	20	5	218	16	28.18	0.13	25	2	11	84
2005	20	6	262	27	28.18	0.11	30	2	10	82
2006	20	5	218	22	7.38	0.03	25	2	3	85
2007	20	3	64	6	1.04	0.02	15	5	2	91
2008	20	3	64	6	3.46	0.05	15	5	5	90
2009	20	3	86	8	8.61	0.1	15	3	9	90
2010	20	4	86	6	2.09	0.02	20	5	2	88
2011	20	3	64	1	2.99	0.05	15	5	4	91
2012	20	4	64	6	15.03	0.23	20	6	19	84

Table 11 Results of sampling location K4 (Kudje) left bank

Years	Total number of variables	Total number of failed variables	Total number of tests	Number of failed tests	Excursion	nse	F_1	F_2	F_3	CCME-WQI
2003	20	4	42	5	1.34	0.03	20	10	3	87
2004	20	5	218	21	11.08	0.05	25	2	5	85
2005	20	5	262	24	10.51	0.04	25	2	4	85
2006	20	5	218	18	13.28	0.06	25	2	6	85
2007	20	4	64	1	4.08	0.06	20	6	6	87
2008	20	5	64	6	17.20	0.27	25	8	21	81
2009	20	3	86	9	33.40	0.39	15	3	28	82
2010	20	4	86	7	2.19	0.03	20	5	2	88
2011	20	2	64	5	4.90	0.08	10	3	7	93
2012	20	3	64	5	8.49	0.13	15	5	12	89

Table 12 Results of sampling location K5 (Kudje) left bank

Years	Total number of variables	Total number of failed variables	Total number of tests	Number of failed tests	Excursion	nse	F_1	F_2	F_3	CCME-WQI
2003	20	3	42	3	1.7	0.04	15	7	4	90
2004	20	5	218	23	50.18	0.23	25	2	19	82
2005	20	5	262	17	36.26	0.14	25	2	12	84
2006	20	5	218	20	9.99	0.05	25	2	4	85
2007	20	3	64	4	1.28	0.02	15	5	2	91
2008	20	3	64	6	2.54	0.04	15	5	4	91
2009	20	3	86	3	4.38	0.05	15	3	5	91
2010	20	3	86	9	2.96	0.03	15	3	3	91
2011	20	3	64	6	7.85	0.12	15	5	11	89
2012	20	3	64	4	16.55	0.26	15	5	21	85

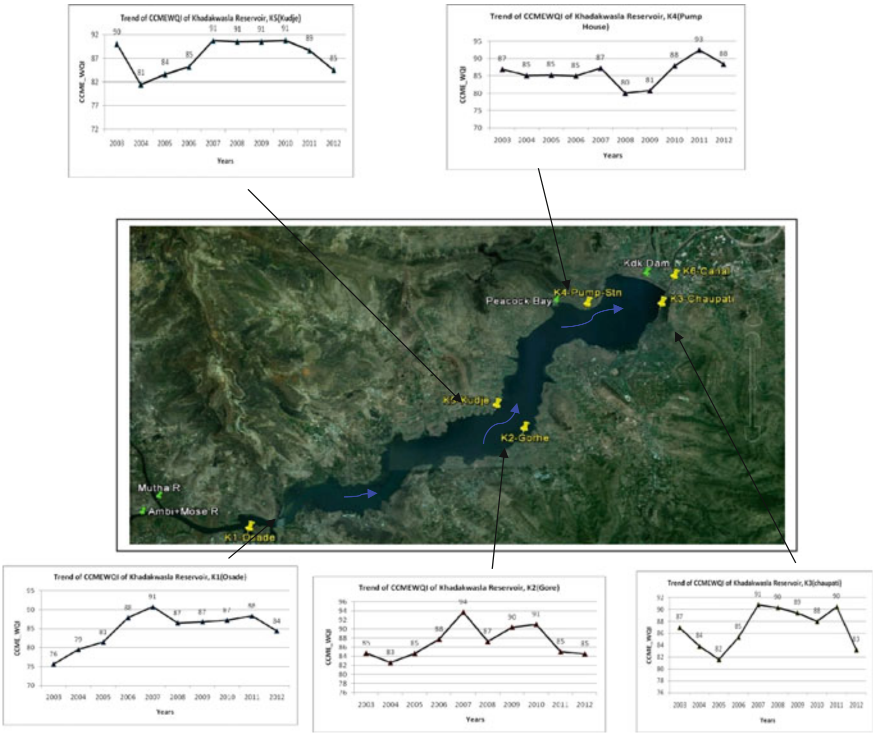

Fig. 3 Trend of CCME-WQI at 5 sampling locations in Khadakwasla reservoir

From the above result tables the following inferences are found:

***F_1* (*Scope*)**: Percentage of failed variables ranged from 10% (K2 in 2007) to 30% (K3 in 2005). In the year 2012, the scope was observed to range between 15 and 25%. Hence it shows an increasing trend.
***F_2* (*Frequency*)**: Percentage of failed tests ranged from 2 to 13%. From year 2003 to 2012 there is decrease in the percent of failed tests to 6–5%.
***F_3* (*Amplitude*)**: The collective amount by which individual tests were out of compliance ranged from 32 in the year 2003 to 1 in the year 2010 and 16–22 in year 2012. This high range of amplitude indicates decrease in water quality.

The trend of CCME-WQI for Khadakwasla in each location was computed and depicted graphically in Fig. 3 indicating spatial and temporal variation of water quality in the reservoir.

The calculated values of CCME-WQI for whole reservoir ranged from 76 to 94. There were no values in range of 95–100, hence 0% for excellent criteria of water quality and no values between range of 45–64, hence no marginal quality and no values between 0 and 44 so no poor quality (Table 13).

Table 13 The CCME-WQI distribution for five locations in Khadakwasla reservoir, Pune

Sampling locations	CCME-WQI values		Quality rating	Quality affecting activities
	Range	Average		
K1	76–89	86	Fair–good	Due to Anthropogenic, Household, Agricultural runoff, and rooftop runoff
K2	85–94	88	Good	
K3	84–91	88	Good	
K4	80–94	88	Good	
K5	83–94	88	Good	DO, pH, BOD, Fe, PO4-P, COD get affected

Conclusion

The CCME-WQI ranged from 76 to 94, indicating grade from fair to good water quality. "Fair" water quality was shown by 2% for location K1, and "good" water quality by 98% for locations K2, K3, K4, and K5. Locations K1 (Osade) and K2 (Matalwadi) are open banks and easy entry points for the nearby villagers for bathing and washing cloths and utensils. Agriculture activities for crops like rice, wheat, jawari, bajra, and vegetables are done near the banks in these two locations. In addition to this there is a cemetery in bank of location K2 constructed during the year 2007–2008. Extensive anthropogenic activities like washing of clothes, cattle, utensils, vehicles, etc., and bathing are carried out daily at this location of the reservoir.

Fencing at K4 and K3 which are restriction wall/embankment/mesh link were constructed in early 2009. This seems to have worked for improvement in water quality by way of containing the garbage created on the land, there itself near K3; and by limiting the access for human and cattle etc. to the left bank near dam (K4) that may cause pollution.

Lower water quality grade, i.e., 76 can be attributed to noncompliance of six variables, which did not comply with the objective values. Non-compliant parameters were DO, pH, BOD, Fe, PO4-P, COD.

Water Quality in this reservoir is facing pressure due to anthropogenic activities from left bank as well as from the right bank. As this reservoir is having less depth (average 5 m) and its surface area is exposed to clean winds throughout the year, which facilitates, very good natural aeration to maintain its dissolved oxygen naturally. As the reservoir water is continuously drawn by canal systems throughout the year, this causes a flow circulation in the reservoir and mixing of surface water with the deeper water at transitional and lacusterine zones. Hence in spite of anthropogenic activities, water wuality was found to be good. Public awareness should be created among the villagers and visiting tourists and the resorts located near the bank. This may reduce the disposal of pollutants in the vicinity (especially at K1) and help to keep the water quality in the range of excellent (CCME-WQI = 95–100).

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Assessment of Agricultural Water Quality of Shallow Groundwater Between Budhni and Chaursakhedi, North of River Narmada, District Sehore, Madhya Pradesh, India

Sunil Kumar Sharma, Shalini Yadav, V.K. Parashar and Pramod Dubey

Abstract Hydrogeochemistry of an area helps in understanding the geological processes which control the chemistry of water and plays an important role in determining the suitability of groundwater for various purposes. In the present study, an attempt has been made to understand the hydrochemistry and the agricultural water quality of water between Budhni and Chaursakhedi, North of river Narmada, District Sehore, Madhya Pradesh. In all 25 representatives, shallow groundwater samples were collected from the study area and physicochemical parameters were analyzed. Results obtained from water chemistry were used in the determination of various irrigational specifications to determine the agricultural quality of shallow groundwater. In the present study prominent specifications like soluble sodium percentage (SSP), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC), are used for determining the suitability of shallow ground water for agricultural purposes. Result shows that the majority of shallow groundwater of the study area belongs to Medium to High Saline and Low sodium water. Kelly's ratio shows that majority of shallow groundwater belongs to suitable class. As per Wilcox classification, the shallow groundwater belongs to Good to Permissible class. The shallow groundwater of the study area belongs to Safe class as per the classification based on RSC. As per the magnesium ratio classification, all the shallow groundwater's of the study area belongs to the suitable class and there are no magnesium hazards and thus they are suitable for agricultural purposes.

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Introduction

Water is an essential form of life on the earth, water resources have been a significant factor in the growth and advancement of human civilization. It plays an important role in all the human activities like housing, agriculture, industry, manufacturing, transportation and many other activities. Water is present both as surface and subsurface water which can be used in irrigation. Good quality of irrigation water is quite necessary for achieving maximum crop efficiency. During recent past, studies on agricultural water quality have been reported by various workers in India like Jayalakshmi Devi et al. (2009), Ravikumar et al. (2011), Sharma et al. (2011), Jhariya et al. (2012), Maghanga et al. (2013), Dhiman (2014) including Shrivastava (1980), Jain and Parashar (1994, 2001) in the alluvial plains of Narmada valley.

Study Area

The study area covers an area of about 300 km^2; with an East-West stretch from Budhni to Chaursakhedi, North of river Narmada. The area cover parts of Sehore district of Madhya Pradesh, India. The study area lies between latitude 22° 35′ 0″ to 22° 50′ 0″N and longitudes 77° 10′ 0″ and 77° 50′ 0″E. The area of present investigation falls on the Survey of India toposheet Nos. 55F/9, 55F/10, 55F/6 and 55F/2. The location and sampling station map of the study area is presented in Fig. 1.

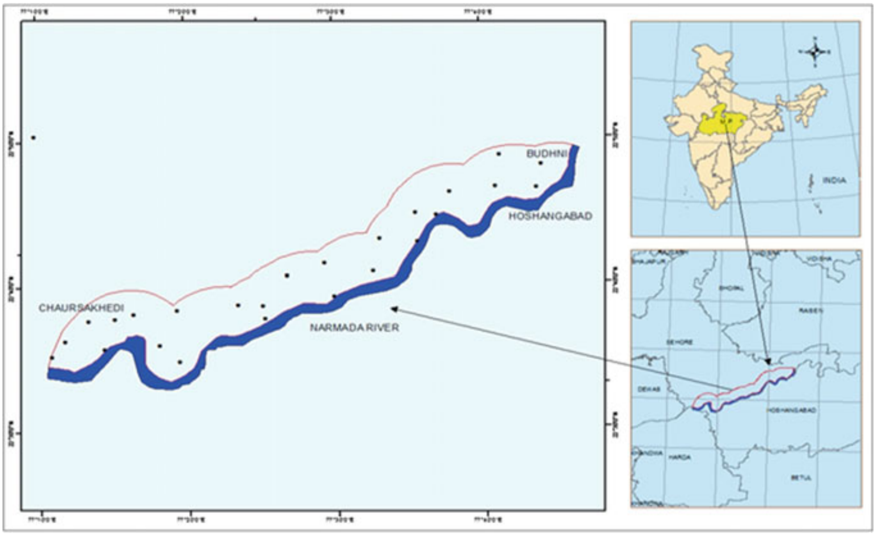

Fig. 1 Location and sampling station map of the study area

The entire catchment area of the Narmada River is characterized by undulating topography with number of hill ranges, valleys and plains. The area of present study is covered with alluvium which has been derived from weathering and mass wasting of Deccan traps and present as filling the faulted trough of the Narmada rift valley. In general the alluvial layer is thickest near the Narmada and tapering towards the foot hill of Satpura. The alluvium is chiefly composed of reddish, brownish, yellowish and sandy clay with numerous intercalations of sand, gravels and kankar along with pisolitic iron granules. The thickness of the alluvial deposits is variable depending upon the floor of the basin of deposition, which happens to be uneven.

The major portion of the study area is upland alluvium formed by deposition of sediments in the inland Narmada depression. The northern portion of it is longitudinally occupied by the alluvium. The constituents and nature of the alluvium vary locally, depending upon the rocks present in the study area, from which they have been derived. The hydro-geomorphological and geological map of the study area is presented in Figs. 2 and 3, respectively.

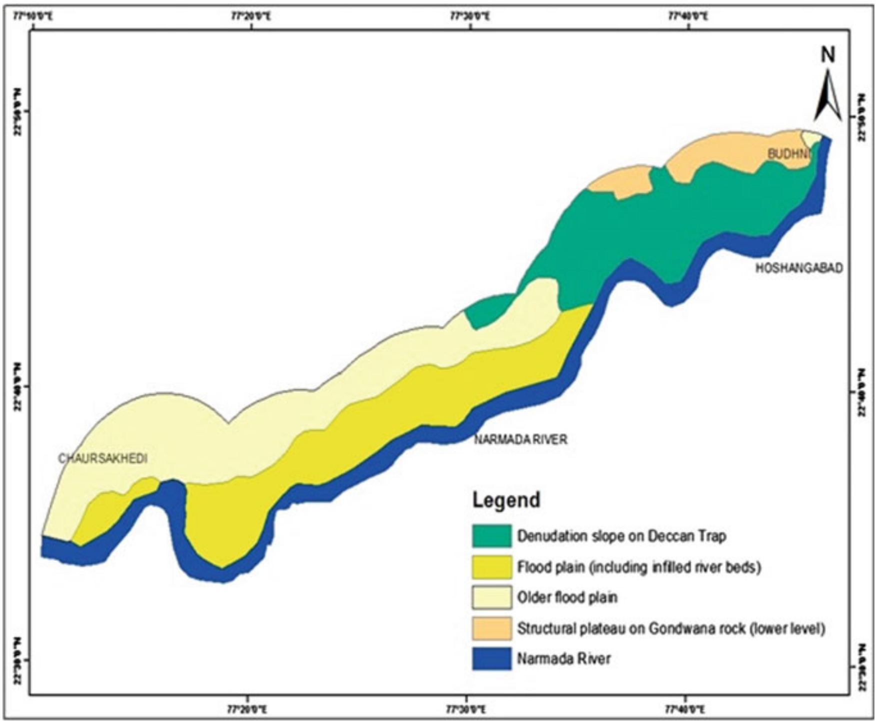

Fig. 2 Hydrogeomorphological map of the study area

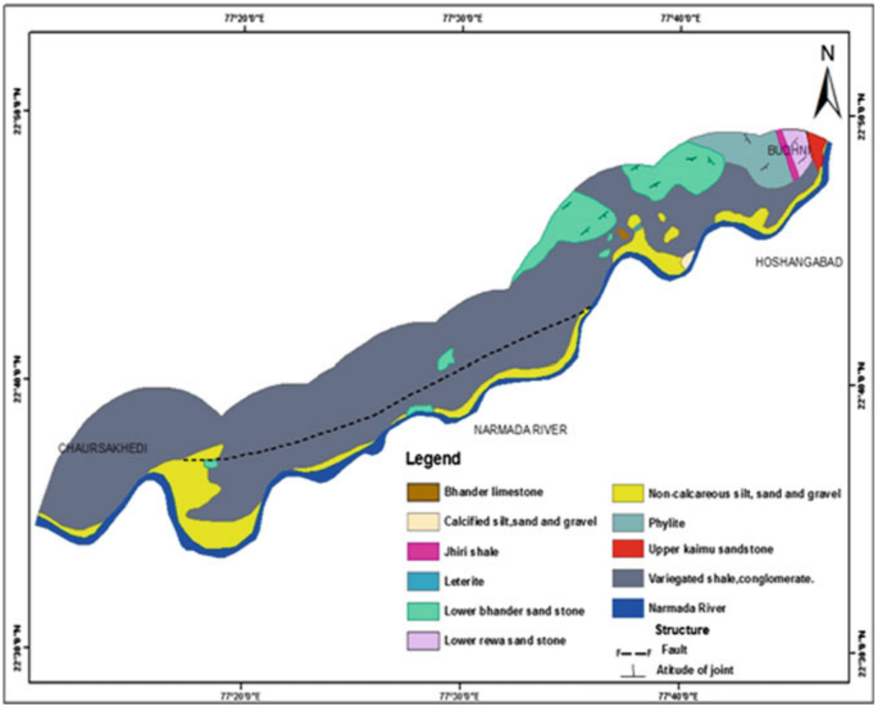

Fig. 3 Geological map of the study area

Materials and Methods

Chemical analyses of water samples provide valuable information about the environment to which natural water are exposed in the hydrologic cycle. The shallow groundwater samples were collected during pre-monsoon and post-monsoon period. The water samples were collected in one litre polyethylene bottles and analyzed by using the procedures given by APHA (1995). The analysis of water samples was carried out by using Hach Spectrophotometer, Flame photometer and titration methods. The physical properties like colour, odour, temperature and taste of water samples were recorded at the sampling stations during field work. The pH of the water samples was determined by pH metre. Conductivity is measured in micro mohs per cm at 25 °C by conductivity metre. Total dissolved solid (TDS) was determined with the help of TDS metre. The carbonate alkalinity was determined by a titrimetric method using phenolphthalein as indicator. The bicarbonate was determined by titrating sample with standard acid solution using methyl orange indicator. Total hardness as $CaCO_3$ was determined by EDTA titrimetric method using Erichrome Black-T indicator. Ca content was calculated from Ca hardness by multiplying with a factor 0.432 and the results were expressed in mg/l. Magnesium content was calculated from Mg hardness by using a formula and results expressed in mg/l. Chloride concentration was determined by titration method involving the formation of a reddish brown complex by adding potassium chromate which is titrated against silver nitrate solution. Nitrate is determined by phenol di sulphuric acid method as per APHA (1995) using Hach DR-4000 UV-Vis Spectrophotometer.

Results and Discussions

General Hydrochemistry

The analytical data of shallow groundwater samples collected both during the pre-monsoon and post-monsoon period are presented in Table 1 which indicates that there occurs considerable variation in the chemistry of shallow groundwater samples from place to place and pre-monsoon to post-monsoon periods, respectively. The range of pH value of shallow ground water of the study area varies from 7.2 to 8.0 in pre-monsoon and 7.0 to 7.9 in post-monsoon period. The electrical conductivity (EC) values in shallow groundwater vary from 420 to 910 µmohs/cm in pre-monsoon and 390 to 880 µmohs/cm in post-monsoon period. Calcium content in shallow ground water varies from 35 to 56 and 31 to 52 mg/l in pre-monsoon and post-monsoon periods, respectively. The Magnesium concentration in shallow ground water varies from 10 to 29 mg/l in pre-monsoon and 08 to 28 mg/l in post-monsoon period. The sodium content in shallow ground water varies from 10 to 76 mg/l in pre-monsoon and 5 to 71 mg/l in post-monsoon period. The Potassium content in shallow groundwater is varies from 1.1 to 8.1 mg/l in pre-monsoon and 0.6 to 7.3 mg/l in post-monsoon period. The total hardness in terms of $CaCO_3$ ranges from 154 to 242 mg/l in pre-monsoon and 140 to 225 mg/l in post-monsoon period.

The carbonate content is found to be absent in all the samples of shallow ground water, collected during the pre-monsoon and post-monsoon periods. Bicarbonate is the predominant anion in the shallow ground water of the study area. Bicarbonate concentration in the shallow ground water varies from 104 to 274 mg/l in pre-monsoon and 85 to 260 mg/l in post-monsoon period.

The chloride concentration in shallow ground water varies from 36 to 96 mg/l in pre-monsoon and 31 to 92 mg/l in post-monsoon period. The Sulphate concentration in the shallow ground water of the study area varies from 18 to 62 mg/l in pre-monsoon and 13 to 57 mg/l in post-monsoon period. The Nitrate in the irrigation water serves as a nutrient to plants and crops. In the present investigation, the Nitrate content in the shallow groundwater varies from 16 to 64 mg/l in pre-monsoon and 12 to 56 mg/l in post-monsoon period. The Phosphate concentration in shallow groundwater of the study area varies from 0.12 to 0.29 mg/l in pre-monsoon and 0.09 to 0.27 mg/l in post-monsoon period.

Table 1 Pre-monsoon and post-monsoon hydrochemistry of shallow groundwater of the study between Budhni and Chaursakhedi

Pre-monsoon															
Well No.	Name of the village	pH	EC × 10^6 at 25°	TDS	Concentrations in mg/I										
					Cations				T.H. as CaC	Anions					
					Na^+	K^+	Ca^{++}	Mg^{++}		HCO_3	CO_3^-	Cl^-	NO_3	SO_4	PO_4
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Budhni	7.8	710	454	70	3.5	42	19	182	180	Abs	77	30	33	0.27
2	Tatpura	7.8	660	422	19	1.3	39	15	160	138	Abs	36	64	22	0.24
3	Devgaun	7.9	640	410	40	1.3	38	25	198	189	Abs	82	45	40	0.27
4	Holipura	7.6	460	294	51	1.9	40	17	170	122	Abs	93	16	52	0.22
5	Unchhakheda	7.7	680	435	66	1.1	36	24	190	195	Abs	65	25	25	0.24
6	Ninor	7.5	910	582	22	6.1	42	17	176	116	Abs	76	55	28	0.21
7	Pathora	7.6	820	525	35	1.5	40	23	194	190	Abs	50	32	20	0.29
8	Aawali	7.5	610	390	20	1.7	56	10	178	127	Abs	86	18	29	0.22
9	Dhankot	7.7	730	467	18	3.9	45	10	154	140	Abs	45	49	18	0.29
10	Mogra	7.6	670	429	42	3.1	50	13	180	206	Abs	49	16	30	0.27
11	Rehugaon	7.6	690	442	36	8.1	36	22	180	140	Abs	75	36	41	0.23
12	Nehlai	7.6	670	429	15	2.8	55	18	212	104	Abs	83	55	32	0.25
13	Ratanpur	7.8	730	467	10	3.7	48	16	186	116	Abs	87	56	25	0.27
14	Sawalkheda	7.9	690	442	39	4.5	46	19	192	109	Abs	96	36	30	0.24
15	Matthagaon	7.7	600	384	47	3.8	38	25	200	172	Abs	85	30	42	0.24
16	Basaniya	7.8	780	500	29	3.2	38	24	194	172	Abs	88	35	18	0.26
17	Chhidgaon	7.9	560	358	46	3.6	43	29	228	169	Abs	81	25	26	0.28
18	Manjhil	7.2	610	390	75	3.3	35	20	170	220	Abs	79	30	20	0.21
19	Tilariya	8	630	403	65	3.4	55	18	210	274	Abs	45	35	26	0.23

(continued)

Table 1 (continued)

Pre-monsoon															
Well No.	Name of the village	pH	EC × 10^6 at 25°	TDS	Concentrations in mg/l										
					Cations				T.H. as CaC	Anions					
					Na^+	K^+	Ca^{++}	Mg^{++}		HCO_3	CO_3^-	Cl^-	NO_3	SO_4	PO_4
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
20	Chich	7.8	420	269	31	3.2	52	27	242	202	Abs	72	39	56	0.27
21	Atraliya	7.7	770	493	29	4.7	50	23	218	157	Abs	82	60	49	0.19
22	Silkhanth	7.6	830	531	76	3.5	42	25	208	186	Abs	53	60	62	0.18
23	Nimakhedi	7.6	510	326	59	3.5	37	20	175	148	Abs	83	57	37	0.27
24	Dholpur	7.5	450	288	70	3.9	50	18	201	255	Abs	49	37	25	0.19
25	Chaursakhedi	7.5	910	582	46	3.3	46	23	210	178	Abs	57	48	45	0.12
	Min.	7.2	420	269	10	1.1	35	10	154	104	Abs	36	16	18	0.12
	Max.	8	910	582	76	8.1	56	29	242	274	Abs	96	64	62	0.29

Post-monsoon															
Well No.	Name of the village	pH	EC × 10^6 at 25 °C	TDS	Concentrations in mg/l										
					Cations				T. H. as CaC	Anions					
					Na^+	K^+	Ca^{++}	Mg^{++}		HCO_3	CO_3^-	Cl^-	NO_3	SO_4	PO_4
1	2	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	Budhni	7.5	690	442	63	2.6	37	18	164	164	Abs	72	27	26	0.25
2	Tatpura	7.6	630	403	14	0.8	35	14	145	120	Abs	31	56	18	0.21
3	Devgaun	7.4	610	390	34	0.9	34	24	183	178	Abs	76	37	33	0.25
4	Holipura	7.2	440	282	46	1.1	36	16	155	102	Abs	89	12	47	0.21

(continued)

Table 1 (continued)

Post-monsoon															
Well No.	Name of the village	pH	EC × 10^6 at 25 °C	TDS	Concentrations in mg/I										
					Cations				T. H. as CaC	Anions					
					Na^+	K^+	Ca^{++}	Mg^{++}		HCO_3	CO_3^-	Cl^-	NO_3	SO_4	PO_4
1	2	17	18	19	20	21	22	23	24	25	26	27	28	29	30
5	Unchhakheda	7.5	650	416	61	0.6	32	21	166	180	Abs	61	21	20	0.22
6	Ninor	7.4	880	563	17	5.1	37	16	159	100	Abs	70	47	25	0.19
7	Pathora	7.3	790	506	30	1	35	22	180	178	Abs	44	27	16	0.27
8	Aawali	7.4	580	371	14	1.6	52	8	163	108	Abs	82	14	26	0.19
9	Dhankot	7.2	700	448	13	3.1	41	9	140	125	Abs	40	42	13	0.27
10	Mogra	7.4	630	403	35	2.7	45	12	164	198	Abs	43	13	26	0.26
11	Rehugaon	7.2	660	422	31	7.3	31	19	157	126	Abs	72	30	37	0.21
12	Nehlai	7.5	640	410	10	2.1	50	17	197	90	Abs	79	49	26	0.23
13	Ratanpur	7.7	700	448	5	3	44	15	173	85	Abs	83	51	21	0.23
14	Sawalkheda	7.6	650	416	34	3.7	42	18	180	97	Abs	92	30	25	0.21
15	Matthagaon	7.3	570	365	41	2.9	35	24	186	157	Abs	80	25	38	0.2
16	Basaniya	7.4	740	474	23	2.5	33	23	180	160	Abs	84	31	13	0.24
17	Chhidgaon	7.6	540	346	40	3	39	28	213	157	Abs	76	20	21	0.27
18	Manjhil	7	590	378	71	2.9	31	19	155	203	Abs	72	26	14	0.19
19	Tilariya	7.9	600	384	60	2.6	50	17	194	260	Abs	41	31	21	0.21
20	Chich	7.7	390	250	26	2.5	47	26	225	190	Abs	68	35	47	0.25
21	Atraliya	7.1	740	474	23	3.9	45	22	203	143	Abs	79	53	43	0.17
22	Silkhanth	7.3	810	518	70	2.7	37	24	192	170	Abs	47	56	57	0.16

(continued)

Table 1 (continued)

Post-monsoon															
Well No.	Name of the village	pH	EC × 10^6 at 25 °C	TDS	Concentrations in mg/I										
					Cations				T. H. as CaC	Anions					
					Na^+	K^+	Ca^{++}	Mg^{++}		HCO_3	CO_3^-	Cl^-	NO_3	SO_4	PO_4
1	2	17	18	19	20	21	22	23	24	25	26	27	28	29	30
23	Nimakhedi	7.4	480	307	53	2.8	33	19	160	138	Abs	78	51	31	0.25
24	Dholpur	7.3	420	269	63	3	45	17	184	240	Abs	44	30	21	0.16
25	Chaursakhedi	7	870	557	39	2.7	42	22	196	162	Abs	53	41	40	0.09
	Min.	7	390	269	5	0.6	31	8	140	85	Abs	31	12	13	0.09
	Max.	7.9	880	557	71	7.3	52	28	225	260	Abs	92	56	57	0.27

Irrigation Water Quality

The suitability of shallow groundwater has been evaluated on the basis of analytical results. Various specifications have been proposed from time to time by different workers including Asgar et al. (1936), Kelley et al. (1940); Wilcox (1948, 1955), Eaton (1950); US Soil Salinity Laboratory Staff (1954), Saligram (1961), Uppal (1964), Ramamoorthy (1964), Federal Water Pollution Control Authority (1968), Paliwal (1972), Environmental Protection Agency (1973) and Ayers and Westcot (1994). In the present study the specifications as proposed by Kelley et al. (1940); Wilcox (1948, 1955), Eaton (1950), US Soil Salinity Laboratory Staff (1954), Paliwal (1972) have been used to assess the suitability of shallow ground water for agricultural purposes.

Results and Discussion

Soluble sodium percentage (SSP), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), Kelly's Ratio and Magnesium hazard are the prominent specifications for determining the suitability of shallow ground water for agricultural purposes and are presented in Table 2. The recommended classification of irrigation water quality with respect to EC, SAR, Kelly's Ratio, Mg. Ratio, RSC and Na% are presented in Table 3.

Salinity hazard is evaluated on the basis of Electrical conductivity and it reflects the total dissolved solids (TDS) in shallow groundwater. High salt content in irrigation water affects the soil structure, permeability and plant growth. As per the classification proposed by Richards (1954), the water is low (if EC below 250 µmohs/cm), the water is medium (if EC between 250 and 750 µmohs/cm), the water is high (if EC content between 750 and 2250 µmohs/cm), the water is very high (if EC is more than 2250 µmohs/cm) with respect to salinity in water. When the shallow groundwater samples compared with this classification, Table 2 clearly indicates that the shallow groundwater varies from 420 to 910 µmohs/cm in pre-monsoon period and 390–880 µmohs/cm in post-monsoon period, respectively, and thus they belongs to Medium to High Salinity class. Table 3, further shows that 76% of shallow groundwater in pre-monsoon and 84% in post-monsoon period belongs to Medium salinity class.

Sodium or alkali hazard is measured on the basis of SAR. The relativity of sodium ion in the exchange reaction with soil is expressed in terms of a ratio known as Sodium Adsorption Ratio (SAR) which is defined as:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\mathrm{Ca} + \mathrm{Mg}/2}} \text{ (Where all concentrations are expressed in epm.)}$$

Table 2 Na%, SAR, Mg ratio and kelly's ratio of the shallow groundwater of the study area

Well No.	Name of village	Pre-monsoon					Post-monsoon				
		Na %	SAR	Mg ratio	RSC	Kelly ratio	Na %	SAR	Mg ratio	RSC	Kelly ratio
1	Budhni	52.04	2.25	31.14	−0.71	1.15	52.23	2.12	32.73	−0.64	1.14
2	Talpura	25.57	0.65	27.77	−0.92	0.35	21.94	0.5	28.57	−0.93	0.28
3	Devgaon	38.35	1.24	39.68	−0.86	0.63	36.59	1.09	41.38	−0.75	0.59
4	Holipura	46.4	1.7	29.82	−1.4	0.89	46.41	1.61	30.77	−1.45	0.88
5	Unchhakheda	51.92	2.09	40	−0.51	1.1	53.22	2.07	39.62	−0.38	1.15
6	Ninor	25.25	0.72	28.8	−1.6	0.37	22.63	0.59	30.19	−1.53	0.32
7	Pathora	35.17	1.09	36.5	−0.78	0.55	34.09	0.97	38.6	−0.64	0.53
8	Aawali	22.8	0.64	15.15	−1.53	0.3	18.51	0.48	13.33	−1.48	0.23
9	Dhankot	23.4	0.63	18.18	−0.78	0.33	19.66	0.48	18	−0.74	0.26
10	Mogra	38.85	1.37	20.61	−0.19	0.66	36.95	1.19	21.05	−0.09	0.61
11	Rehugaon	35.25	1.17	37.93	−1.32	0.62	35.1	1.08	38	−1.05	0.62
12	Nehlai	16.51	0.44	24.65	−2.52	0.2	12.64	0.3	25.37	−2.43	0.15
13	Ratanpur	12.87	0.31	25	−1.82	0.15	7.46	0.16	25.41	−2.04	0.08
14	Sawalkheda	35.94	1.23	29.23	−2.07	0.6	34.8	1.11	30	−1.99	0.57
15	Matthagaon	41.3	1.45	39.67	−1.14	0.74	39.84	0.3	40.67	−1.15	0.69
16	Basaniya	30.78	0.91	38.71	−1.05	0.47	28.22	0.6	41.07	−0.92	0.41
17	Chhidgaon	37.82	1.33	40.27	−1.16	0.64	36.36	1.2	41.71	−1.68	0.6
18	Manjhil	56.26	2.5	36.36	−0.22	1.36	57.3	2.49	38	0.22	1.42
19	Tilariya	45.97	1.95	24.65	0.27	0.89	46.29	1.87	25.36	0.36	0.89
20	Chich	27.38	0.87	34.18	−1.5	0.39	25.61	0.75	35.61	−1.38	0.35
21	Atraliya	27.33	0.85	31.49	−1.82	0.4	24.49	0.7	32.83	−1.72	0.34
22	Silkhanth	51.87	2.29	37.31	−1.11	1.13	52.35	2.2	39.35	−1.03	1.15

(continued)

Table 2 (continued)

Well No.	Name of village	Pre-monsoon					Post-monsoon				
		Na %	SAR	Mg ratio	RSC	Kelly ratio	Na %	SAR	Mg ratio	RSC	Kelly ratio
23	Nimakhedi	49.37	1.96	35.08	−1.06	1.63	49.16	1.82	36.53	−0.95	1.02
24	Dholpur	49.33	2.15	26.47	0.2	1.03	49.21	2.04	27.42	0.28	1.01
25	Chaursakhedi	38.88	1.38	33.33	−1.27	0.66	36.89	1.22	34.37	−0.26	0.61

Table 3 Tabular classification of shallow groundwater of the study area

Irrigational specifications	Range	Class	Type of water			
			Pre-monsoon		Post-monsoon	
			No. of samples	%	No. of samples	%
EC	<250	Low	0	Nil	0	Nil
	250–750	Medium	19	76%	21	84%
	750–2250	High	6	24%	4	16%
	>2250	Very high	0	Nil	0	Nil
	Total		**25**	**100%**	**25**	**100%**
SAR	<10	Low	25	100%	25	100%
	18-Oct	Medium	0	Nil	0	Nil
	18–26	High	0	Nil	0	Nil
	>26	Very high	0	Nil	0	Nil
	Total		**25**	**100%**	**25**	**100%**
Kelly's ratio	<1	Suitable	19	76%	19	76%
	1–2	Marginal	6	24%	6	24%
	>2	Unsuitable	Nil	Nil	Nil	Nil
	Total		**25**	**100%**	**25**	**100%**
Magnesium ratio	< 50	Suitable	25	100%	25	100%
	>50	Unsuitable	Nil	Nil	Nil	Nil
	Total		**25**	**100%**	**25**	**100%**
Residual sodium carbonate (RSC)	<1.25	Safe	25	100%	25	100%
	1.25–2.50	Marginal	Nil	Nil	Nil	Nil
	>2.50	Unsuitable	Nil	Nil	Nil	Nil
	Total		**25**	**100%**	**25**	**100%**
Soluble sodium percentage (SSP)	<20	Excellent	2	8%	4	16%
	20–40	Good	14	56%	13	52%
	40–60	Permissible	9	36%	8	32%
	60–80	Doubtful	0	Nil	0	Nil
	>80	Unsuitable	0	Nil	0	Nil
	Total		**25**	**100%**	**25**	**100%**

Excess sodium content in irrigation water produces the undesirable effects on soil properties and it reduces soil permeability. As per the classification based on SAR, the sodium hazard is Low, if SAR content is less than 10; Medium, if SAR content is in between 10 and 18; High, if SAR content is in between 18 and 26 and Very High if SAR content is more than 26. When the shallow groundwater samples compared with this classification and refer Table 3, it clearly indicates that the shallow groundwater belongs to Low Sodium waters in pre and post-monsoon, respectively.

Kelley's et al. (1940) has proposed the specification in which the potential sodium hazard in irrigation water can be evaluated on the basis of the following ratio:

$$\text{Kelley's ratio} = \frac{\text{Na}}{\text{Ca} + \text{Mg}}, \text{ where all the conc expressed in epm.}$$

Kelley et al. (1940) mentioned that if this ratio is less than unity the water is suitable, more than two the water is unsuitable and in between one and two the water is marginal for irrigational purposes. It is seen from Table 2, the Kelly's ratio varies from 0.15 to 1.63 in pre-monsoon and 0.08 to 1.42 in post-monsoon period. Table 3 shows that 76% of shallow groundwater in pre and post-monsoon belongs to the suitable class and 24% belongs to the marginal class in pre and post-monsoon period. Thus, the majority of shallow groundwater is suitable for agricultural purposes.

Wilcox (1955) has proposed a classification and classify the irrigation waters into Excellent (if Na% is less than 20), Good (if Na% is in between 20 and 40), Permissible (if Na% is in between 40 and 60), Doubtful (if Na% is in between 60 and 80) and Unsuitable (if Na% is more than 80) classes on the basis of Soluble Sodium Percentage (SSP), which can be calculated by the following equation:

$$\text{SSP} = \frac{(\text{Na} + \text{K}) \times 100}{\text{Ca} + \text{Mg} + \text{Na} + \text{K}}, \text{ where all concentration are expressed in epm}$$

It is seen from the Table 2, the Na% varies from 12.87 to 56.26 in pre-monsoon and 7.46 to 57.30 in post-monsoon period. Table 3 shows that 56% of shallow groundwater in pre-monsoon period and 52% in post-monsoon period belong to Good class and 36% of shallow groundwater in pre-monsoon period and 32% in post-monsoon period belongs to Permissible class which shows that the majority of shallow groundwater is suitable for agricultural purposes.

Eaton (1950) recommended that water having Carbonate and Bicarbonate ions in excess of Calcium and Magnesium will lead to much greater alkali formation. The carbonate and bicarbonate hazards in agricultural water quality are measured in terms of residual sodium carbonate (RSC) by the following equation:

$$\text{RSC} = (\text{CO}_3 + \text{HCO}_3) - (\text{Ca} + \text{Mg}), \text{where all concentration are expressed in epm}$$

Based on RSC the irrigation Waters are classified as Safe (if RSC is less than 1.25), Marginal (if RSC is in between 1.25 and 2.5) and Unsuitable (if RSC is more than 2.5). RSC of shallow groundwater of the study area varies from −2.52 to −0.19 in pre-monsoon and −2.43 to −0.09 in post-monsoon period, respectively. After imperative examination of Tables 2 and 3, it reveals that all the shallow groundwater of the study area belongs to Safe class and thus they are suitable for agricultural purposes.

Paliwal (1972) has proposed the ratio Mg × 100/Ca + Mg as an index of magnesium hazards to irrigation waters. As per the classification, if the Mg Ratio less than 50% the waters are suitable and if Mg ratio is more than 50% the water belongs to Unsuitable. The magnesium ratio of shallow groundwater of the study area varies from 15.15 to 40.27 in pre-monsoon and 13.33 to 41.71 in post-monsoon period, respectively. After vital examination of Table 3, it reveals that all the shallow groundwater of the study area belongs to the suitable class and there is no magnesium hazard in shallow groundwater of the study area.

Conclusions

Agricultural water quality was determined on the basis of Salinity hazard, Sodium hazard and Bicarbonate hazard. According to the classification of shallow groundwater with respect to SAR and EC, the majority of shallow groundwater of the study area belongs to belongs to medium to high salinity class and Low sodium water. Kelly's ratio shows that 76% of shallow groundwater in pre and post-monsoon belongs to the suitable class. As per Wilcox classification, the shallow groundwater in pre-monsoon period and post-monsoon period belongs to Good to Permissible class. Classification based on RSC clearly indicates that all the shallow groundwater of the study area belongs to Safe class and thus they are suitable for agricultural purposes. As per the magnesium ratio classification, all the shallow groundwater of the study area belongs to the suitable class and there are no magnesium hazards in shallow groundwater of the study area.

From the above-mentioned discussion and interpretation of the hydrochemistry and irrigational specifications, it can be concluded that the shallow groundwater of the study area is quite appropriate for irrigational purposes.

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Active Water Quality Management in Rural Small Watersheds

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Abstract Diverse land and water uses are found in rural areas of Monsoon regions. Based on field studies in Japan and Bangladesh, water quality management problems are considered at small watershed levels. A study site in Japan is chosen in a hilly area. Upland tea plantations in the site are the major source of nitrate pollution to the downstream water bodies because of heavy fertilizer application. Utilizing paddy fields and irrigation tanks as buffer of the polluted water is feasible, but it risks vulnerable aquatic ecosystems. Another study site is in the floodplains of Bangladesh. Countless ponds are used in the rural communities for domestic, animal watering and fishery purposes. Introduction of comparatively warm groundwater into the ponds during winter seasons may accelerate the growth of fish. However, groundwater depletion is the major concern. The concept of Markov decision processes is applied to find the optimal actions for the two different water quality management problems.

Introduction

Rural land and water resources in Monsoon regions are used for multi-purposes due to seasonal climatic variations. Sound distribution of water in terms of both quantity and quality in such cases is a complex issue involving hydrology, hydraulics, sociology, economics and ecology. Phong et al. (2010) focused on the integration of aquaculture into rice farming systems in this context. In this study, scientific methodologies are considered to promote active water quality management for rice-fish culture at rural community levels. Contrasting field studies were conducted in Japan and Bangladesh, to formulate abstract mathematical optimization problems.

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A study site in Japan is chosen in a hilly area, where forests, paddy fields, tea plantations and irrigation tanks are the dominant land uses. The upland tea plantations developed in the 1960s, are being the major source of nitrate pollution to the downstream water bodies because of heavy application of fertilizers. Utilizing the paddy fields and the irrigation tanks as buffer of polluted water from the tea plantations is a feasible option, but it risks vulnerable aquatic ecosystems (Mabaya et al. 2016).

Another study site in Bangladesh is in the Brahmaputra-Jamuna floodplains with double-cropping paddy rice system. In recent decades, the dry season paddy irrigation for *boro* rice has deteriorated groundwater resources (Shahid and Hazarika 2010; Rahman and Mahbub 2012), while countless artificial ponds are used in the rural communities for domestic, animal watering and fishery purposes. Introduction of comparatively warm and less polluted groundwater into the artificial ponds during winter seasons may accelerate the growth of fish, which have high economic values. However, groundwater depletion during the following rice irrigation seasons is still the major concern.

The concept of Markov decision processes can be applicable to finding the optimal actions for sustainable rural development involving water quality management. It is shown that the different practical problems in the two study sites can be dealt with in the same mathematical framework. Dynamics of water storage, rice growth and fish growth are modelled to determine transition probabilities for spatio-temporally discrete processes. The Bellman equation, which is a recursive formula, is used for computing optimal policies based on the principle of dynamic programming.

Field Studies

Concurrent Use of Japanese Irrigation Tanks for Rice Cultivation and Aquaculture

There exist about 200,000 irrigation tanks in Japan, mostly purposing rice cultivation during the summer seasons from April through September. However, it also used to be a common practice to rear edible fish species such as *Cyprinus carpio* (common carp) and *Carassius cuvieri* (white crucian carp) in irrigation tanks (Tamura 1961). Field studies from different hydro-environmental aspects have been conducted in a small watershed, which is referred to as Site I, located in Imago of Shiga Prefecture, Japan (Hiramatsu et al. 2003; Mabaya et al. 2016). There are four irrigation tanks in Site I, none of which is currently used for aquaculture. However, the presence of aquatic species including *Oryzias latipes* (Japanese rice-fish), *Misgurnus anguillicaudatus* (Japanese weather loach), *Palaemon paucidens* (freshwater prawn) and *Rhinogobius* sp. (freshwater gobies) has been confirmed in the irrigation tanks, paddy fields and/or valley bottoms of inland valleys. Nitrate

Table 1 Results of nitrate concentration tests in Site I

Sub-watershed	Number of samples	Nitrate concentration (mg/L)
Higashi irrigation tank	11	Average = 0.04, range: 0–0.3
Imago irrigation tank	8	Average = 1.93, range: 0.2–5
Sueda inland valley seepage runoff	8	Above 10

concentrations were measured in different water bodies distributed in Site I, using simplified on-site water quality pack tests (Kyoritsu Chemical Check Laboratory Corporation, Tokyo, Japan). Nitrate has long term effects on general health, growth and breeding ability of fish (Nakasone et al. 2002). A study of Kincheloe et al. (1979) has demonstrated a positive correlation between the worst total mortality rates and nitrate exposures. Higashi and Imago irrigation tanks are two of the four irrigation tanks, contrasting in terms of catchment areas without and with tea plantation coverages, respectively. Another larger dam located outside of the Site I's watershed supplement Imago irrigation tank with less polluted water via a canal. There is an inland valley referred to as Sueda inland valley, where seepage runoff at a cliff is also observed. The catchment area of Sueda inland valley is dominantly used for tea plantations, and there is no irrigation tank downstream. From the test results shown in Table 1, it is inferred that tea plantations are the sources of high nitrate concentrations.

Therefore, rearing profitable fish in Imago irrigation tank is a challenging enterprise, as the water quality and the irrigation demand are the critical constraints.

Potential Use of Groundwater for Aquaculture in Bangladeshi Paddy Areas

Bangladeshi winter season (*shitkal*) lasts from mid-December to mid-February, corresponding to the period between rainfed (*kharif*) crop harvesting and starting of irrigation season for *boro* rice. Rural environmental characteristics of the season are low air temperature, less precipitation, high but declining groundwater table and less farming activities (Shankar et al. 2004). The temperature of groundwater is almost stable throughout the year. In order to confirm these characteristics, field measurements using HOBO U20 pressure/temperature data loggers were conducted from September 9, 2012 through September 24, 2014 in a small watershed, which is referred to as Site G, located in Godashimla of Jamalpur District, Dhaka Division, Bangladesh. Figure 1 shows observed data series of accumulated rainfall depths measured by Decagon ECRN-50 raingauge (Rain), groundwater levels (GWL) and temperatures (GWT), air temperatures (Air T), water depths (Pond h) and temperatures (Pond T) of a pond for aquaculture. The pond is connected to an irrigation canal, whose water source is pump lifted groundwater.

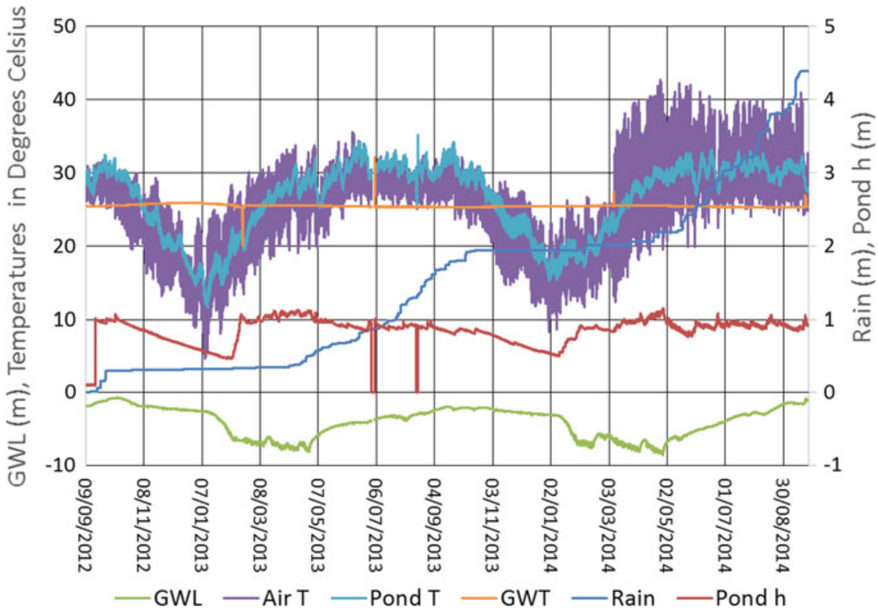

Fig. 1 Data series observed in Site G

Aquaculture of carp species such as *Catla catla*, *Labeo rohita* and *Cirrhinus cirrhosus* is an emerging enterprise in rural areas of the country (Mamun and Mahmud 2014), substituting for a traditional fishery in natural rivers and wetlands (Craig et al. 2004). However, the major constraint of such modern aquaculture is adequate supply of fingerlings due to low growth rate of fish during the winter season (Sarker et al. 2006).

It can be hypothesized that introduction of the relatively warm groundwater into fish ponds to produce off-season fingerlings will yield livelihood benefits and high income for farmers, provided that it will not dry up the aquifer during the following rice irrigation season.

Mathematical Approach

Markov Decision Processes

A Markov decision process is a spatio-temporal discrete process $X_t \in \Omega$, with which the operator chooses a decision $a_t = a$ from a finite set of decisions A to transit the state X_t from to X_{t+1} according to the transition probabilities

$$P_{ij}(a) = P\{X_{t+1} = j | X_t = i,\ a_t = a\}. \tag{1}$$

If the decision $a \in A$ is chosen for the state i, then the cost $f(i, a)$ is incurred. A policy Π is a map from Ω to A. The expected value of the total cost incurring from the current time s until a prescribed terminal time T for $X_s = i$ is denoted by

$$V^{\Pi}(s, i) = E^{\Pi}\left[\sum_{t=s}^{t<T} f(X_t, a_t) | X_s = i\right]. \tag{2}$$

The policy Π^* is said to be optimal if

$$V^{\Pi^*}(s, i) = \inf_{\Pi} V^{\Pi}(s, i) \tag{3}$$

for any time s and any state i. From the principle of dynamic programming, the Bellman equation

$$V^{\Pi^*}(s, i) = \min_{a \in A}\left\{ f(i, a) + \sum_j P_{ij}(a) V^{\Pi^*}(s+1, j)\right\} \tag{4}$$

is deduced and is solved with the terminal condition

$$V^{\Pi^*}(T, i) = 0, \quad \forall i \in \Omega, \tag{5}$$

to determine the value function $V^{\Pi^*}(s, i)$ as well as the optimal policy Π^* (Ben-Tal et al. 2009).

Problem Formulation

The practical water quality management problems posed for Site I and Site G are formulated as a unified optimization problem for Markov decision processes. The state x of water storage commonly represents the storage volume of Imago irrigation tank in Site I and that of the aquifer in Site G. The capacity of the water storage is normalized as unity. The governing equation of x is the water balance equation

$$\frac{\mathrm{d}x}{\mathrm{d}t} = Q - u \tag{6}$$

where Q is the uncontrollable water balance, and u is the intake discharge as the decision variable. The states y and z are considered for the growth levels of rice and fish, respectively. The dynamics of the states y and z are assumed to be represented by the common logistic equations

$$\frac{\mathrm{d}y}{\mathrm{d}t} = r_y\left(K_y - y\right)y, \quad \frac{\mathrm{d}z}{\mathrm{d}t} = r_z(K_z - z)z \tag{7}$$

where r_y and r_z are the growth rates, and K_y and K_z are the carrying capacities for y and z, respectively. Maturity of rice and fish is also normalized as unity. Then, the x-y-z domain $(0,1)^3$ is discretized into $n_x \times n_y \times n_z$ sub-cubes. The i_x-i_y-i_z sub-cube is indexed as $i = i_x n_y n_z + i_y n_z + i_z$ to constitute the domain Ω of a Markov decision process. Only two options are considered for decisions: to intake water at a prescribed rate ($a = 1$) or not to intake water at all ($a = 0$). Therefore, the set of decisions is

$$A = \{0, 1\}. \tag{8}$$

Table 2 shows the parameters specified for Site I and Site G. The time domain is commonly set as $[0, T] = [0, 180]$ (days). The cost function, which is also the same for the two sites, is prescribed as

$$f(i,a) = a\,\exp\left(-\frac{i_x}{n_x}\right) - 5\chi_{i_y,n_y-1} - \left(1 + \cos\left(\frac{\pi t}{T}\right)\right)\chi_{i_z,n_z-1} \tag{9}$$

where $\chi_{i,k}$ is the indicator function which is equal to 1 when $i = k$ and is equal to 0 otherwise.

The transition probabilities are calculated so that the drifts of the states accord with the dynamics specified in (6) and (7). However, stochastic diffusion is inevitably included due to spatio-temporal discretization. The diffusion effect is intentionally taken larger for the fish growths, since aquaculture is assumed to be more risky enterprise than rice cultivation in both of the two sites.

Table 2 Parameters set for Site I and Site G

Parameters	Site I	Site G
Q	$1/30$	$-1/30$
u	$\begin{cases} 0 & (a=0) \\ -2/30 & (a=1) \end{cases}$	$\begin{cases} 0 & (a=0) \\ -1/30 & (a=1) \end{cases}$
r_y	$\begin{cases} 0 & (a=0) \\ 3/30 & (a=1) \end{cases}$	0 for $t < 60$, $\begin{cases} 1/30 & (a=0) \\ 3/30 & (a=1) \end{cases}$ for $60 \le t$
K_y	1	1
r_z	$2/30$	$\begin{cases} 0 & (a=0) \\ 5/30 & (a=1) \end{cases}$ for $t < 60$, 0 for $60 \le t$
K_z	$\frac{i_x}{n_x}$	1

Computational Results

The value functions $V^{\Pi^*}(t, i)$ as well as the optimal policies Π^* for active water quality management in Site I and Site G are obtained as the numerical solutions for the Bellman equation with $n_x \times n_y \times n_z = 10 \times 10 \times 10 = 1{,}000$ states. Figures 2, 3 and 4 show the computational results at $t = 30$, $t = 90$ and $t = 150$, respectively. The difference between Site I and Site G is significant in the early stages of active water quality management. This is because rice cultivation has already started in Site I but only fish rearing is practiced in Site G. Figure 2 shows complex dependency of the optimal decision a on the three states i_x, i_y and i_z in Site I.

In contrast, a is a monotone function of i_z in Site G. Rice growth in Site I and fish growth in Site G are substantially in juvenile stages. Therefore, securing enough initial water storage is necessary for successful rice-fish culture. Figures 3 and 4 show similar distributions of the optimal decision a in the two sites. Rice growth dominantly determines the optimal decision a, however, irrigation should be suspended when both of water storage and rice growth are at low levels. The domain of such restriction levels enlarges in the later stage of Fig. 4. The only difference between Site I and Site G in Figs. 3 and 4 is the optimal decision a when water storage is full and rice is matured. This is a consequence of the different r_y, which vanishes in Site I but remains positive in Site G when $a = 0$.

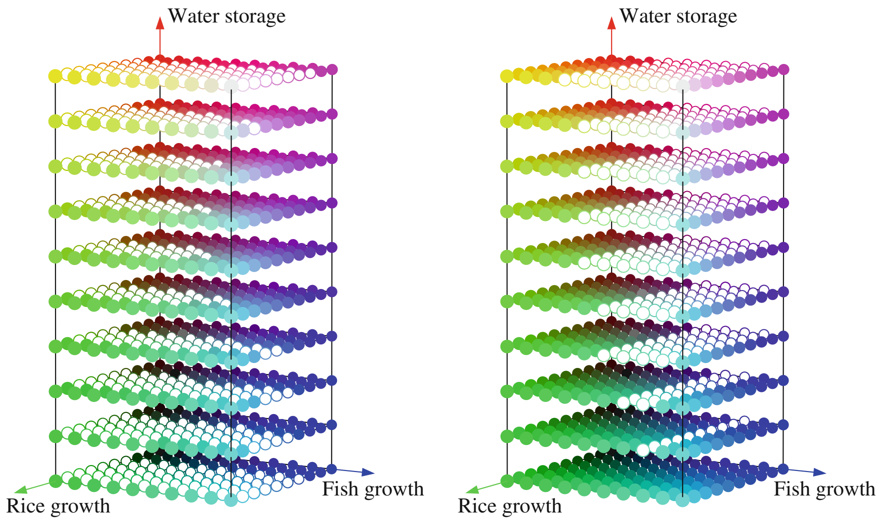

Fig. 2 Value functions and optimal policies at $t = 30$ for Site I (*left panel*) and Site G (*right panel*). Circles of larger sizes represent the larger profit (negative cost). *Filled circles* represent $a = 0$, and *white circles* represent $a = 1$

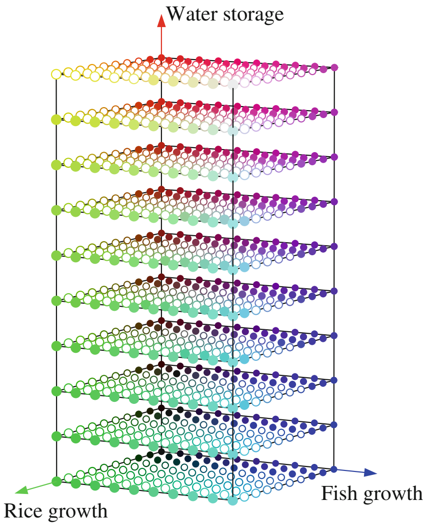

Fig. 3 Value functions and optimal policies at $t = 90$ for Site I (*left panel*) and Site G (*right panel*). Circles of larger sizes represent the larger profit (negative cost). *Filled circles* represent $a = 0$, and *white circles* represent $a = 1$

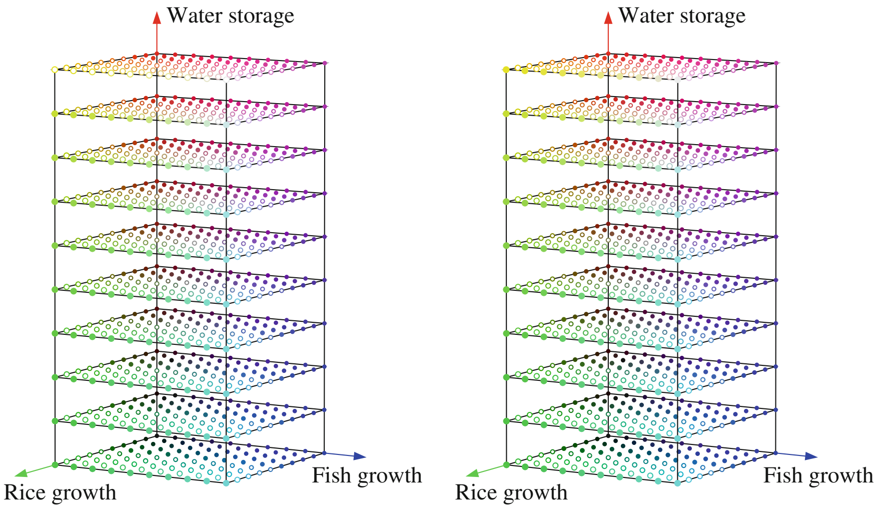

Fig. 4 Value functions and optimal policies at $t = 150$ for Site I (*left panel*) and Site G (*right panel*). Circles of larger sizes represent the larger profit (negative cost). *Filled circles* represent $a = 0$, and *white circles* represent $a = 1$

Summary

Motivated by the two contrasting sites in Monsoon Asia, the optimization problem for Markov decision processes was formulated to address active water quality management for potential rice-fish culture. The three state variables considered were the volume of water stored in the irrigation tank or in the aquifer, the growth level of rice, and the growth level of fish. These were discretized and integrated as the single spatio-temporally discrete process. The water quality items to be managed were the nitrate concentration in Site I and the water temperature in Site G, and those actual data were collected in the field studies. The decisions made at rural community levels were the simplest water intake operations of bang-bang type. The cost function did not include discount rate but considered a fixed terminal time. Consequently, the optimal policies were time dependent. Computational loads for the numerical solution of the Bellman equation were minimum due to a band-width limiting discretization scheme for calculation of the transition probabilities. The obtained optimal policies were intuitively reasonable, even though hypothetical values were used for the parameters. Explicitly including stochastic dynamics of the states will improve the validity of the mathematical approach.

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Evaluation of the Surface Water Quality Index of Jharia Coal Mining Region and Its Management of Surface Water Resources

Prasoon Kumar Singh, Binay Prakash Panigrahy, Poornima Verma and Bijendra Kumar

Abstract In this paper, the level of surface water contamination near the mine site is examined of Jharia coal field, Jharkhand. A modified *Water quality index* was used to determine the change in surface water quality. A total of 18 surface water samples were collected from different mining area of the study area. The domination of cations and anions was in the order of $Ca^{2+} > Mg^{2+} > Na^{+} > K$ for cations and $HCO_3 > SO_4{}^{2-} > Cl^{-}$ anions. Nine parameters have been considered for calculating the WQI such as: pH, total hardness, calcium, magnesium, bicarbonate, chloride, nitrate, sulphate and total dissolved solids. The computed WQI shows that 17% of Good category and 22% falls in very poor category and most of the sample fall in poor category 61% overall percentage of the Surface Water. Such waters are not suitable for drinking purposes under normal condition and further action for salinity control is required. The high value of WQI at this site has been found to be mainly due to the higher values of TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCo_3^{-} and SO_4^{2-} where it was found that there is a very high correlation coefficient between them. On careful examination of the data it was found that most of the water quality parameters were beyond the desired limit prescribed by BIS, making the water unsafe for human consumption.

Keywords Surface water · Anthropogenic · Water quality index

Introduction

Water resource becomes more and more demanding in everyday life, based on the population growth, the production rate of food stocks and in the evolving industry. The most important fresh water source in the world, based on stability and

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importance, is the groundwater (Neag 2000). Changes in local topography and drainage system directly affect both quality and quantity of the surface water (Vasanthavigar et al. 2010a, b). Once the surface water is contaminated, its quality cannot be restored by stopping the pollutants from the source; therefore, it becomes very important to regularly monitor the quality of groundwater and to device ways and means to protect it. WQI, a technique of rating water quality, is an effective tool to assess spatial and temporal changes in ground water quality and communicate information on the quality of water to the concerned citizens and policy makers (Mishra and Patel 2001; Tiwari and Mishra 1985). WQI is defined as a rating reflecting the composite influence of different water quality parameters, which is calculated from the point of view of the suitability of surface water for human consumption. WQI has been successfully applied to assess the quality of groundwater in the recent years due to its serves the understanding of water quality issues by integrating complex data and generating a score that describes water quality status (Horton 1965). WQI is an arithmetic tools used to transform large water quality data into a single cumulatively derived number. It is represent a certain level of water quality while eliminating the subjective assessment of such quality (Stambuk-Giljanovic 1999). The objective of an index is to turn multifaceted water quality data into simple information that is comprehensible and useable by the public. It is one of the aggregate indices that have been accepted as a rating that reflects the composite influence on the overall quality of numbers of precise water quality characteristics (Tiwari and Mishra 1985). WQI reflects a composite influence of contributing factors on the quality of water for any water system (Kakati and Sarma 2007). WQI a well-known method as well as one of the most effective tools to express water quality that offers a simple, stable, reproducible unit of measure and communicate information of water quality to the policy makers and concerned citizens. It thus, becomes an important parameter for the assessment and management of ground water (Chauhan et al. 2010). WQI helps in categorizing the water whether it is fit or unfit for drinking. The calculation of the water quality index originally started with (Horton 1965). Brown (1972) and his colleagues developed a water quality index by assigning proper weight age for the parameters based on their analysis. The contaminants which alter the groundwater both physically and chemically can be altogether expressed in WQI. The WQI is a single number that expresses water quality by aggregating the measurements of water quality parameters (such as, pH, nitrate, sulphate, chloride, hardness, calcium, magnesium etc.). Usually, the lower score alludes to better water quality (excellent, good) and higher score to degraded quality (bad, poor). Temporal changes in the source and nature of the recharged water, hydrologic and human factors may cause periodic changes in Surface water quality.

Study Area

Jharia Coal mining area is one of the most important Coal mining areas in India. It is roughly elliptical or sickles-shaped, located in Dhanbad district of Jharkhand lies between latitude 23° 39′N and 23° 48′N and longitudes 86° 11′E and 86° 27′E. It is bounded in the North by Eastern Railway and in the south by Damodar River. The main component of the natural drainage in JCF is the Damodar river, a fourth order stream that flows approximately west to east and captures all the surface drainage from the JCF, the drainage pattern of the drainage system in the area is dendritic. Geology, the major feature is the great coal basin of this region with intervening areas of crystalline rocks. The ancient rock types of Dharwar and post-Dharwars period from the basement rock which the lower Gondwana group of sedimentary strata consisting of coal seams and patches of sandstone are formed. The region is important for its large reserves of lower Gondwana coal distributed in these fields, the main axis of the Jharia coalfield basin runs west-north–west-east–south-east and is petering gently towards west and can be seen by the dips of the Raniganj strata along the Jamunia River.

Materials and Methods

For the assessment of surface water quality of the Jharia coalfields, systematic samplings were carried out during post-monsoon, 2013. Eighteen surface water samples were collected from rivers and ponds of the Jharia coalfield area (Fig. 1). The surface water samples were collected in one liter narrow mouth pre-washed polyethylene bottles. Electrical conductivity (EC) and pH values were measured in the field using a portable conductivity and pH meter. In the laboratory, the water samples were filtered through 0.45 μm Millipore membrane filters to separate suspended particles.

Results and Discussion

Major Ion Chemistry

Among major cations, calcium was the dominant ions representing on average 39% of total cations. Sodium and magnesium ions were of secondary importance, representing on average 31 and 25% of total cations, respectively. Potassium was least dominant cation and representing 5% of the total cations (Fig. 2). The order of cation abundance was $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$. Among the major anions,

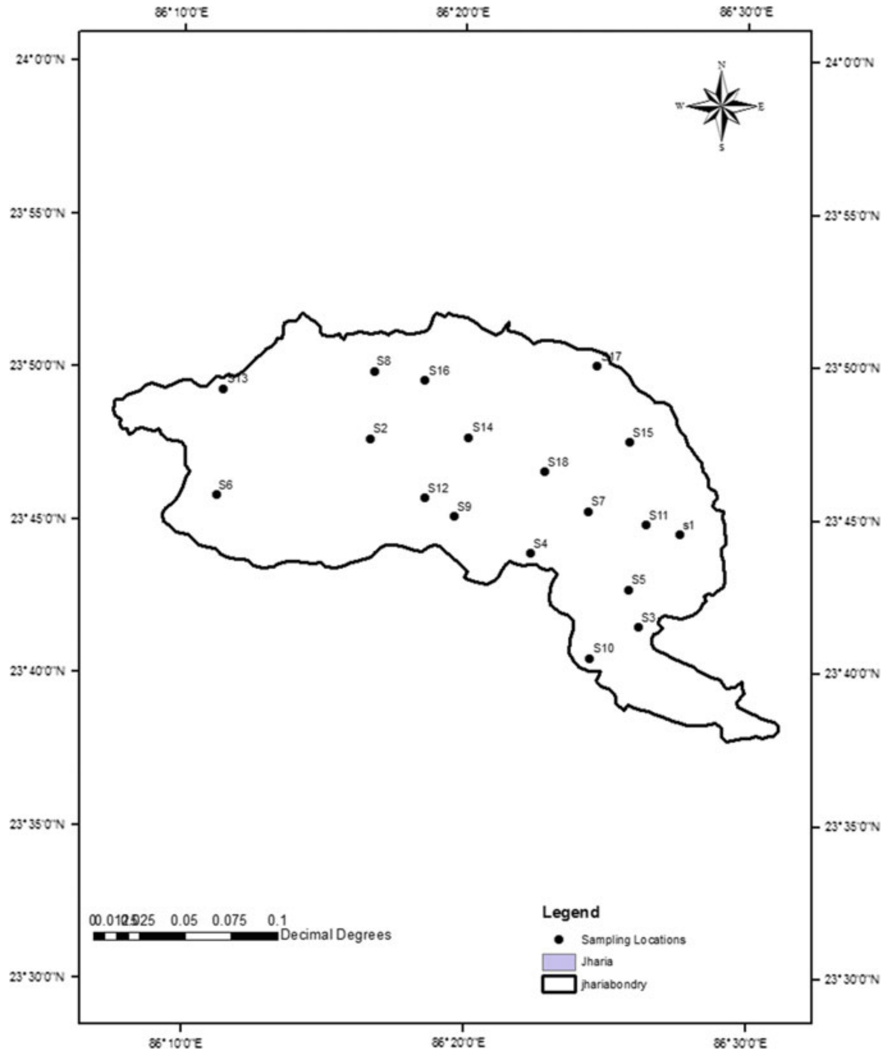

Fig. 1 Location map of Jharia Coalfield showing the sampling site

bicarbonate was generally dominant and representing on average 83% of the total anions. Sulphate is the second dominant anion, representing on an average 13% of the total anions. Chloride was less dominant ions and contributing 4% to the total anions respectively (Fig. 3). Nitrate is the least dominant anion of the total anions. The order of anions abundance in the surface was found as $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$.

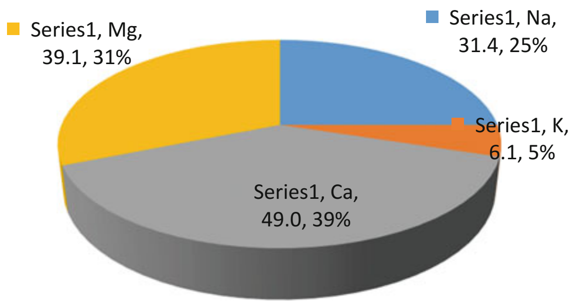

Fig. 2 Percentage contribution of cations to the total cationic balance (TZ^{+})

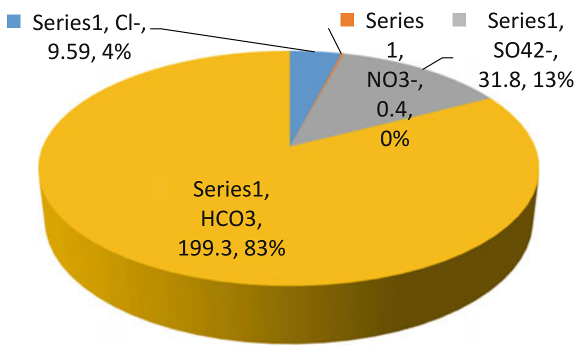

Fig. 3 Percentage contribution of anions to the total anionic balance (TZ^{-})

Water Quality Index

Water quality index is one of the most effective tools to monitor the surface as well as ground water. Pollution and can be used efficiently in the implementation of water quality upgrading programmes. The objective of an index is to turn multi-faceted water quality data into simple information that is comprehensible and useable by the public. It is one of the aggregate indices that have been accepted as a rating that reflects the composite influence on the overall quality of numbers of precise water quality characteristics. Water quality index provides information on a rating scale from zero to hundred. Higher value of WQI indicates better quality of water and lower value shows poor water quality. WQI is defined as a rating reflecting the composite influence of different water quality parameters, which is calculated from the point of view of the suitability of groundwater for human consumption. The concept of WQI was firstly used by Horton (1965), and then developed by Brown et al. (1970) and further improved by Deininger (Scottish Development Department 1975). WQI a well-known method as well as one of the most effective tools to express water quality that offers a simple, stable, reproducible unit of measure and communicate information about water quality to the policy makers and concerned citizens (Singh et al. 2013).

Estimation of WQI

Water quality index (WQI) is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water (Singh et al. 2013). WQI is a mathematical equation used to transform a large number of water quality data into a single number (Stambuk-Giljanovic 1999). It is simple and easy to understandable for decision makers about quality and possible uses of any water body (Bordalo et al. 2001). For assessing the suitability of drinking water, the water quality data of the analyzed samples were compared with the prescribed drinking water standard of BIS 2003 (IS:10500) have been considered for the calculation of WQI. The Indian Standards as per ISI for the drinking water together with its corresponding status categories of WQI (Rao 1997). In computing WQI three steps are followed. In the first step, each of the 10 parameters (pH, TDS, F^-, Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+}, TH) has been assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes (Table 1). The maximum weight of 5 has been assigned to the parameters like TDS, F^-, Cl^-, NO_3^- and SO_4^{2-} due to their major importance in water quality assessment (Vasanthavigar et al. 2010a, b). HCO_3^- is given the minimum weight of 1. Other parameters like Ca^{2+}, Mg^{2+}, Na^+ and TH were assigned a weight (w_i) between 1 and 5 depending on their importance in water quality determination. In the second step, the relative weight (W_i) is computed from the following equation as it plays an insignificant role in the water quality assessment.

$$W_i = w_i / \sum_{i=1}^{n} w_i$$

where the W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameters.

Table 1 Chemical parameters corresponding the IS: 10500

Chemical parameters	Standards (BIS)	Weight (w_i)	Relative weight (W_i)
pH	8.5	4	0.11
Total dissolved solids	500	5	0.13
Fluoride	1	5	0.13
Chloride	250	5	0.13
Nitrate	45	5	0.13
Sulphate	200	5	0.13
Bicarbonate	200	1	0.03
Calcium	75	3	0.08
Magnesium	30	3	0.08
Total Hardness	300	2	0.05
		$\Sigma w_i = 38$	$\Sigma W_i = 1.00$

All concentration in mg/l, accept pH.

Calculated relative weight (W_i) values of each parameter are given in Table 1.

In the third step, a quality rating scale (q_i) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS 10500 (2003) and the result is multiplied by 100.

$$q_i = (C_i/S_i) \times 100$$

where, the q_i is the quality rating, C_i is the concentration of each chemical parameter in each water sample in mg L^{-1} and S_i is the BIS standard for each chemical parameter in mg L^{-1}according to the guidelines of the BIS 10500 (2003).

$$SI_i = W_i \times q_i$$

$$WQI = \sum SI_i$$

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation where, the SI_i is the sub-index of *i*th parameter, q_i is the rating based on concentration of *i*th parameter and *n* is the number of parameters. Water quality category, were determined on the basis of WQI. The computed WQI values range from 21 to 131 and average 73 respectively (Fig. 4). WQI range and category of water can be classified (Tables 2 and 3).

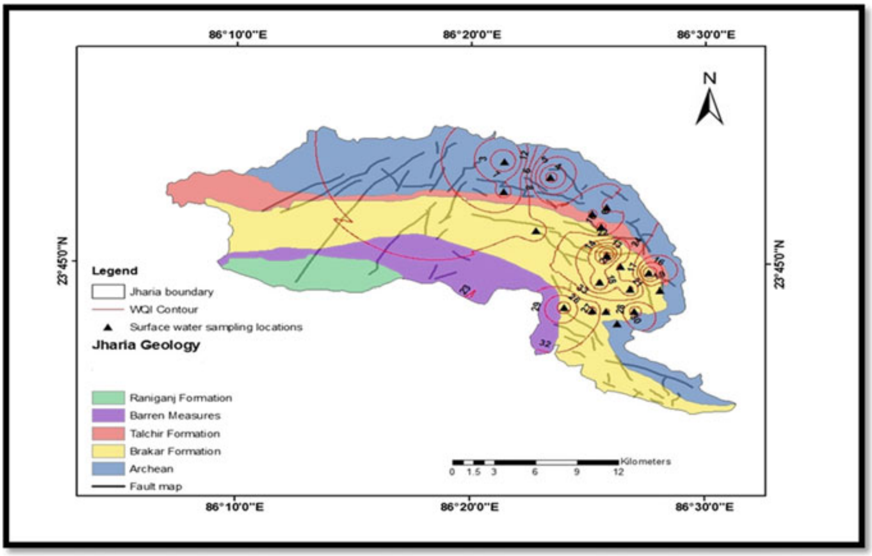

Fig. 4 Distribution of WQI of Surface water in Jharia Coalfield

Table 2 Classification of WQI range and category of water

WQI	Status
<50	Excellent water
50–100	Good water
100–200	Poor water
200–300	Very Poor water
>300	Unfit for drinking purpose

Table 3 Water quality index for surface water of Jharia Coalfield

Location	WQI	Status
Ghanoodih	79	Very poor
Goluckhdih	57.2	Poor
Titinga bad	41.3	Good
Manjhladih	69.4	Poor
Jatudih	53.5	Poor
Amdih	68.1	Poor
Modibitha	22	Good
Bagdigih Basti	83	Very poor
Dumrah	74.6	Very poor
Baghmara	58.5	Poor
Sudamdih river water	48.9	Good
Jamunia River	35.3	Good
Katri Nadi	52.9	Poor
Lilori Dham	60.9	Poor
Navagharka Barkha Talaab	61.2	poor
Moonidih	73.1	Poor
Mahuda	34.1	Good
Damodar	61.2	Poor

Conclusion

This paper presents the surface water quality assessment of Jharia Coal field. Seventeen samples were taken from different sites of Jharia coal field. Which surface water of Jharia coalfield is slightly alkaline in nature. The chemistry of surface water is dominated by Ca^{2+} and Na^{+} and HCO_3^{-} and SO_4^{2-}. In the majority of the samples, the analyzed parameters are well within the desirable limits and water is potable for drinking purposes. However, concentrations of TDS, TH, Ca^{2+} and Mg^{2+} exceed the desirable limit at few sites. The surface water of this area is very much affected by various natural sources such as rock weathering and anthropogenic sources, like Mining activity, agricultural wastes and domestic sewage disposals. The values of WQI showed higher percentage of the poor category. This shows that the water is not suitable for direct consumption and requires treatment before its utilization.

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Studies on the Production of Salt-Tolerant Alkaline Protease Isolated from *Proteus mirabilis* and Its Degradation of Hyper-Saline Soak Liquor

P. Maharaja, E. Nanthini, S. Swarnalatha and G. Sekaran

Abstract This study mainly focuses on the degradation of soluble biomolecules present in high salt containing (3–7%) Soak liquor (SL) discharge from the tanneries using the alkaline protease (AP) extracted from *Proteus mirabilis* (PM). The isolation of bacterial strains from SL was done and the screening for halophilic identification was carried out for the degradation of proteins at saline medium. The characterization of bacterial strain (PM) was carried out by using 16S-rDNA sequencing analysis. The bacterial strain (PM) growth rate was optimized with the effect of time, external carbon source, pH, temperature and metal ions. It was obtained time 48 h, pH = 7.0, T = 30 °C, addition of glucose as the external carbon source and the addition of Fe^{2+} salts as optimum for the better growth rate of PM. The production of alkaline protease was carried out by using soak liquor as the substrate and the process parameters such as the effect of time, pH, and temperature were optimized. The activity and the stability of alkaline protease was done. The study on the degradation of proteins was carried out and the process parameters were optimized for the maximum conversion of proteins into amino acids. The instrumental analyses such as UV–visible, fluorescence, FT-IR spectroscopic studies, and TGA analysis confirmed the degradation of proteins into amino acid units present in the SL efficiently.

Keywords Soak liquor · Alkaline protease · *Protease mirabilis*
Protein degradation

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Introduction

Tannery sector is the significant contributor to the export of Indian economy and provides large scale employment opportunity for people of economically weaker section of the society. Further 93% of the tanneries in organized sector come under the small scale industry category. Besides being important for economic and employment generation consideration, the tannery sector is also important from environment protection point of view, because preservation and processing of rawhides and skins into leather cause a severe pollution problem. The main problem in handling raw hides/skins is the transport from the slaughterhouse to the tanneries. The slaughterhouses are not well organized, situated in remote areas. So transport of the raw skins/hides to the tanneries takes more time. But during transportation, the raw skin/hide degrades as a result of variation in temperature and the microbial attack due to the presence of moisture and nutrients. Therefore, the preservation of the raw skins/hides is necessary (Tunay et al. 1995; Senthilkumar et al. 2008; Dhaneshwar 1990).

The presence of moisture makes the hides and skins very liable to bacterial attack. Putrefying bacteria degrade the hides and skins causing damage to both grain and flesh side of the pelt and lead to a greater degree of degradation. To avoid this, generally salt (30–40% on raw hide/skin weight basis) is applied on the flesh side of the hides and skins. The salt dehydrates the hides and skins to moisture content insufficient to support the growth of molds.

The wastewaters generated from leather industry are richer in both organic and inorganic dissolved solids (TDS) and thus limits the treatability of waste water by conventional biological wastewater treatment processes. The soak liquor generated from leather industry majorly consisting of soluble proteins such as albumin and globulin and suspended matters like dirt dung and blood in addition to inorganic salt. Since salt (sodium chloride) is used to preserve the fresh hides/skins during transportation and storage. The salt has to be removed by soaking in water for 12 h from the hides/skins before taking into leather process. The soak liquor is characterized by high organic load (albumin, globulin, and natural fat and muco polysaccharides), high suspended solids (sand, lime, hair, flesh, dung, etc.) and high salinity. The conventional biological methods are also ineffective to degrade the organic pollutants due to the presence of high inorganic TDS in the soak liquor (Gautam 2009).

The high inorganic TDS in soak liquor cause microbial cell rupture by plasmolysis and loss of activity of the cells, which results in the poor removal of BOD or COD (Ugyur 2006). Biological treatment techniques such as sequential batch reactor (Lefebvre et al. 2005), UASB reactor, anaerobic digestion and the combined anaerobic/aerobic treatment of soak liquor (Lefebvre et al. 2006), Membrane Sequencing Bio Reactor (MSBR), hybrid upflow anaerobic sludge blanket reactors are being widely used for the treatment of tannery waste water. The major issues of biological treatment of saline wastewaters are (i) a limited extent of adaptation, as conventional cultures could not be effectively used to treat saline wastewaters of values higher than 3–5% (w/v) salt. (ii) Salt adaptations of cultures were easily lost when subjected to salt-free medium. (iii) Change in ionic strength certainly disrupted in cell by shift in salt concentration, from 0.5 to 2% (w/v), caused significant reductions in system performance (Glass and Silverstein 1999). Even with acclimatized cultures, satisfactory performance required a constant ionic composition). Rapid changes in salt concentration cause adverse effects more than gradual changes. This can be alleviated by an increase in hydraulic retention time (HRT) for satisfactory performance on treatment of saline waste water. Thus, many advance oxidation processes have been attempted to treat salt laden wastewater, but none of them showed an effective removal of pollution control norms.

Hence, the soak waste water in leather industry is being collected and evaporated in solar evaporation pans/thermal evaporators in India. The presence of high concentrations of dissolved organic matter and suspended solids (SS) retards the rate of evaporation in solar evaporation pans (SEP). Thus, tanneries require large areas to manage the soak liquor and moreover, the evaporated residue obtained from SEPs cannot be reused because of its high organic content. The direct discharge of residual dried slat to open land severely contaminates the soil and water pollution. Hence, it has been advised by pollution control agencies to find an alternative suitable technology for the management of soak liquor.

Since the dissolved sodium chloride is not easily treatable and removed from the wastewater, the discharge of untreated spent soak wastewater into land leads to the significant addition of salinity to the soil. The transport of salt through the ground water affects the water bodies in the region posing a major environmental challenge. Cost-effective solutions to the TDS problem through either avoidance or end of pipe treatment are not yet forthcoming. The residue majorly consists of sodium chloride and organic pollutants. If the organic pollutants are removed from the soak liquor, there is a scope for the reusability of the evaporated residue and thus eliminate the burden on disposal of evaporated residue. There are many reports on the treatment of soak liquor wastewater containing high salinity discharged from leather industry (Ugyur and Kargi 2004; Santos et al. 2001). Biological, chemical and/or integrated treatment techniques have been attempted for the treatment of soak liquor (Dincer and Kargi 2001; Moon et al. 2003; Kubo et al. 2001). However, there is no report on the complete removal of organic pollutants from the soak liquor to meet the discharge standards set by the pollution control board. Since the conventional biological and chemical treatment methods have certain limitations on the degradation of refractory organic pollutants due to high inorganic TDS in soak liquor.

Many researchers are attempted to treat soak liquor generated from leather industry by advanced oxidation processes such as Fenton reagent, Photochemical oxidation and electrochemical oxidation. However, advanced oxidation processes did not completely remove the organic pollutants due to refractive nature of soak liquor (De Laat et al. 2004; Umar et al. 2010). The complexity lies in the treatment of soak liquor is due to the fragmentation of heavier organics such as proteins (albumin and globulin), natural fat and muco polysaccharides (Shin et al. 1989; Adamczak and Krishna 2004; Ramani et al. 2010). Hence the present study is mainly focused on the degradation of organic biomolecule, i.e., protein by the proteolytic enzyme isolated from salt-tolerant bacterial strain *Proteus mirabilis*. After the initial degradation of protein into amino acids it will be subjected to completely mineralize the sub units by the further unit operations effectively.

Materials and Methods

Isolation of Microorganisms

The microorganisms were isolated from soak liquor acclimatized tannery soil collected from nearby CLRI tannery. The salt tolerant proteolytic bacteria were isolated from the above samples by the serial dilution method (APHA 1992). The samples were serially diluted with sterile distilled water and the bacteria were isolated on the saline skim milk agar plates containing by the standard pour plate technique (APHA 1992). The plates were then incubated at 37 °C for 3–96 h. Colonies forming transparent zones around the bacterial colony due to hydrolysis of milk casein, after 3–96 h of incubation were taken as evidence for qualitative determination of protease producing bacteria. Totally eight morphologically distinct bacterial colonies showing the clear zone were selected and re-streaked several times on the nutrient agar to obtain pure isolates. From all the eight cultures the organisms which show high degree of zone of clearance were taken for further saline-tolerant screening studies.

Screening of Bacteria for Protease Production in Saline Medium

Individual bacterial colonies were screened for protease production on skim milk agar medium. Two cultures were selected and streaked on the skim milk agar plates and incubated at 37 °C for 3–96 h at 1, 2, 3, and 4% NaCl concentrations. The isolates having maximum clearance zone were selected for studies. The bacterial strain (Org-8) showed maximum clearance when treated with skim milk agar containing 1, 2, 3, and 4% of NaCl compared to another strain. Hence, that bacterial strain was selected for production of protease for the degradation of soak liquor.

P. mirabilis has bacillus morphology and is a Gram-negative bacterium. It is motile, alternating between vegetative swimmers and hyper-flagellated swarmer cells. It also makes a variety of fimbriae. The endotoxins of its LPS membrane elicit an inflammatory response from the host.

Kingdom	Bacteria
Phylum	Proteobacteria
Class	Gamma proteobacteria
Order	Enterobacteriales
Family	Enterobacteria
Genus	*Proteus*
Species	*Proteus mirabilis*

P. mirabilis produces urease is an enzyme that converts urea into ammonia by the following Eq. (1),

$$(NH_2)_2CO \rightarrow 2NH_3 + CO_2 \quad (1)$$

Infection by *P. mirabilis* can therefore be detected by an alkaline urine sample (pH 8 and above) with large amounts of ammonia.

Alkaline proteases have considerable industrial potential in detergents, leather processing, silver recovery, medical purposes, food processing, feeds and chemical industries, as well as tannery waste treatment. At present, the largest part of the hydrolytic enzyme market is occupied by the alkali proteases. Extreme environments are important sources for isolation of microorganisms for novel industries and enzymes production (Vanitha et al. 2014; Karadzic et al. 2006).

Bacterial Strain Selection and Identification

Depending on the maximum relative proteolytic activity two bacterial strains were selected and identified. Various morphological, physiological, and biochemical tests were performed and results were interpreted according to Bergey's Manual of Determinative Bacteriology (Holt et al. 1994).

Molecular Characterization

Genomic DNA was extracted by CTAB protocol. For all the strains, 16S rRNA gene was amplified by universal primers (27F, 1492R). PCR was performed in a reaction volume of 50 µL consisting of 10X PCR buffer (5.0 µL), $MgCl_2$ (1.5 mm), dNTPs mix (0.2 mm), (0.4 µm) of 27F, (0.4 µm) of 1492R primer, Taq Polymerase (1.5 U), DNA (5 µL). PCR amplification was performed with 30 cycles following denaturation at 94 °C for 1 min, annealing at 55 °C for 1 min and extension at 72 °C for 2 min. Purified samples were sequenced in ABI 3130 Genetic Analyzer. Sequences were then submitted to Gen Bank and accession number was assigned for each strain.

Studies on Optimization of Culture Growth Conditions in Soak Liquor

The characteristic culture growth conditions at different times were optimized for maximum population of organism, *P. mirabilis,* in soak liquor with 3–4% of NaCl concentration. The culture growth was checked at different time intervals such as 3, 6, 24, 48, 72, and 96 h in terms of optical density. Microbes, such as bacteria, are more tolerant of environmental conditions than other organisms. However, each species has its own characteristic and particular range of values in which it grows and reproduces best. The isolated organism, *P. mirabilis,* was inoculated with in soak liquor with 3–4% of NaCl concentration and kept at different temperature conditions such as 10, 20, 30, 40, and 50 °C, respectively. The isolated organism, *P. mirabilis,* was inoculated in soak liquor with 3–4% of NaCl concentration and 1% of different carbon sources such as glucose, fructose, lactose, and maltose were added to the culture. The isolated organism was inoculated in soak liquor with 3–4% of NaCl concentration and 0.5% of different metal ions such as KCl, $FeSO_4$, $MgCl_2$, $CaCl_2$, and $CuSO_4$ were added to the culture for the effect of metal ions involved in the growth of the organism.

Extraction and Purification of Extracellular Enzymes

Acetone Precipitation

The production media after 48 h is centrifuged at 5000 rpm for 15 min. The supernatant was collected and two volumes of cold acetone added to the supernatant and it was incubated at 20 °C for 24 h. After the overnight incubation the precipitated cultures are centrifuged at 5000 rpm for 15 min pellets are collected and it is mixed in 0.2 M phosphate buffer (pH 7) and stored at 4 °C.

Analytical Methods

The COD, BOD_5, TOC, TDS, TSS, and TS were measured by the methods summarized in standard methods of analysis of wastewater (APHA 1992). The quantification of protein in soak liquor and degradation studies were measured as per Lowry's method using bovine serum albumin BSA (Himedia) as the standard at λ650 nm using Cary 100 UV–visible spectrophotometer. Standard curves for concentration calculations were plotted from 0, 10, 25, and 50 mg/L bovine serum albumin (BSA) diluted from a concentrated stock of BSA. Amino acids generated after the degradation of protein in soak liquor were determined.

Assay of Protease Activity

The protease activity was measured by using casein as the substrate with slight modifications. The reaction mixture consisted of enzyme sample of volume 1 mL prepared by centrifuging the cell culture suspension at 10,000 rpm for 10 min and the supernatant was used for assay. The reaction was carried out by the addition of 2.0 mL of 50 mM phosphate buffer at pH 7.0 and incubated at 30 °C for 15 min. The reaction was terminated by the addition of trichloroacetic acid (TCA) of 2.5 mL, 10% (w/v). This mixture was further incubated at 30 °C for 15 min and kept at room temperature for 30 min. 0.5 mL of the mixture was added to 5.0 mL of 0.5 M Na_2CO_3 and kept at room temperature for 20 min. 0.5 mL of Folin–Ciocalteu reagent: water (1:2) was added to yield a blue color and the absorbance was measured at λ 660 nm. A 'blank' was prepared by the same procedure using distilled water. One unit of protease activity is defined as the amount of enzyme required to liberate one μg of tyrosine per min per mL at reaction conditions. The specific activity of enzyme was expressed as enzyme units per mg protein.

Degradation of Soak Liquor

1 kg of animal hide was soaked in 3 L of water (300% w/v) for overnight and left for settling for about 2 h, filtered and used for further studies. Later 1 mL of enzyme was added and to the 50 mL soak liquor sample and the degradation ability of the extracellular enzyme was estimated by measuring the degradation of protein, protease activity, and formation of amino acid at regular time intervals (0 min, 15 min, 30 min, 45 min, and 1 h).

Instrumental Analysis

The different kinds of functional groups present in soak liquor and its degradation using the alkaline protease were confirmed using FT-IR spectrophotometer (Perkin Elmer). The samples were air-dried in sterile conditions to make as powder completely free of moisture and made in the form of pellet with the thickness of 1 mm and diameter of 13 mm, using spectroscopic-grade KBr. The spectrum was analyzed in the spectral range of 400–4000 cm^{-1}. The enzymatic degradation of soak liquor was studied by UV–visible absorption spectra were collected in CARY 5E UV–VIS–NIR Spectrophotometer. The enzymatic reaction mixtures were pre-scanned using fluorescence spectrophotometer to study the excitation and emission characteristics of both soak liquor and the degraded products in the range of λ 200–800 nm (Cary Eclipse). The thermostability of the components present in soak liquor and its degradation using the alkaline protease was studied by thermogravimetric analysis (TGA) was carried out under a nitrogen atmosphere from 30 to 800 °C with a temperature gradient of 10 °C min^{-1} and scans were recorded using a TGA Q50 (V20.6 Build 31).

Results and Discussion

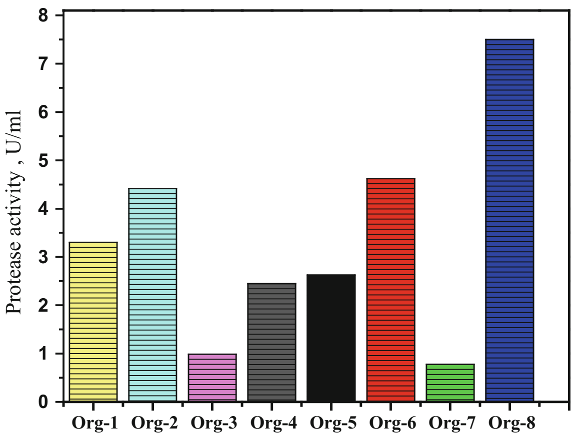
Isolation of Microorganisms and Their Protease Activity

The serial dilution method was used to isolate microorganisms from the soil collected from tannery located in nearby Chennai. Eight salt tolerant organisms which can able to grow in soak liquor were isolated from this (soil) source (Narendra et al. 2012). Figure 1 shows the organisms isolated from soil and their protease activity used in this study respectively.

The protease activity is checked for the isolated microorganisms, the organism-8 is found to have high protease activity while comparing to other seven microorganisms. So this organism is selected for further studies.

The isolated organisms were inoculated into skim milk agar plates and observed zone of clearance for their protein hydrolyzing capability. The plates incubated were observed for zone of hydrolysis after 24 h at 37 °C. The maximum zone of hydrolysis was observed for organism-8 and the same is shown in Fig. 2. Organism showing maximum zone of hydrolysis is considered to be efficient at degradation of protein (Vanitha et al. 2014) and further characterized using biochemical tests. Thus organism-8 has been selected to be utilized in degradation of soak liquor in this study.

Fig. 1 Protease activity of organisms isolated from tannery soil



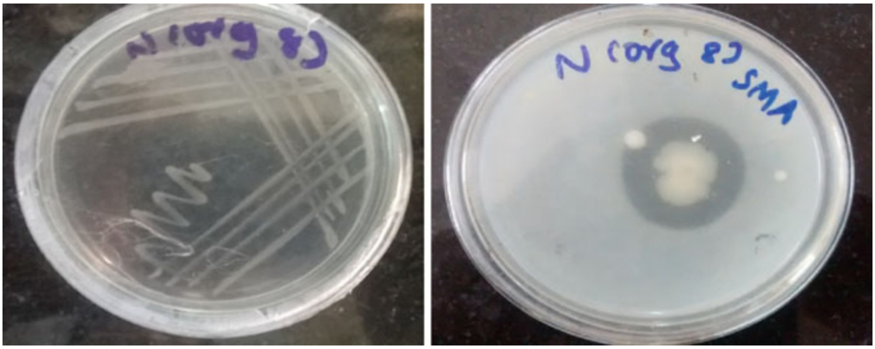


Fig. 2 Organism-8 (*P. mirabilis*) and its zone of hydrolysis

Characterization and Identification of Organism

The isolate, organism-8, from the terrestrial soil showed maximum hydrolysis of skim milk agar was further characterized. The morphological staining characteristic of the isolate was studied through simple Gram staining, followed by observation under phase contrast microscope.

The biochemical characterization tests such as catalase, IMViC tests, Nitrates reduction test, sugar fermentation tests were studied by overnight incubation of organism-8 on the strip and the results were presented in Table 1. The strain was phylogenetically identified as *P. mirabilis* with gene bank accession number of HQ005734 (Fig. 3).

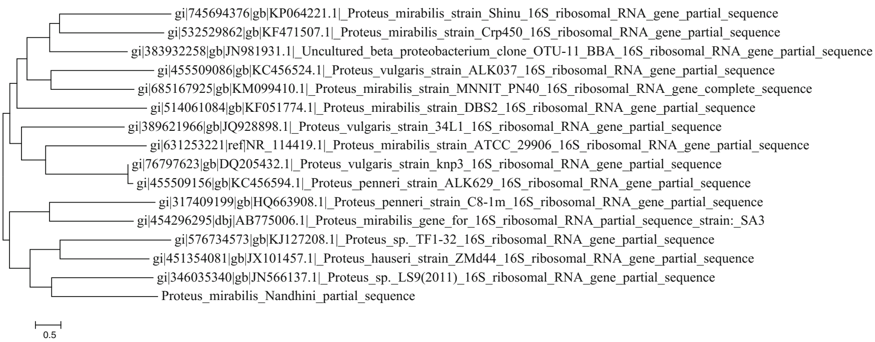


Fig. 3 Phylogenetic tree of *Proteus mirabilis* isolated from tannery soil

Table 1 Biochemical characteristics organism-8 (*P. mirabilis*)

S. No.	Test	Organism 8
1	Gram reaction	Gram-negative
2	Morphology	Rod
3	Rhamnose	+
4	Catalase	+
5	Indole	−
6	Urease	+
7	Methyl red	−
8	Voges–Proskauer's	−
9	Citrate utilization	+
10	H_2S	+
11	ONPG	−
12	Lysine utilization	No reaction
13	Ornithine utilization	+
14	Malonite utilization	+
15	Nitrate	+
16	Glucose	+
17	Lactose	+
18	Saccharose	−
19	Phenyl alanine deamination	+
20	Saccharose	+
21	Raffinose	−
22	Trehalose	+

Studies on Optimization of Culture Growth Conditions

Optimization of Time and Temperature

The growth of microorganism by up taking soak liquor was observed as a function of time. The growth rate of the *P. mirabilis* was observed to take a lag period of 3 h, followed by log growth from 3 to 24 h, from there after exponential growth till 48 h. Decay phase was observed from 72 h onwards. Thus maximum growth time of 48 h was considered to be the optimum time for growth of microorganism in soak liquor. The organism *P. mirabilis* used in this study showed to be sensitive with respect to temperature during study on the temperature range of 10–50 °C. The graphical representation of the effect of temperature on growth of microorganism is presented in Fig. 4a, b. The maximum growth at 30 °C and minimum growth at 50 °C was observed.

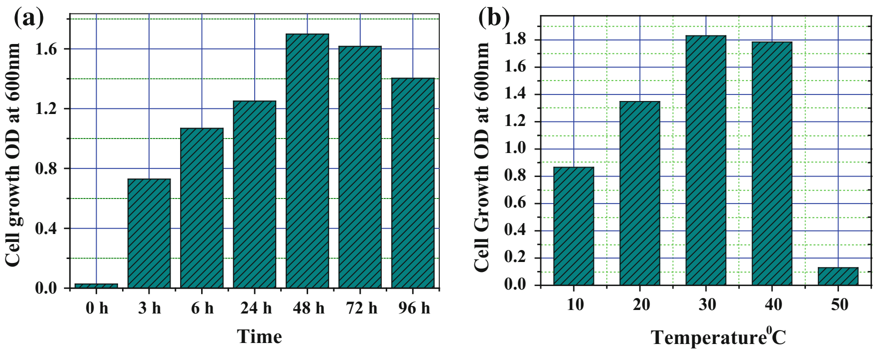


Fig. 4 Optimization of **a** time, and **b** temperature for the cell growth of *Proteus mirabilis*

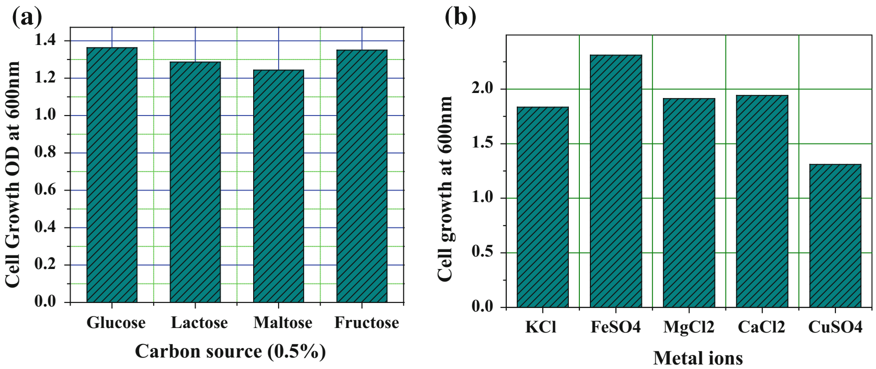


Fig. 5 Optimization of **a** external carbon source, **b** metal ions for the cell growth of *Proteus mirabilis*

Optimization of Carbon Source and Metal Ions

A vast majority of microorganisms, the C-heterotrophs, retrieve their macronutrients and carbon for build-up of cell material from organic nutrients, e.g., cellulose, starch, sucrose, and glucose from other organisms. The organism in this was exposed to different carbon sources, metal ions, and their effect are presented in Fig. 5a, b. The highest optical density was observed for Fe ion; however, it might be due to the color formed due to oxidation of ferrous ion. Next to Fe ion, calcium, magnesium and potassium ions showed almost same effect over growth of microorganism with very small variations. Copper was observed to show least effect on the growth of microorganism.

Studies on Enzyme Production and Its Stability

Enzyme Production

From the above-optimized conditions the organism selected for production at 48 h with pH = 7 and optimized temperature 20 °C. After incubation with acetone precipitation was done for the organism to extract extracellular enzyme protease and dissolved in phosphate buffer (pH = 7) and the enzyme was purified by dialysis method. Then, the stability of protease enzyme was studied at different pH and temperature conditions.

Effect of pH

The protease activity was observed in different pH from 1 to 14, result is shown in Fig. 6a. Many researchers found that the protease activity is highly pH dependent and they are generally active in the range of pH 8–10 (Patel et al. 2006; Dodia et al. 2008). However, there are many examples where optimum pH was higher; pH 11, with a broad range of activity from pH 8–11 (Purohit and Singh 2011). However, the pH optimum was quite low pH 7.5 for the two novel halo-tolerant extracellular proteases from *Bacillus subtilis* strain FP-133 (Setyorini et al. 2006) and pH 8 for alkaline protease from novel haloalkaliphilic *Bacillus* sp. (Patel et al. 2006; Rahman et al. 2005).

The activity was very low at acidic pH range of 5 and the activity was found to be very high at pH 9. Hence, the enzyme used was observed to be alkaline protease. The activity was gradually decreasing by increasing the pH up to 14.

The activity was very low at the highest temperature of 60 ºC, and the maximum was observed to be at a temperature of 30 ºC. It was also observed that enzyme was very sensitive and showed low activity towards higher temperatures beyond 30 °C as given in Fig. 6b.

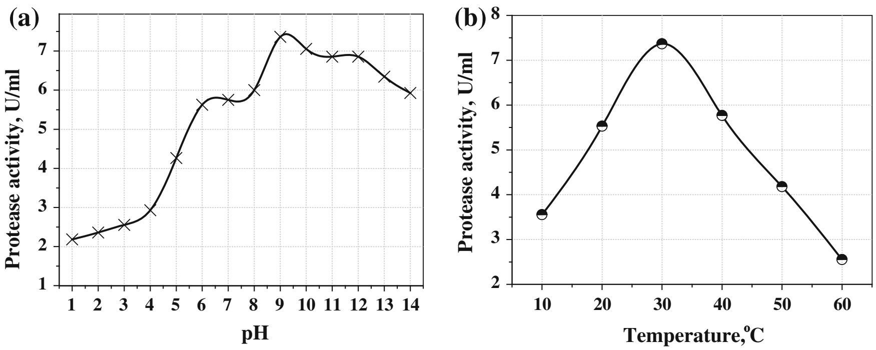


Fig. 6 **a** Effect of pH, and **b** temperature on the stability of alkaline protease isolated from *Proteus mirabilis*

Studies on Degradation of Soak Liquor

Characteristics of Soak Liquor

The initial characteristics of the soak liquor after the removal of suspended solids using SOAR (Sequential Oxic-Anoxic Bio Reactor) were determined according to standard methods (APHA 1992) and it was listed in Table 2.

Effect of Time

The extracted alkaline protease from the organism, *P. mirabilis* was inoculated in 50 mL of soak liquor at different time intervals from 0 to 60 min. The protein, amino acid content of the initial soak liquor was checked. After the alkaline protease treatment, the proteins were degraded by cleaving the peptide bond between the peptides and converted into amino acid. There was a gradual decrease in protein concentration from the initial concentration to at 45 min and it remains same at 60 min. The degradation of protein in soak liquor as a function of time, corresponding amino acid formation with respect to time was presented in Fig. 7.

Effect of Temperature

The alkaline protease solution isolated from the organism *P. mirabilis* has been inoculated with 50 mL of soak liquor and kept at different temperatures such as 10, 20, 30, 40 and 50 °C. The protein content was high as 390 mg/L at 10 °C and at 20 °C it was 340 mg/L and at 30 °C it was 190 mg/L, at 40 °C it was observed to be 150 mg/L, at 50 °C it was found to be 280 mg/L. Thermo stable enzymes are of special interest for industrial applications due to their stability under typical operation conditions; such as high temperatures and wide pH range. The thermophilic proteases catalyze the reaction and maintain the stability at higher temperatures. In addition,

Table 2 Initial characteristics of soak liquor after SOAR reactor

Parameters	Values
pH	7.49
Chemical Oxygen Demand, mg/L	4025
Biochemical Oxygen Demand, mg/L	1800
NH_3, mg/L	229
Total Nitrogen, mg/L	330
Protein, mg/L	557
Amino acids, mg/L	390
Lipids, mg/L	30.7
Total suspended solids (TSS), mg/L	1480
Total dissolved solids (TDS), mg/L	61,824

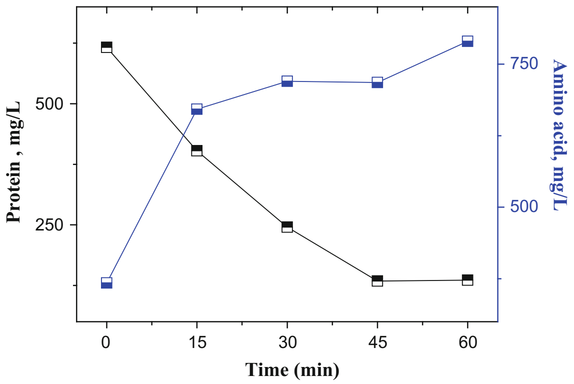


Fig. 7 Effect of time on soak liquor degradation using alkaline protease in terms of protein and amino acid concentration

higher temperatures can accelerate the reaction rates, increase the solubility of non-gaseous reactants and products and decrease the incidence of microbial contamination by mesophilic organisms. Many thermophiles, such as *Bacillus stearothermophilus, Thermus aquaticus*, *Bacillus licheniformis*, *Bacillus pumilus* and *Thermoanaerobacter yonseiensis*, produce a variety of thermo stable extracellular proteases (De Carvalho 2011; Ueda et al. 2008; Wang et al. 2008). It has been known that enzymes from thermophilic bacteria are unusually thermostable, while possessing other properties identical with enzymes found in mesophilic bacteria. There are number of thermostable proteases reported from thermophilic organisms, similar citations from non-thermophilic organisms are quite rare. The thermostable enzymes from other groups of extremophiles would be quite attractive in providing the biocatalysts with the abilities to function under multitudes of non-conventional conditions. The formation of amino acid has also evidenced the degradation of protein present in soak liquor with the respective temperature. Hence the optimum temperature was 30 °C and the results are shown in Fig. 8a, b.

Instrumental Evidence for Soak Liquor Degradation

UV–visible and Fluorescence Spectroscopic Studies

UV–visible spectroscopic studies were carried out for the confirmation of degradation of soak liquor in the presence of the halo-tolerant organism *P. mirabilis* and the isolated alkaline protease was shown in Fig. 9a. The absorption intensity of the initial soak liquor was observed to be high before the treatment and the peak values were observed in the region of 210–230 nm and 260–275 nm which was denoted the presence of proteneous matter in the wastewater.

The above mentioned peaks were slightly disappeared after the treatment with the isolated organism *P. mirabilis* and they were completely disappeared in the

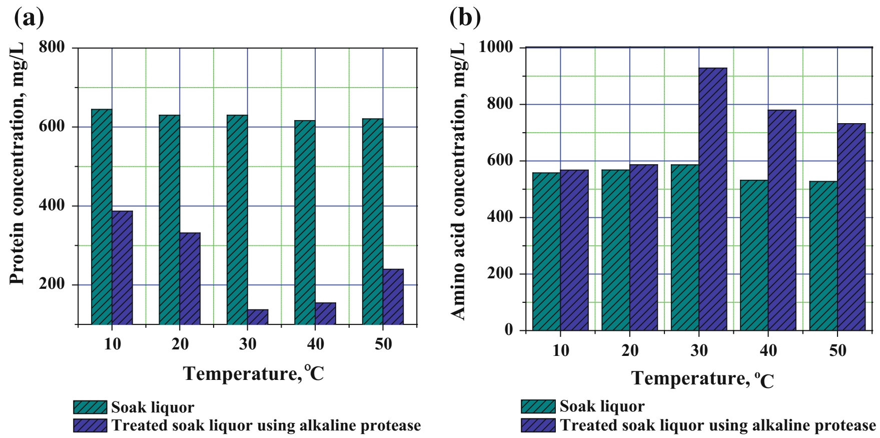


Fig. 8 Effect of temperature on soak liquor degradation in terms of **a** protein concentration, and **b** amino acid concentration

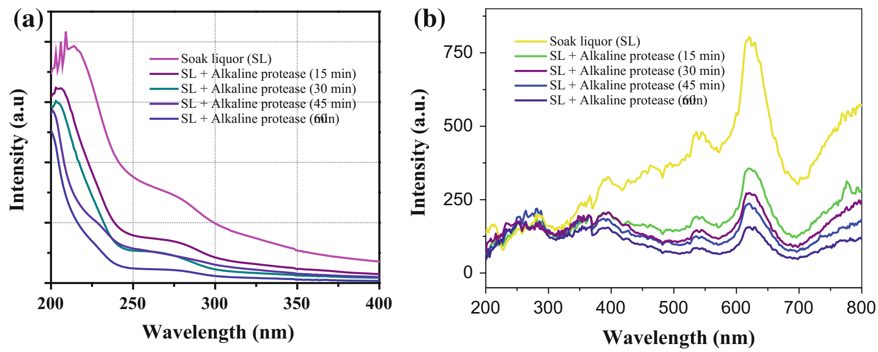


Fig. 9 **a** UV–visible and **b** UV–fluorescence spectrum of the soak liquor, SL+Alkaline protease isolated from PM

presence of alkaline protease at the optimized conditions. It was noted that the intensity difference between the absorption peaks appeared in the enzymatic and the microbial degradation of soak liquor and it was clearly shown in Fig. 9a. Hence, the enzymatic degradation using the alkaline protease from the halo-tolerant organism *P. mirabilis* would be the effective process compare with the pure organism for the degradation of soak liquor.

UV–fluorescence absorption studies were carried out for the confirmation of degradation of soak liquor in the presence of the halo-tolerant organism *P. mirabilis* and the isolated alkaline protease was shown in Fig. 9b. The spectrum shows the difference in intensities between the soak liquor and the treated samples after the enzymatic degradation and microbial degradation at the optimized conditions. The spectrum evidenced for the presence of fluorescent inactive compounds present in the soak liquor and in the treated samples so that the spectrum only show the absorption peaks and not show the emission peaks. But it was noted that the difference between the peaks of soak liquor and the degraded samples evidenced that the presence of proteins in the soak liquor may be degraded as the polypeptides or small chain peptides by the isolated alkaline protease.

TGA Studies

Thermogravimetric analysis was carried out for the confirmation of degradation of soak liquor in the presence of alkaline protease isolated from halo-tolerant organism *P. mirabilis* and the results were shown in Fig. 10. It was noted that there was a residual mass of 91.16% in TGA spectrum of soak liquor evidenced that the presence of high inorganic chloride or sulfate TDS and the organic compounds in maximum and only 8.84% of organic compounds present.

Hence, the difficulty occurs for the degradation of such organic molecules in the presence of high TDS environment. TGA spectrum of the enzymatically degraded samples shows the residual mass of 96.69% and the mass loss of 3.31%, respectively which evidenced the degradation of organic compounds in the saline environment by the alkaline protease isolated from halo-tolerant organism *P. mirabilis*.

FT-IR Spectroscopic Studies

The FT-IR spectrum of the soak liquor and its degraded product was shown in Fig. 11 evidenced that the peak at 3400–3200 cm^{-1} indicates N–H stretching vibrations which are common to amino acids.

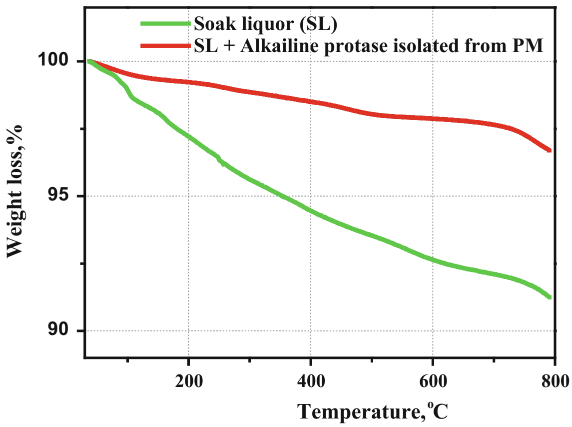


Fig. 10 TGA thermo gram of **a** soak liquor, **b** treated SL +Alkaline protease isolated from *Proteus mirabilis*

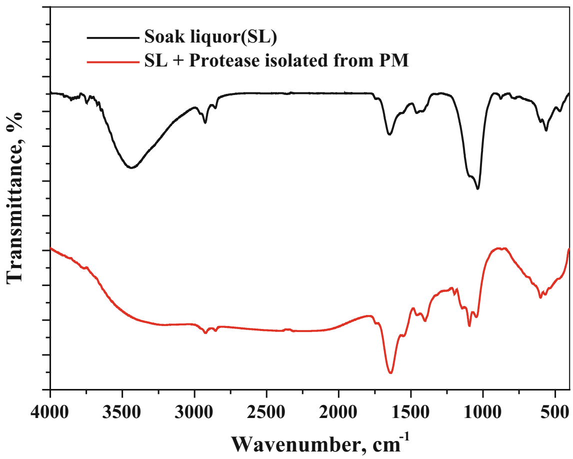


Fig. 11 FT-IR spectrum of soak liquor and its degradation using alkaline protease

The peak 2508 cm^{-1} shows a strong symmetrical C–H stretching of methyl groups. The peak at 1653 cm^{-1} indicates that the presence of amide bond (–C (=O)–NH) depicts that the secondary structure of peptides. The C–O stretching of carboxylic groups appears at near 1208 cm^{-1}. The peak at near 700–600 cm^{-1} shows that –NH bending vibrations of the amino compounds present in soak liquor. The FT-IR spectrum of soak liquor after enzymatic degradation indicates that the presence of 1465 cm^{-1} band may represents to –C=O Stretching of the carboxylate group present in the peptide or polypeptide bond due to the cleavage of peptide bond of protein present in the soak liqour. The peak at 1220–1190 $cm^{- 1}$ indicates that the strong stretching vibrations of –C–C (=O)–O bond of the amino acids present in the soak liquor present in the soak liquor after enzymatic degradation. Hence the degradation of proteins present in the soak liquor by the enzymes confirmed through FT-IR spectrum.

Conclusion

This research study concludes that the treatment of saline wastewater is feasible, through the bacterial extracellular protease. The use of enzymes is particularly efficient for the removal of high amounts of organic matter in effluents. Generally, biological treatment is inhibited by high salt concentrations. However, this study has proved feasibility of degradation using salt-adapted microorganisms capable of withstanding high salinities and at the same time of degrading the pollutants in wastewater.

The organism isolated was identified by 16S rDNA sequencing as ***P. mirabilis*** (***HQ005734***). The Optimum growth conditions in both nutrient broth and soak liquor were noted to be pH 7, time 48 h and temperature 30 °C. The alkaline protease was extracted from PM. The protease activity was stable at pH 7–9 and temperature 30–40 °C. The degradation of protein content of soak liquor was done by using alkaline protease and it was confirmed through UV-visible, fluorescence, TGA and FT-IR spectroscopic studies. From this study, it was concluded that the biological origin of enzymes reduces their adverse impact on the environment thereby making enzymatic wastewater treatment an ecologically sustainable technique.

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Relative Contribution of Phosphorus from Various Sources to the Upper Lake, Bhopal

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Abstract An investigation on phosphorus loading from the point and non point sources to the Upper Lake, Bhopal and its contribution on eutrophication was undertaken at Indian Institute of Soil Science, Bhopal. Geo-referenced water samples from different entry points (15 locations), where water from different sources (agriculture and municipal water) enters to the Upper Lake, were collected and analyzed for various P fractions. The results showed that the total phosphorus (TP) content varied from 0.30 to 0.73 mg/L with a mean value of 0.47 mg/L having lowest and highest content from Kholukhedi (agriculture source) and Bhadbada (domestic wastewater), respectively. Among the P fractions, the bioavailable P fraction (total dissolved phosphorus-TDP) was highest in the water sample from the domestic source, whereas, the dominant P fractions in the water samples from agricultural source was particulate P (PP). The results shows that the total P in the sediment of post-monsoon stage samples ranges from 0.03 to 0.07% with a mean value of 0.04%. The mean sediment inorganic phosphorus (SIP) and the sediment organic phosphorus (SOP) is 68.01 and 31.98% of total phosphorus (TP), respectively. Among the inorganic P fractions in the sediment, Ca bound P was maximum and found to be in the range of 86.32–96.97% of total sediment inorganic P followed by Fe bound P (2.10–11.51%) and loosely sorbed P (LSP) (0.39–5.66%). To summarize, the source of water from the city (domestic wastewater) and at idol immersion location contains relatively higher total phosphorus (TP) and dissolved reactive phosphorus (DRP).

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Introduction

Phosphorus is one of the key elements necessary for the growth of all forms of life and therefore for food production. There is no substitute for phosphorus in food production and it cannot be manufactured, hence its greater significance to humanity. Phosphate rock, like oil, is a non-renewable resource and approximately 50–100 years remain of current known reserves. Further, a peak in global production—peak phosphorus—is estimated to occur by 2035. After the peak, supply is expected to decrease year by year, constrained by economic and energy costs, despite rising demand. On the other hand, remaining reserves is declining due to: (a) lower concentration of phosphorus (% P_2O_5) in the remaining phosphate rock reserves; and (b) increasing concentrations of heavy metals like cadmium and uranium that are highly toxic to soils, flora, fauna and humans. While good agronomic management requires use of P to optimize crop growth, excessive application of P may degrade water quality. Thus, phosphorus plays a key role in crop production as well as environmental sustainability.

The investigation from the UNEP (United Nation Environmental Protection) indicates that about 30–40% of the lakes and reservoirs have been affected more or less by water eutrophication all over the world. Eutrophication is the natural aging of lakes or streams brought on by nutrient enrichment and eventually promote excessive plant growth, favoring simple algae and plankton over other more complicated plants, and cause a severe reduction in water quality. Eutrophication process can be greatly accelerated by human activities which increase nutrient loading rates to water. While nitrogen, phosphorus, carbon and in some cases, silicon contribute to eutrophication, P is the primary agent in freshwater eutrophication, as many algae are able to obtain N from the atmosphere (Schindler 1997). Phosphorus has fewer sources, making it easier to achieve smaller concentrations. Also, it is easier to make phosphorus insoluble in water, thus making it less available to plants for their growth. In addition, phosphorus sources are more often from human activities that we may be able to control more easily than natural sources. Thus, controlling eutrophication mainly requires reducing P inputs to surface waters, despite the fact that P is an essential nutrient for crop and animal production.

Since, late 1960s, the relative contributions of P to water bodies, both from point and diffuse sources have changed dramatically. In recent years, relatively greater efforts have been made to control P pollution from point sources discharge. But less attention have been directed to control diffuse sources of P, mainly due to the difficulty in their identification and control (Sharpley and Rekolainen 1997). Thus, control of diffuse sources of P is a major hurdle for protecting fresh surface waters from eutrophication (Sharpley and Tunney 2000; Withers et al. 2014). A plenty of information is available on point and non-point sources (NPS) of phosphorus loading to the lake system, across the world. However, in India, limited research work is done on phosphorus loading from non point sources to the lake system. The Upper and Lower lakes of Bhopal, constructed in the eleventh and eighteenth century, respectively are glaring examples of urban water bodies. Till the middle of the last century, the water of Upper Lake did not require any treatment before supply for drinking purposes. However, increased anthropogenic activities around this lake resulted in the deterioration of water quality of the lakes. While the Lower Lake became eutrophic, only certain pockets of Upper Lake have reached the level of eutrophication. The Upper Lake still contributes about 40% of water supply to the city. Hence protection of this valuable resource from pollution for sustainable use is of great importance. Keeping this in view, the present research project envisioned to study the NPS of phosphorus loading to the Upper Lake, Bhopal.

Materials and Methods

The Study Area

In the present study, the Upper Lake which is geographically located at 23° 12′N latitude and 77° 18′E longitude of Bhopal (M.P.) at an altitude of 508.65 m above mean sea level is considered as a case study to quantify relative contribution of phosphorus from different sources to the lake water bodies. The Upper Lake is one of the oldest lake constructed in the eleventh century and largest impoundments and a major drinking water source for the city of Bhopal. The Upper Lake still contributes about 40% of water supply to the city. In view of its ecological importance, the Ministry of Environment and Forests, Government of India has recognized Upper Lake as wetland of national importance in 1998 and later declared it as Ramsar site in the year 2002.

The Upper Lake is an east-westerly elongated manmade lake with the total submergence area of 36.54 km^2. Total water storage capacity of the lake is approximately 117 mm^3 with maximum depths of 11.7 m. In shallow portion of lake, luxuriant growth of aquatic vegetation can be observed. Catchment of the Upper Lake displays a complete range of urban and rural activity with varying intensities that contribute nutrients and pollution load through point and non-point pollution sources. Majority of the catchment area is under agricultural activities (213.1 km^2) followed by scrub or without scrub (87.7 km^2) and built-up area (20.9 km^2).

Sampling Plan and Analytical Procedure

As shown in Fig. 1, water and sediment samples were collected from various location (15 locations) using GPS from the lake representing the shallow and deeper zone of lake as well as various urban activities. Also samples were collected from 15 different entry points where water enters to the lake system. For each identified locations a replicates of 5 samples were collected in a clean polyethylene bottle whereas in case of sediment the samples were collected in a plastic container. Prior to water and sediment sample collection the plastic bottle and container were thoroughly rinsed with deionized water. Water and sediment sampling was carried out during post-monsoon season 2013. Water samples were collected using open water grab sampler and for sediment, Peterson's sediment sampler equipped with a simple pull-ring were used (Photo 1). Approximately, 5 L of water sample and 1 kg of sediment samples were collected from each location. Collected samples were preserved and brought to the laboratory for analysis.

The sediment samples were analyzed for various phosphorus fractions as described by Kuo (1996). The fractionation procedures are based on the differential solubility's of the various inorganic P forms in various extracts. Ammonium chloride (NH_4Cl) is used first to remove soluble and loosely bound P, followed by separating Al–P from Fe–P with (NH_4F), then removing Fe–P with NaOH. The reductant-soluble P is removed with CDB (sodium citrate-sodium dithionite-sodium bicarbonate) extraction. The Ca–P is extracted with sulfuric acid (H_2SO_4) or HCl since Ca–P is insoluble in CDB. Since NH_4F reacts with $CaCO_3$ to form CaF_2 in calcareous soils, which will precipitate soluble P and reduce the effectiveness of NH_4F to extract P, the NH_4F extraction is omitted for calcareous soils. For water sample, various fraction of phosphorus were determined as described by

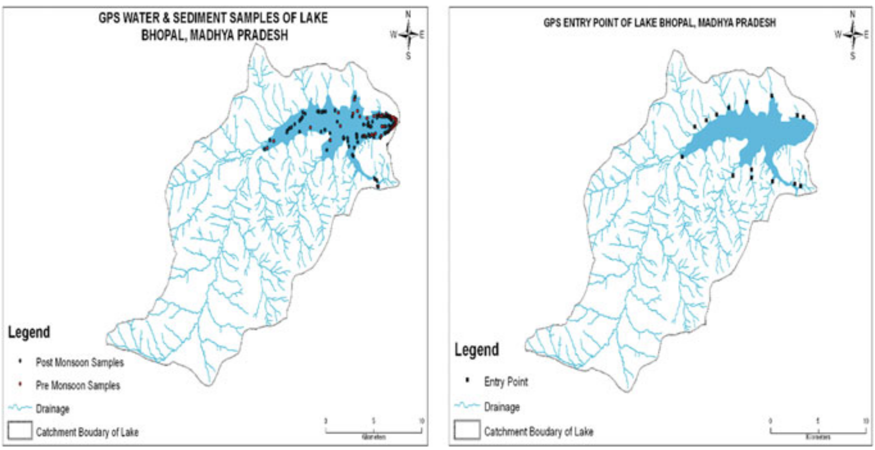

Fig. 1 GPS based sampling location for water and sediment sample collection from various locations in Upper Lake and entry point of Upper Lake, Bhopal

Photo 1 Peterson sediment sampler used for sediment sample collection from the Upper Lake, Bhopal

Murphy and Riley (1962). To determine the total dissolved P fraction, the particulate P is separated by filtering the water sample through a 0.45 µm pore diameter membrane filter before beginning the digestion procedure. To determine total P (dissolved + particulate), an unfiltered sample is taken just before measuring the subsample for digestion.

Results and Discussion

Phosphorus Fractions in Water and Sediment Samples of Upper Lake

The result shows that the total P in the sediment of post-monsoon stage samples varied from 0.03 to 0.07% with a mean value of 0.04%. The mean sediment inorganic phosphorus (SIP) and the sediment organic phosphorus (SOP) is 68.01 and 31.98% of total phosphorus (TP), respectively (Table 1). Among the inorganic P fractions in the sediment, Ca bound P was maximum and found to be in the range

Table 1 Phosphorus fractions in sediment samples collected from different locations from Upper Lake, Bhopal (post-monsoon, 2013)

Overall	TP (%)	% of TP		% of Inorganic P		
		Inorganic P	Organic P	Ca–P	Fe–P	Loosely sorbed P
Range	0.03–0.07	65.73–70.41	29.12–33.77	86.32–96.97	2.10–11.5	0.39–5.66
Mean	0.04	68.01	31.98	89.29	8.18	2.54
STDEV	±0.009	±0.059	±0.026	±0.214	±0.136	±0.072

Table 2 Phosphorus fractions (ppm) in water samples collected from different locations from Upper Lake, Bhopal (post-monsoon, 2013)

Overall	TP (ppm)	% of TP				
		TDP	TRP	DRP	DOP	PP
Range	0.28–0.47	28.57–36.17	17.34–29.14	3.64–18.36	3.29–17.97	58.87–79.04
Mean	0.386	31.05	20.31	10.39	18.73	68.94
STDEV	±0.0458	±0.0286	±0.0136	±0.0118	±0.0274	±0.0362

of 86.32 to 96.97% of total sediment inorganic P followed by Fe bound P (2.10–11.51%) and loosely sorbed P (LSP) (0.39–5.66%). The total P value in the water samples ranges from 0.28 to 0.47 mg/L with a mean value of 0.39 mg/L. The total Dissolved P, Total Reactive P and Dissolved Reactive P ranges from 0.08 to 0.17, 0.05 to 0.09 and 0.008 to 0.04 mg/L with a mean value of 0.13, 0.08 and 0.03 mg/L, respectively. The mean Total Dissolved P (TDP), Total Reactive P (TRP), Dissolved Reactive P (DRP), Dissolved Organic P (DOP) and Particulate P (PP) was 31.05, 20.31, 10.39, 18.73 and 68.94% of TP, respectively (Table 2). The results indicated that the total P in the lake water collected at post-monsoon sample is higher than limit for eutrophication (0.2 mg/L). The findings of this study is in line with the result reported by Choubey et al. (2007) who observed that the concentration of total phosphate phosphorous was quite high as compared to the orthophosphate phosphorous. Also the phosphorus concentration varied in the Upper Lake from 0.09 to 0.31 mg/L with mean value of 0.19 mg/L in June 2004, from 0.09 to 3.38 mg/L with mean value of 0.61 mg/L in July 2004, from 0.04 to 0.33 mg/L with a mean value of 0.09 mg/L in December 2004, from 0.09 to 1.08 mg/L with a mean value of 0.29 mg/L in May 2005 and from 0.12 to 1.72 mg/L with mean value of 0.48 mg/L in August 2005. Higher value of phosphates were observed in the month of July 2004 which may be attributed to the main tributary Kolans which carry runoff from agricultural fields surrounding lakes using phosphatic fertilizers (Choubey et al. 2007).

The water samples collected from different entry points (15 locations) where water enters from different sources (agricultural and municipal wastewater) to the Upper Lake were analyzed for various P fractions (Tables 3 and 4). The results showed that the total phosphate (TP) in the water sample (entry point) ranges from 0.30 to 0.73 mg/L with a mean value of 0.47 mg/L with the lowest and highest value from Kholukhedi (agricultural source) and Bhadbada (domestic wastewater), respectively. The Total Dissolved P (TDP), Total Reactive P (TRP), Dissolved Reactive P (DRP), Dissolved Organic P (DOP) and Particulate P (PP) in the water samples collected at entry point varied from 19.60 to 44.66, 3.41 to 36.25, 1.70 to 23.09, 5.84 to 27.56 and 55.34 to 80.40% of TP, respectively. The mean Total Dissolved P (TDP), Total Reactive P (TRP), Dissolved Reactive P (DRP), Dissolved Organic P (DOP) and Particulate P (PP) was 29.43, 14.07, 8.88, 14.36 and 70.57% of TP, respectively (Table 3). Among the P fractions, the bioavailable P fractions (TDP) were highest in domestic wastewater, where the dominant P

Table 3 Total Phosphorus and bioavailable P fraction (DRP) in water samples collected at different entry points of Upper Lake, Bhopal

Location	TP (ppm)	DRP (ppm)
Koh-e-fiza (city)	0.46	0.107
Shahid Nagar (city)	0.41	0.062
Lalgati (Ag)	0.36	0.019
Bairagarh (Idol)	0.48	0.100
Baisenkhedi (Ag)	0.38	0.016
Bhauri (Ag)	0.35	0.012
Jamoniya Cherra (Ag)	0.35	0.017
Kholukhedi (Ag)	0.30	0.037
Kolans Nala (Ag)	0.36	0.066
Mugaliya Chap (Ag)	0.38	0.016
Goregoan (Ag)	0.35	0.003
Barkeranathu (Ag)	0.35	0.006
Bhadbada (Idol)	0.73	0.082
Prempura (city)	0.41	0.029
Badbhada lake sample	0.39	0.057
Min	0.30	0.003
Max	0.73	0.107
Average	0.47	0.042

Ag represents water drains to lake predominately from agriculture (Ag) field run off

Table 4 Phosphorus fractions (% of total phosphorus) in water samples collected at different entry points of Upper Lake, Bhopal

Location	% of TP				
	DRP	TRP	TDP	PP	DOP
Koh-e-fiza (City)	23.09	36.25	44.66	55.34	27.56
Shahid Nagar (City)	15.07	28.68	40.95	59.05	19.94
Lalgati (Ag)	6.25	12.17	30.82	69.18	11.17
Bairagarh (Idol)	20.92	29.92	35.56	64.44	25.92
Baisenkhedi (Ag)	4.21	6.32	26.05	73.95	9.08
Bhauri (Ag)	3.43	5.43	25.14	74.86	8.33
Jamoniya Cherra (Ag)	4.89	7.47	25.29	74.71	9.87
Kholukhedi (Ag)	10.28	13.91	24.44	75.56	15.26
Kolans Nala (Ag)	2.54	5.07	20.85	79.15	18.57
Mugaliya Chap (Ag)	4.25	6.37	23.11	76.89	9.24
Goregoan	3.69	5.96	23.26	76.74	5.84
Barkeranathu (Ag)	1.70	3.41	19.60	80.40	6.69

(continued)

Table 4 (continued)

Location	% of TP				
	DRP	TRP	TDP	PP	DOP
Bhadbada (Idol)	11.29	19.83	40.08	59.92	16.28
Prempura (city)	7.00	8.70	31.16	68.84	11.99
Badbhada lake sample	14.62	21.54	30.51	69.49	19.61
Min	1.70	3.41	19.60	55.34	5.84
Max	23.09	36.25	44.66	80.40	27.56
Average	8.88	14.07	29.43	70.57	14.36

Ag represents water drains to lake predominately from agriculture (Ag) field run off

fractions in the water samples from agricultural source were particulate P (PP). The physico-chemical status of Upper Lake (Bhopal, India) with special reference to phosphate and nitrate has been investigated during the year 2003–2004. The phosphate and nitrate are two important nutrients in the lake loading through point and non-point pollution sources such as washing, bathing, agricultural activities in fringe area, joining of domestic raw sewage, and cultivation of trapa and huge growth of aquatic macrophytes. These nutrients support the fast growth of the aquatic plants (mainly Eichhornia crassipes, Hydrilla, Ceratophyllum, etc.) as a result these plants lead to gradual shrinking of wetland area along with other complications like low light penetration, reduces oxygen concentration, clogging of water channels, lowers entertainment value of lake and some time the level of oxygen depletes so much that it can lead to fish mortality also (Tamot and Sharma 2006).

Conclusion

From the study it was concluded phosphorus is one of the key elements necessary for the growth of all forms of life and therefore, for food production. While good agronomic management requires use of P to optimize crop growth, excessive application of P may degrade water quality (eutrophication). The results indicated that the total P in the lake water collected at post-monsoon sample varied from 0.28 to 0.47 mg/L with a mean value of 0.39 mg/L, which is higher than limit for eutrophication (0.2 mg/L). The source of water from the city and at idol immersion location contains relatively higher TP and dissolved reactive phosphorus (DRP) indicating potential release of bioavailable P fractions from the urban activities.

Acknowledgements This work is the part of institute funded project entitled “Non-point sources of phosphorus loading to the Upper Lake, Bhopal”. We acknowledge the Director, IISS; HOD of the department and the concerned scientist for the valuable advice and support.

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Assessment of Fluoride in Rainfed and Irrigated Agricultural Soil of Tonalite–Trondjhemite Series in Central India

Bijendra Kumar and Anshumali

Abstract The systematic and comprehensive geochemical analysis of fluoride (F) in 20 agricultural soil samples was carried out to understand the spatial variability, mechanism of retention and release, and the areas of potential risk due to poor or high concentrations of soil F around Sidhi District, Central India. The spatial variations in physicochemical parameters revealed significant difference in the methods of cultivation due to geomorphological constraints, availability of surface water and ground water, rainfall pattern, etc., in the study area. The north and small pocket in central Sidhi were rich in fertile soils due to availability of surface water and ground water. The southern and eastern Sidhi were rainfed areas, hence, the mono-cropping system by traditional methods showed less impact on the soil physicochemical parameters. The soil F varied from 366.94 to 1178 mg/kg and 2–4 times greater than the background soil value (320 mg/kg) of the world. The pollution indexes were <1 revealed prevalence of elevated soil fluoride.

Keywords Soil fluoride · Fertilizers · Geogenic · Silicate minerals
Surface water · Rainfed

Introduction

The Sidhi District is situated on the northeastern boundary of the Madhya Pradesh State, India which lies over a transitional area between the Indo-Gangetic plain in the north and the Deccan plateau in the south and the remotest district of Madhya Pradesh. Soil is one of the important and valuable resources of the nature. All living things are directly and indirectly dependent on soil for day-to-day needs and 95% of the human food is derived from the earth. Making plan for having healthy and

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productive soil is essential to human survival. Soil is a natural body consisting of layers (soil horizons) of mineral constituents of variable thicknesses, which differ from the parent materials in their morphological, physical, chemical, and mineralogical characteristics. Soil is composed of particles of broken rock that have been altered by chemical and mechanical processes that include weathering and erosion. The total fluoride concentration in soils are often derived from parent material, whereby its distribution in soil profiles is a function of soil-forming process, of which the degree of weathering and clay content are the most prominent factors. The average fluoride content of most soils worldwide has been documented as 329 mg/kg (Kabata-Pendias and Pendia 1992). In general, the lowest F contents are found in sandy soils in humid climate, whereas higher F concentrations occur in heavy clay soils and in soils from weathered mafic rocks (Fuge and Andrews 1988). Most of the fluoride in the soil is insoluble and, therefore, less available to plants. However, high soil fluoride concentrations or low pH, clay and/or organic matter can increase fluoride levels in soil solution, increasing uptake via the plant root. If fluoride is taken up through the root, its concentrations are often higher in the root than in the shoot, due to the low mobility of fluoride in the plant. Symptoms of fluoride toxicity include emaciation, stiffness of joints, abnormal teeth and bones, lowered milk production, and detrimental effects on the reproductive capacity of animals. Soil is the medium from which plants and animals directly or indirectly derive their nutrients and food, however, information regarding the concentrations of fluoride in the around cultivated soils of the Sidhi District is limited or unavailable.

In view of this, no attention has ever been drawn to address the problem of fluoride toxicity due to elevated concentration in the agricultural soils. In this connection, the present work aims at the determination of spatial distribution of fluoride.

Study Area

The Sidhi District is situated on the northeastern boundary of the Madhya Pradesh State, India which lies over a transitional area between the Indo-Gangetic plain in the north and the Deccan plateau in the south. It is situated between 22° 47.5′ and 24° 42.10′ North latitude and 81° 18.40′ and 82° 48.30′ East latitude (Fig. 1).

The physiography is characterized by low hill, extensive plateaus and river valleys such as Sone river valley which is a depository of the Gondwana rocks. Topographically the district can be divided into three zones, Vindhyan hills or Kaimour range, Gondwana zone and Archean zone. Clay minerals like kaolinite, halloysite, diaspore, gibbsite, nacrite, dicktite, etc., were derived by the localized weathering of arkosicmeta sediments (Mehrotra et al. 1979). The average elevation of the area is 311 m above MSL. The climate of the area is tropical monsoon type with three distinct seasons as hot and dry summer (March–June), monsoon (July–September), and winter (November–February). The average annual rainfall varies from 1000 to 1200 mm, peaks in the months of July and August. The total

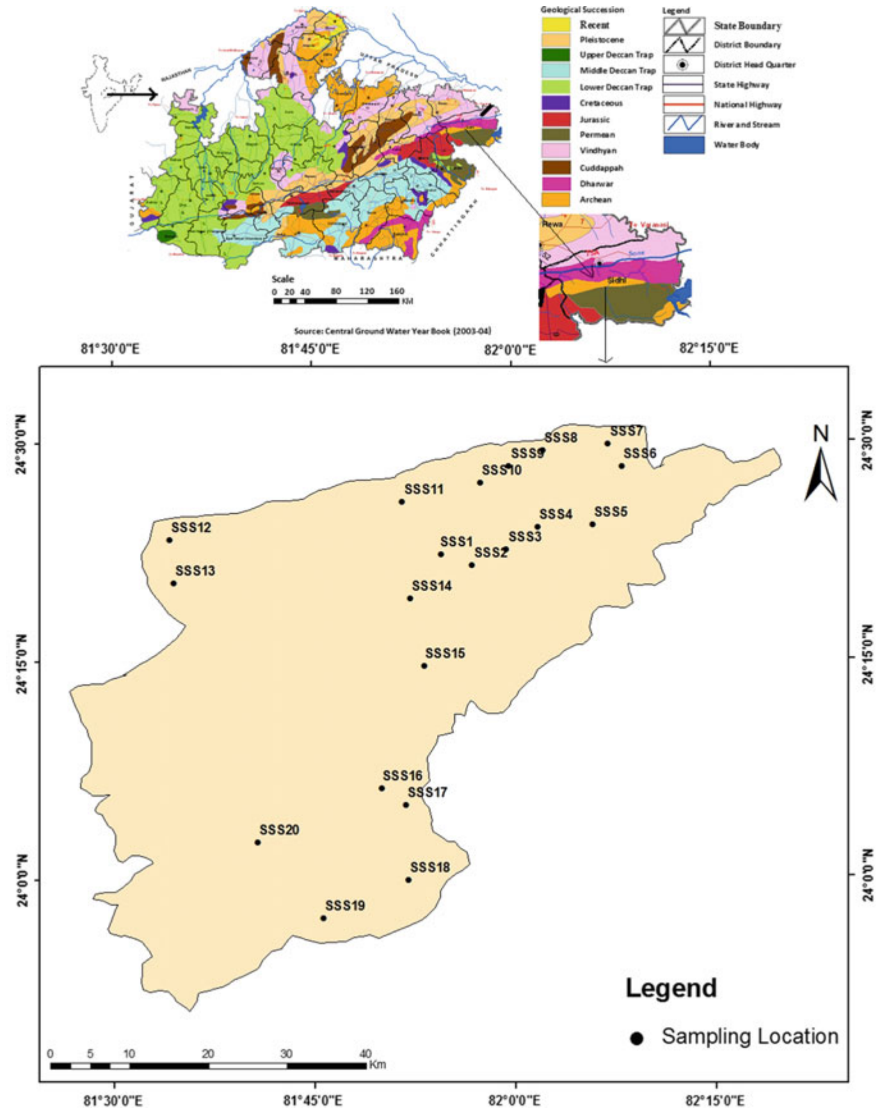

Fig. 1 Map of study area showing geology and sampling locations

population of the area is 1,126,515 spread with a density of 110/km^2 (Census 2011). The total land covered in the Sidhi District is 10,536 km^2 in which the forest area covers 40%. The portion of the land used for agricultural purpose is 47%, but only 17% of the land used for agricultural purpose has assured supply of irrigation and the rest of the agricultural land is dependent on rainfed irrigation and produces only one crop a year. The land is largely undulating terrain, which often has steep gradients not ideal for cultivation; the valleys along the major rivers like the Son and the Gopad have fertile soils. The crops grown are rice, maize, barley, pigeon pea, and jute in Kharif season, and wheat, mustard and lentil in Rabi season. Sugarcane and cotton are grown at places under irrigated conditions. The natural vegetation comprises tropical dry deciduous forests.

Method

Sampling: Moist Soil samples with water were collected from 20 different locations of Sidhi District, where agricultural activities are more. These 20 sampling locations are indicated in the map numbered from SSS1 to SSS20. The laboratory analysis is as follows: The pH and electrical conductivity (EC) were measured on a 1:2.5 and 1:5 soil: water (w/v) ratio, respectively (Allison and Moodie 1965); soil organic carbon and organic matter content was determined by the Walkley and Black dichromate oxidation method (Nelson and Sommers 1982); the cation exchange capacity (CEC) by ammonium acetate method; The total soil fluoride was obtained using the alkaline fusion method (Mcquaker and Gurney 1977). The total carbon (TC) and total nitrogen (TN) by Elemental Analyser (Thermo Flash 2000). The elements (Al, Fe, Ca, Mg, Mn, and P) were analyzed by the ICP-OES (Leeman Profile Plus) at NMDC, Donimalai, Karnataka. The particle size analysis was carried out by Microtrac S3500 analyzer in Jawaharlal Nehru University. To assess the pollution degree of fluoride in soils, single factor pollution index (SFPI) method was used (EPAC 2005): Pi = C_i/S_i, where Pi is the single factor pollution index of fluoride, C_i is the content of fluoride in soils at the sampling site, and S_i is the evaluative standard value of fluoride. The background value (320 mg/kg) of the world was taken as references to determine the starting value and contamination levels of soils (Alina and Henryk 1984). The descriptive statistical analysis was carried out by the SPSS (version 16.00). The map of fluoride spatial distribution pattern was produced by using the Arcview (9.3) software for ordinary kriging interpolation.

Results and Discussion

The pH of soil samples varied from 6.5 to 7.9 with scarce differences in mean soil pH between sites. Particle size analysis of soil samples showed a diversified range of sand, silt, and clay as 1.52–43.66%, 45.91–84.41% and 10.43–44.97%, respectively, with silt as the most dominating fraction. The soil organic carbon (SOC) and soil organic matter (SOM) at different locations were found to be ranging from 0.24 to 1.93% and 0.43 to 3.32%, respectively. Across all locations CEC showed significant spatial variation ranging from 7.65 to 20.38 Cmol/kg. The fluoride concentrations ranged from 366.94 to 1178 mg/kg (Table 1). The soil fluoride concentrations in the Sidhi District were much higher than 320 mg/kg in

Table 1 Variation of pollution degree of fluoride in study area

S. No.	Sampling locations	C_i	S_i	Pi = C_i/S_i
1	SSS1	413.56	320	1.29
2	SSS2	618.64	320	1.93
3	SSS3	505.08	320	1.58
4	SSS4	486.44	320	1.52
5	SSS5	403.56	320	1.26
6	SSS6	1177.97	320	3.68
7	SSS7	640.68	320	2.00
8	SSS8	749.15	320	2.34
9	SSS9	606.78	320	1.90
10	SSS10	396.61	320	1.24
11	SSS11	394.92	320	1.23
12	SSS12	381.36	320	1.19
13	SSS13	574.58	320	1.80
14	SSS14	725.42	320	2.27
15	SSS15	627.12	320	1.96
16	SSS16	389.83	320	1.22
17	SSS17	430.85	320	1.35
18	SSS18	366.95	320	1.15
19	SSS19	561.02	320	1.75
20	SSS20	412.03	320	1.29

worldwide soils (Alina and Henryk 1984). The high concentrations are found to be associated with geogenic and anthropogenic sources in Sidhi district. Jha et al. (2008) reported total soil F concentrations varied from 322 to 456 mg/kg in surface soils around suburb of Lucknow. Jha (2013) studied the geochemical characteristics and the spatial distribution of the fluoride in the soils of Indo-Gangetic plains and found that total fluoride ranged from 248 to 786 mg/kg with a mean of 515.1 mg/kg. In order to depict the spatial variability of soil fluoride in the district, ordinary kriging procedure was used to create the spatial distribution map. From Fig. 2, it can be seen that fluoride has distinct geographical distribution, with high concentrations (Table 2) in the north and a small pocket in central portion of the Sidhi District. This may be due to double cropping system (include paddy and wheat cropping) which demand excess fertilizer application, induced weathering of soils, and irrigation of cultivated land by surface and groundwater rich in dissolved fluoride.

The element fluoride is always present in phosphatic fertilizers, soils and plants and falls by two orders of magnitude at each stage in the sequence: fertilizer > soil > plant (Larsen and Widdowson 1971). Superphosphate, which contains between 1 and 3% F, makes a significant contribution to fluoride content of

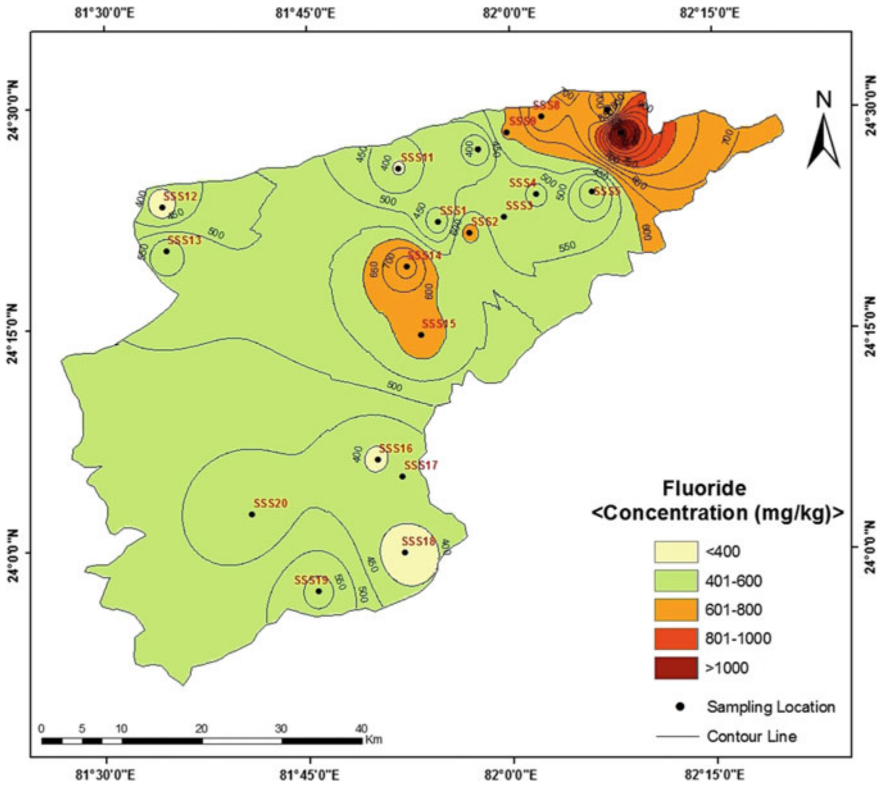

Fig. 2 Spatial variability of soil fluoride in Sidhi district

Table 2 The soil texture, agricultural practices around the study area

Sampling location	Soil texture	Causes		Fluoride concentration (mg/kg)
		Weathering activities occurs	Agricultural practices	
SSS1	Silt loam	Yes	Mono cropping	413.56
SSS2	Silt loam	Yes	Mono cropping	618.64
SSS3	Silt loam	Yes	Mono cropping	505.08
SSS4	Silt loam	Yes	Mono cropping	486.44
SSS5	Silt clay	Yes	Double cropping	403.56
SSS6	Silt loam	Yes	Double cropping	1177.97
SSS7	Silt loam	Yes	Double cropping	640.68
SSS8	Silt loam	Yes	Double cropping	749.15
SSS9	Silt loam	Yes	Double cropping	606.78
SSS10	Silt loam	Yes	Double cropping	396.61

(continued)

Table 2 (continued)

Sampling location	Soil texture	Causes		Fluoride concentration (mg/kg)
		Weathering activities occurs	Agricultural practices	
SSS11	Silt clay loam	Yes	Double cropping	394.92
SSS12	Silt loam	Yes	Double cropping	381.36
SSS13	Silt loam	Yes	Double cropping	574.58
SSS14	Silt loam	Yes	Double cropping	725.42
SSS15	Silt loam	Yes	Double cropping	627.12
SSS16	Loam	Yes	Mono cropping	389.83
SSS17	Silt loam	Yes	Mono cropping	430.85
SSS18	Loam	Yes	Mono cropping	366.95
SSS19	Loam	Yes	Mono cropping	561.02
SSS20	Silt loam	Yes	Mono cropping	412.03

agricultural soils. The major part of the district confirmed that the spatial distribution of soil fluoride (<400–600 mg/kg) was controlled by properties of regional parent rocks than anthropogenic fluoride input.

Conclusions

The major cause of higher soil fluoride in northern Sidhi District and small pocket in central Sidhi, is not only by weathering of fluoride-rich minerals in the country rocks but also by intensive agricultural activities, which is a major livelihood option, accelerated the cycling of soil fluoride. The overall contents of pedogenic elements reflect the highly weathered, dominance of non-silicate forms. From the distribution of factor scores and loadings, it is observed that the predominant retention mechanism of fluoride on clays is supported by fine soil texture, organic matter, and organic carbon. The double cropping systems augment fluoride toxicity in the northern Sidhi and a small pocket in central Sidhi. The major anthropogenic factor responsible for fluoride enrichment is intensive fertilizer application. In a nutshell, the natural sources are weathering of parent rocks and irrigation of cultivated land by surface water and ground water rich in dissolved fluoride.

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Biomonitoring of Paravur Lake in Kerala Using Macro-Invertebrates

J. Sreeja

Abstract Macro-invertebrates are the most commonly suggested bioindicators for biomonitoring and have been extensively studied in temperate areas. On the other hand, the methodology and theoretical background of biomonitoring have not yet been sufficiently adapted to tropical aquatic environments. Bioassessment/biomonitoring is a reliable and holistic method of ecosystem assessment integrating water quality assessment, habitat assessment and biological assessment. Bio assessment protocol using macro-invertebrates was adapted from United States Environment Protection Agency (USEPA) and applied successfully in Paravur Lake, located on the southwest coast of Kerala. This lake is one of the ecologically degraded lakes due to certain anthropogenic activities. Three sites were selected in order to assess the health status of Paravur Lake. From the three sites selected, site I was less polluted (Reference Station), site II was slightly polluted and site III was heavily polluted. Category I macroorganisms were found in site I, category II were found dominant in site II and category III organisms were dominant in site III. A multimetric analysis using physicochemical parameters, species diversity and community analysis of macro-invertebrates were carried out to evaluate the present health status of Paravur Lake ecosystem.

Introduction

Backwaters are valuable fishery resources that contribute to the inland fish production of a country. Environmental conditions play a vital role in governing the life history, behavior distribution and abundance of organisms particularly in the aquatic environments. Knowledge of the environmental condition is highly essential for understanding the occurrence and abundance of aquatic organisms.

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It also provides valuable information for suitable management practices to be taken for their sustainability. Thus regular monitoring of different environmental parameters is a pre requisite for proper evaluation of the ecosystem.

Biomonitoring is a technique that utilizes living organisms in the assessment of environmental health. The success of biomonitoring is dependent on the ability to find and utilize an indicator species whose presence/abundance/behavior reflect stresses in the environment. Biomonitoring is the study of biological organisms and their response to environmental condition using algae, fish or insect communities. Macro-invertebrates are animals without backbones and are large enough to be seen with our naked eyes. They are affected by physical, chemical, and biological conditions of water bodies. They cannot escape from pollution and show the effect of short- and long-term pollution events. It shows the cumulative impact of pollution and habitat loss. Macro-invertebrates are an important part of food web, easy for sampling, identification and more economic.

Materials and Methods

The Study Area

The Paravur Lake (lat: 8° 41′–8° 46′N; long: 76° 44′–76° 48′E) is a comparatively shallow estuary of Kollam district, Kerala. The lake is connected to the adjoining Lakshadweep Sea by a narrow flood water outlet channel with regulator. Climate is typically tropical. The influence of southwest and northeast monsoons are substantial, the former from June–September and later during October–January. The Ithikkara River originating from the Western Ghats drains fresh water into Paravur Lake (Station I-Kallumkunnu). The main body of the lake is about 10 km long and 2 km mean wide and remain separated from the Lakshadweep Sea by a narrow strip of land (Station II-Perumpuzha). This water body is connected to the Ashtamudi lake lying north through the Kollam canal (Station III-Alumkadavu). On the southern side, the Paravur canal connects it with the Edava–Nadayara backwater.

Various physicochemical factors were determined during regular monthly sampling from January–December 2014 and analyzed following the standard procedures (Kaul and Gautham 2002). pH of the water sample was determined with Elico digital pH meter. Salinity was determined using digital salinometer. Dissolved Oxygen (DO) was estimated by Winkler's method (Strickland and Parsons 1972). The chemical analysis of water for phosphate and nitrate were made according to (Trivedi and Goel 1986) and for nitrite by (Grasshoff 1983). Simple correlation metrices between various water quality parameters were analyzed. Macro-invertebrates were collected for 2 h with a strainer, picked from the substrate and preserved in the field with 70% alcohol. The benthic organisms were collected with a D-shaped net for 10 min, with separation and sorting done in the laboratory. The diversity of macro-invertebrates were assessed during January–December 2014 following standard techniques (Hilsenhoff 1998). Hilsenhoff Biotic Index (HBI), Family Biotic Index (FBI), Pollution Tolerance Index (PTI) were calculated.

Result

The results of various physico–chemical parameters revealed that the Station III is highly depleted and has poor water quality (HBI = 6.5, PTI = 8, FBI = 8.5) and was below the desirable limits o f US-EPA and CPCB (Central Pollution Control Board). In Station II HBI = 4.2, PTI = 5, FBI = 5.3 and thus water quality is in a desirable level. Station I is the reference site where HBI = 2.1, PTI = 1 and FBI = 3.8. Hence the water quality is very good. Different types of macro-invertebrates collected from different Stations are represented in Figs. 1, 2, 3 and 4).

From the multimetric indices-IBI showed that the organisms like caddis fly larvae, may fly larvae and stone fly larvae, water penny and dytiscus larvae are very sensitive to pollution and seen only in site I. The nymph of stone flies and May flies are the first to disappear from water which has high organic pollution. As pollution increases caddis fly larvae, dytiscus larvae and water pennies move into less polluted region. These organisms found in site I are completely absent in site II and III due to organic pollution. In Station II, Mussels are the dominant organisms, followed by shrimp. Dragon and damsel fly larvae are seen in region where the water quality is in desirable limit. Category II organisms comparatively have more tolerance than category I organisms. In Station III mosquito larvae are the dominant species followed by snails, chironomous larvae, tubifex and rat tailed maggots.

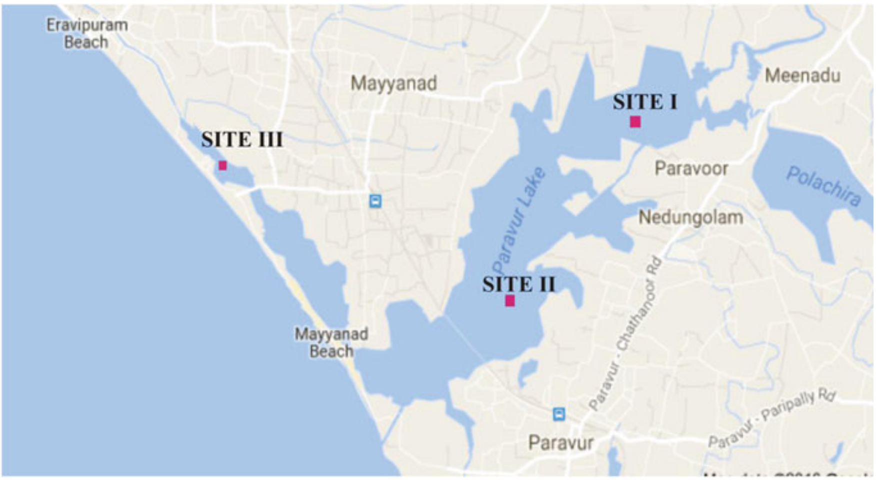

Fig. 1 Map showing study area of Paravur lake

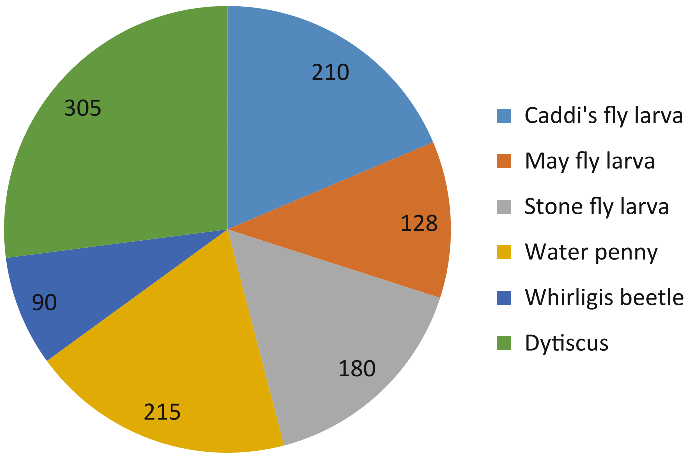

Fig. 2 Macro-invertebrates collected from Station I (Category I)

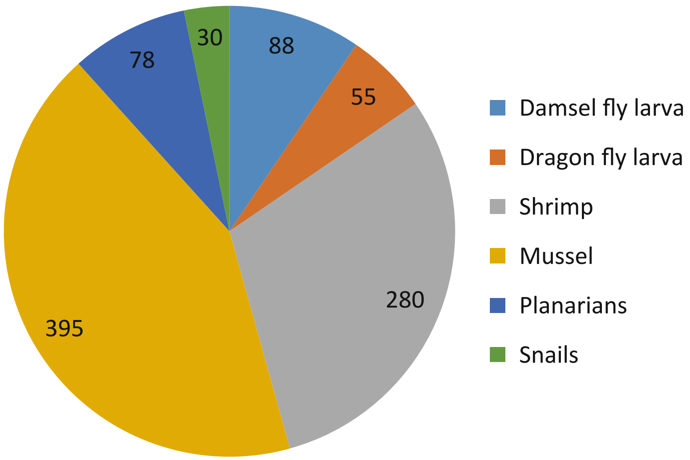

Fig. 3 Macro-invertebrates collected from Station II (Category II)

These category III organisms have high pollution tolerance index. Hence they are able to survive in such a highly polluted area like StationIII.

The different physico-chemical parameters of the three Stations were represented in Tables 1, 2 and 3. Atmospheric temperature varied between 25 °C (Monsoon season, Station III) to 30 °C (Post monsoon period in Station I). Water temperature varied between 22 °C (Monsoon season, Station III) to 28 °C (Post monsoon period in Station I). pH variation noted during all the seasons and ranged between 6.8 in Station I during pre-monsoon season and 12 in Station III during post monsoon period. Maximum salinity (6‰) noticed in Station II during monsoon season and no salinity at Station I in monsoon season. Dissolved oxygen ranged between

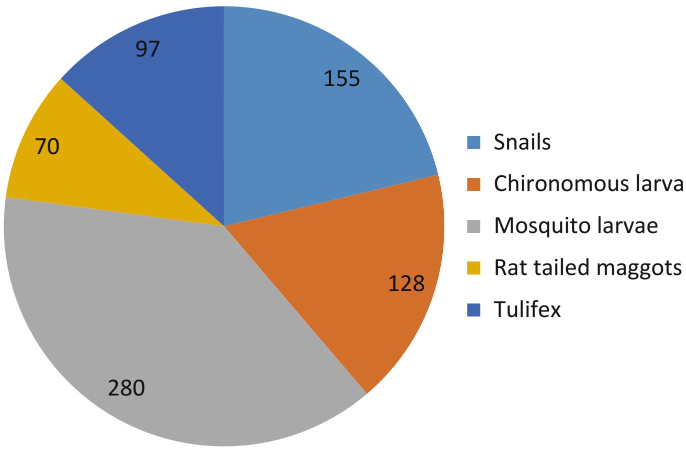

Fig. 4 Macro-invertebrates collected from Station III (Category III)

Table 1 Different water quality parameters of Station–I (Kallumkunnu region)

Station I	Atm. temp (°C)	Water temp (°C)	pH	Salinity (‰)	DO (mg/L)	BOD	Nitrate (µg/L)	Nitrite (µg/L)	Phosphate (µg/L)
Pre-monsoon	29	26	6.8	2	3.4	1	0.38	0.04	0.04
Monsoon	26	23	7	0	4	0	0.16	0.17	0.09
Post monsoon	30	28	7.5	2.3	4.2	1	0.58	0.06	0.05

Table 2 Different water quality parameters of Station–II (Perumpuzha region)

Station II	Atm. temp (°C)	Water temp (°C)	pH	Salinity (‰)	DO (mg/L)	BOD	Nitrate (µg/L)	Nitrite (µg/L)	Phosphate (µg/L)
Pre-monsoon	28	26	8	5	2.2	3	3.2	0.9	1.5
Monsoon	27	24	7.8	6	2.5	2	1.01	2.1	2.3
Post monsoon	28	25	7.9	4	2.08	3	2.6	2.2	2.8

Table 3 Different water quality parameters of Station–III (Alumkadavu region)

Station III	Atm. temp (°C)	Water temp (°C)	pH	Salinity (‰)	DO (mg/L)	BOD	Nitrate (µg/L)	Nitrite (µg/L)	Phosphate (µg/L)
Pre-monsoon	26	24	11	3	0.84	6	6.5	5.4	8.5
Monsoon	25	22	10	5	1.2	5	4.2	4.8	6.9
Post monsoon	27	25	12	4	0.52	6	5.7	5.9	7.8

0.52 mg/L in Station III and 4.2 mg/L in Station I. Low BOD values were noticed in Station I and high values (6) were seen in Station III. Nitrate was noted to be high with a value of 6.5 μg/L at Station III in pre-monsoon season and low with a value of 0.16 μg/L at Station I in pre-monsoon season. Nitrite showed the highest value of 5.9 μg/L in post monsoon season at Station III and lowest value of 0.04 μg/L in pre-monsoon season at Station I. The high value of Phosphate (8.5 μg/L) was noted at Station III during pre-monsoon season and low value (0.04 μg/L) was observed at Station I in pre-monsoon season.

Water quality analysis of physicochemical parameters of different seasons at different stations is highly significant.

Discussion

The study area, the Paravur Lake, is one of the largest backwater systems in southern part of Kerala. The hydro-chemistry of Paravur backwater is mainly controlled by tidal action from the sea, through the spillway shutter and freshwater discharge from the Ithikkara River. Water temperature in the present study ranged between 22 °C (Monsoon season, Station III) to 28 °C (Post monsoon period in Station I). The water temperature is low during monsoon season due to the southwest monsoonal effect. Southwest monsoon has an important role in Kerala coast. Madhukumar and Anirudhan (1996) also recorded the similar temperature variations in the surface water at Edava–Nadayara and Paravur backwater, which is within the range of present study. Shibu (1991) recorded the similar temperature fluctuation of 22–28 °C in Paravur backwater system.

In the present study, the temperature fluctuations in Paravur backwater at three different stations depends upon the geographical location, sampling time, season as well as temperature of the effluents coming into the system.

Seasonwise variation of hydrogen ion concentration noticed at three different stations in Paravur backwater showed wide fluctuations. The normal pH of freshwater ranged between 7.5 and 8.5. Maximum hydrogen ion concentration may be due to climatological and vegetational factors (Kant and Kachroo 1975). The high value of hydrogen ion concentration may be due to intrusion of sea water. Rainfall, river discharge, intrusion from the sea and effluent from Kollam canal are important factors that influence pH variation in the backwater system (Nair et al. 1984). Hoq et al. (2002) also recorded the same range of pH at Sunderbans mangrove area. Hydrogen ion concentration value above 10 will lead to mortality of the majority of flora and fauna (Albester and Lloyd 1980). Oxygen can be used as a pulse of the aquatic system. Dissolved oxygen in natural water is of prime importance both as a regulator of metabolic process of floral and faunal community and is an indicator of water condition. Depletion of dissolved oxygen was probably frequent because of certain forms of water pollution. Dissolved oxygen content of Paravur backwater system showed maximum value in Station I (4.2 mg/L) and minimum in Station III (0.52 mg/L). This may be due to the disposal of organic waste like poultry and domestic waste. Oxygen depletion may be due to the accumulation of organic waste (Trivedi 1986). The high dissolved oxygen at Station I may be due to mixing up of freshwater discharge from the Ithikkara river and due to the high rate of primary production by phytoplankton and benthic macro algae. The same phenomena in Paravur Lake were also observed earlier (Nair et al. 1984; Santosh 2002). BOD is directly proportional to organic pollution while DO is inversely proportional to organic pollution.

Maximum salinity (6‰) was noticed in Station II during monsoon season due to the ingression of saline water through the spillway shutter and no salinity was observed at Station I in monsoon season because of fresh water intrusion from Ithikkara River. The present study revealed that salinity was within the range of earlier observation Hoq et al. (2002).

A significant maximum value of nutrients was observed in Station III. This is due to the nutrient-rich disposal from Kollam canal. The low value of nutrients was noted in Station I due to the ingression of freshwater from Ithikkara river. Intermediate value of nutrients was seen in Station II because it is located in between Station I and III. Similar observations were noticed in earlier studies in Paravur Lake (Santosh 2002).

From the present investigation it can be concluded that Station I is less polluted, Station II is moderately polluted and Station III of Paravur Lake is highly polluted in physicochemical nature.

No data is available for comparing the results of biomonitoring of macro-invertebrates of Paravur Lake. Macro-invertebrates are the most commonly suggested bio indicators for biomonitoring and have been extensively studied in temperate areas. On the other hand, the methodology and theoretical background of biomonitoring have not yet been sufficiently adapted to tropical aquatic environments (Stein et al. 2008). The current challenges to implement macro-invertebrate biomonitoring in tropical countries include limited scientific knowledge of the fauna, few or no training opportunities and poor understanding of the benefits. Protocols for using macro-invertebrates to monitor water quality have been published and implemented in many countries including Australia (Australian River Assessment System AUSRIVAS 2005), Canada (Rosenberg et al. 2005) the European Union (European Union Water Framework Directive 2000), New Zealand (Stark et al. 2001), United Kingdom (RIVPACS 2005) and the US (Barbour et al. 1999). Asian biologists have modified these guidelines to meet their own particular needs, primarily to accommodate different habitat and taxa in their own country.

In Paravur Lake, Category I organisms were seen in less polluted Station I. Category II organisms were collected from moderately polluted Station II and Category III organisms from highly polluted Station III. The difference in combinations of biological and ecological traits of communities was linked to tributary influences or anthropogenic disturbances to evaluate the actual state of ecosystems, to discriminate among different types of human impact, and to develop monitoring tools considering the functional diversity of communities (Jungwirth and Muhar 2000). Multimetric integrity of biotic index score of macro-invertebrates (M-IBI) obtained from nine benthic metrics ranged from 11 to 45 showed that Vellayani Lake ranked under excellent water quality with 45 as IBI score where as poor to very poor conditions at Veli-Akkulam lake (Abhijna and Biju Kumar 2012; Abhijna and Biju Kumar 2014). The relative taxonomic composition of macro-invertebrate taxa showed maximum abundance and dominance of less pollution tolerant group in Vellayani lake of Kerala (Abhijna et al. 2013). The result of the Paravur Lake is in agreement with the studies done in Vellayani lake in Kerala (Abhijna and Biju Kumar 2014). Therefore the study recommends the introduction of biomonitoring techniques and improvement of water quality by proper management practices to restore water quality conditions and ensure the health status of Paravur Lake in Kerala.

Conclusion

The hydrographical study can be concluded as that Station I was less polluted, Station II was moderately polluted and Station III of Paravur Lake was highly polluted. Biomonitoring methodology also revealed the same result. Hence this technique is a simple and reliable method for sustainable management of water resources.

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Change Detection of Sodic Land in Raebareli District Using Remote Sensing and GIS Techniques

Arif Ahmad, R.K. Upadhyay, B. Lal and Dhananjay Singh

Abstract Remote sensing and GIS play a vital role in trend analysis over sodic land and use of alternative measures to minimize the time and cost in reclamation processes. Sodic land is the highly contaminated of salt having pH range of 9.5–10.5 and sodium percentage greater than 15% above which is caused by naturally and anthropogenic. In this study, Raebareli district has been taken as the study area for mapping and monitoring the change detection with respect to sodic lands. LISS III data are used for mapping sodic land in both years 1997 and 2012. The maximum likelihood algorithm method was used for area statistics of different categories of sodic land followed by integration of both the classification of satellite data of Rabi seasons. The Sodic land covers 28823.91 ha area in 1997, which is 8.80% of the total geographical area of the district. At present the total area of sodic

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lands have been decreased by 18483.60 ha, which covers 10340.31 ha area in 2012, which is 5.64% of the total geographical area of the district. The major changes have been reported mainly in terms of wastelands, fallow land and sodic land areas, which have been reported to decrease over the years.

Keywords Remote sensing and GIS · Sodic land · Multi seasonal remote sensing satellite data · NDVI · Change detection

Introduction

Salt-influenced soils have a field over the world, particularly in semi-arid, arid and sub-humid regions. Salt-influenced soils happen both normally and as the after effect of man's adjustment of the hydrologic forms which activate and accumulate salts within the landscape. Nonetheless, it ought to be noted at the start that there are two expansive classes of salt-influenced soils. Saline soils are those with a lifted convergence of any sort of salt, though "sodic" soils are those soils with a high extent of sodium particles in respect to different cations in the soil or water. An extensive list of land disturbance activities, including road development, happen on sodium-influenced soils. Soils with abnormal amounts of replaceable sodium and low levels of aggregate dissolvable salts are vulnerable to clay dispersion which prompts to crusting, low permeability, high bulk density and low porosity. Soil saltiness and water logging are two of the fundamental requirements introduce in irrigated agricultural lands. The capacity of space platforms to give synoptic perspective of the region makes remote sensing an exceptional tool for quick and timely observing of earth resources and depiction of salt-influenced soils. The combination of remote sensing with the geographical information system (GIS) is utilized for assortment information to delineate salt affected soil.

The most regularly utilized procedure for a salinity index is the calculation of various indices and proportion pictures utilizing infrared and visible spectral band in the electromagnetic range. Dry soil for the most part has higher reflectance and no absorption in red region have been utilized in vegetation indices. Among a few vegetation indices, normalized difference vegetation index (NDVI), soil adjusted vegetation index (SAVI), and were utilized to describe crop growth condition impacted by salinity (ref.).

Three spectral indices for the identification of saltiness in Raebareli, Uttar Pradesh, India, using the LISS-III sensor on IRS-platform 1C and P6, are the soil brightness index (SBI), normalized difference vegetation index (NDVI), Statistical investigation of the study area and generation of Change detection map delineate with the help of satellite data (IRS-stage 1C and P6). Land cover/land use and sodic land changes additionally include the alteration either immediate or roundabout of characteristic natural surroundings and their effect on the ecology of the area. Remote sensing technology for catching the spatial information, Geographic Information System for undertaking coordinated investigation, presentation of spatial and associated attribute information are observed to be a great deal more successful to known the change detection of land use/land cover.

Study Area

The study area is Raebareli district, Uttar Pradesh, India. The study area is situated between geo-coordinates UTM_Zone_44, 25° 49′ to 26° 36′N Latitude and between 100° 41′ and 81° 34′E Longitude. The district of Raebareli has a large area cover of 4,609 km^2. Though compact and irregular in shape the dimensions of district changes every year due to the course of holy River Ganga and its action. Little change in the stream of river makes significant variation in the area of this territory that is likely to every year. Loamy sand, sandy loam, clay loam and silt loam soils are found in the district. During summers the mercury level could go as high as 45–50 °C. A little alleviation could be seen by mid June with precipitation principally from South Western Winds. It rains from 900 to 1200 mm here from June to September approximately every year (Fig. 1).

Material and Method

For the purpose following multi-date LISS III Satellite data of 01 February 1997 and 07 February 2012 are used for image processing and salt delineation of the study area. During the month of February and May salt has got accumulated on the surface due to high evaporation rates. The published soil survey reports, soil maps, atlas of India, and water quality reports (RSAC, UP) for the study area, were are collected and utilized during interpretation and field work. Salinity is a natural characteristic of soil, but salinization is caused by the human interactions. Salinity is defined by the accumulation of Salt soluble in the soil.

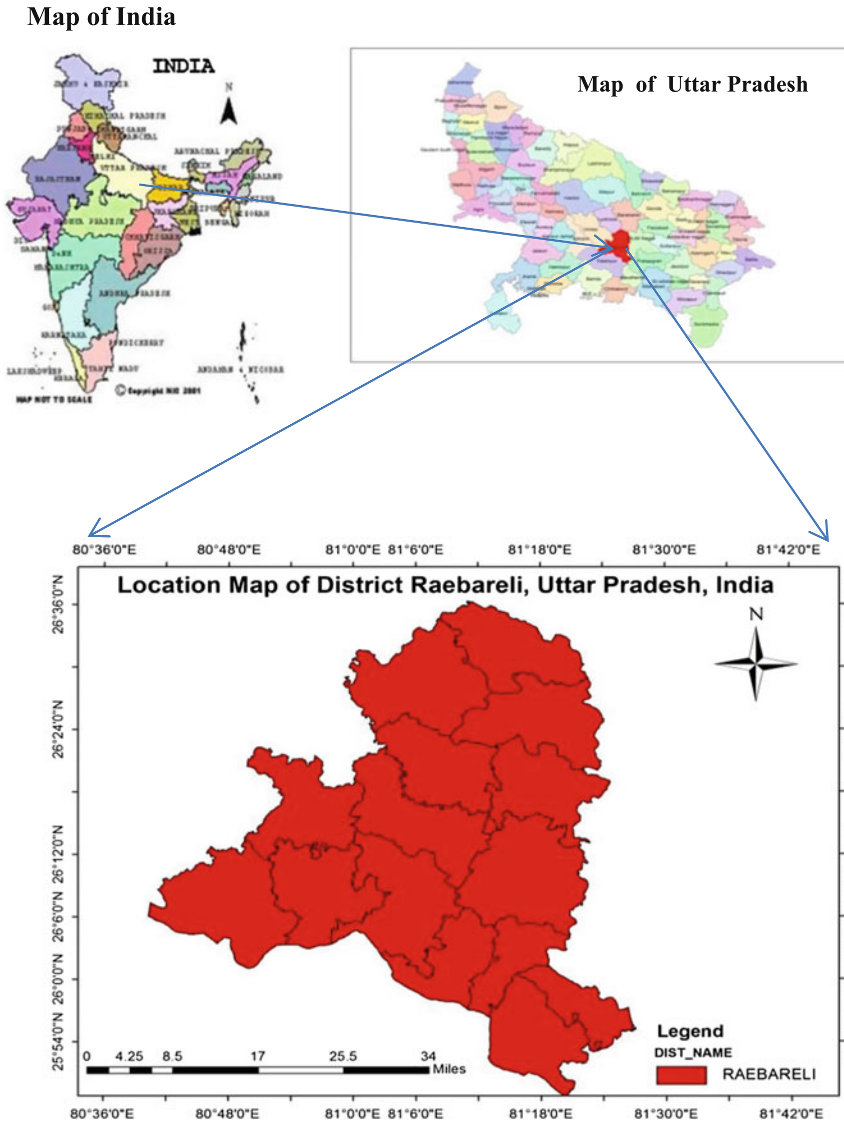
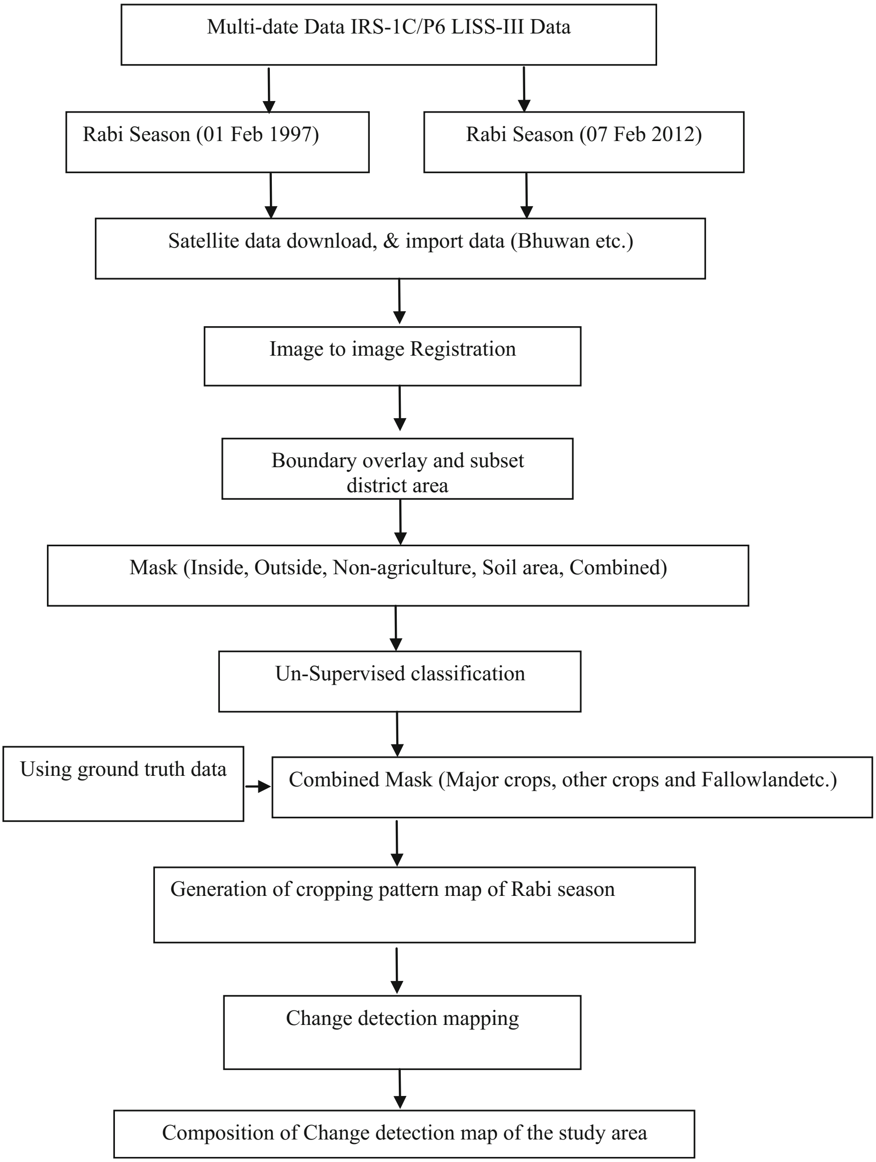


Fig. 1 Location map of study area (district Raebareli)


Multi-date Data IRS-1C/P6 LISS-III Data
Rabi Season (01 Feb 1997)
Rabi Season (07 Feb 2012)
Satellite data download, & import data (Bhuwan etc.)
Image to image Registration
Boundary overlay and subset district area
Mask (Inside, Outside, Non-agriculture, Soil area, Combined)
Un-Supervised classification
Using ground truth data
Combined Mask (Major crops, other crops and Fallowlandetc.)
Generation of cropping pattern map of Rabi season
Change detection mapping
Composition of Change detection map of the study area

Data Used

Geocoded False Colour Composite scene of IRS-IC LISS III and IRS-P6 LISS III data (year 1997 and 2012 respectively) coinciding with survey of India (SOI) Toposheet is used on 1:50,000 scale in the present study.

Preparation of Base Map

The base maps indicating permanent features such as major canals, highways, roads, railways, villages and sand dunes were prepared in ERDAS IMAGING software. The Survey of India toposheet was georeferenced using the Geographic Universal Transverse Mercator UTM_44 coordinate system and the WGS84. We have used some GPS point locations in the study areato locate the sodic land areas on the satellite data. After that calculation of the sodic land area (in Hectare) of sodic land for accuracy of change detection is performed. We have used post classification process in GIS System. Ground data is attributed to collection, verification and measurement of information about the different surface features on earth, which is responsible for occurrence of specific spectral reflectance behaviour patterns (Fig. 2).

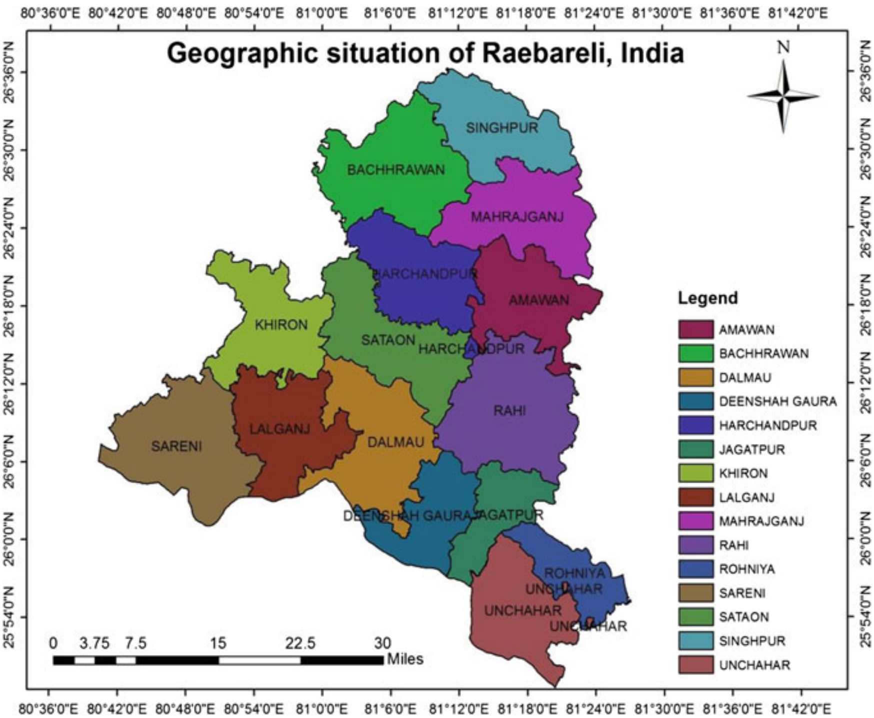


Fig. 2 Geographic situation of district Raebareli, Uttar Pradesh, India

Mask Generation

For further analysis to be carried out different masks such as District Outside mask non-agricultural mask, non-agriculture area, inside mask and combined (outside + non-ag.) mask of district boundary and block boundary were generated. The first case is the image layer sign followed by literal numeric value such as 1, 2 or 3, indicating layer 1, 2 or 3 of the implicit database. All the rules for image layers also apply to bitmap layers, except that the variables are prefixed with two percent characters instead of one.

Result and Discussion

There are a number of broad units that contain several inclusions. The inclusions couldn't be separated because of their small extents. So approximations of inclusions are based on the tone reflected on the scene and proportion of their extent. The sodic land cover types are classified as fallow sand details of land use/land cover statistics of study area for year 1997 and 2012, respectively. Area under major sodic land categories was calculated for the year 1997 and 2012. Land use/land cover and sodic land has been categorized into six different classes that are crop, Plantation, sodic land, fallow land, water-body and sand. Approx. 36% of total areas have changed from 1997 to 2012 where land cover part is decreasing while land use part is increasing year by year.

Sodic Land Status and Results of Analysis

The imaginary demarcates the area which is highly salt affected and are easy to classify for further analysis which was performed. In Raebareli district, sodic land covers 45286.19 ha area in 1997, which is 10.14% of the total geographical area of the district. In this satellite image shows the area which are highly salt affected areas easy to classify and point out those areas which are change in year of 2012. The total area of sodic lands has been decreased by 12650.56 ha, which covers 32635.63 ha area in 2012, which is 7.31% of the total geographical area of the district. Total area of the district is 327285.97 ha. The major changes have taken place in wastelands, fallow land and sodic land areas, which have decreased over the years (Fig. 3).

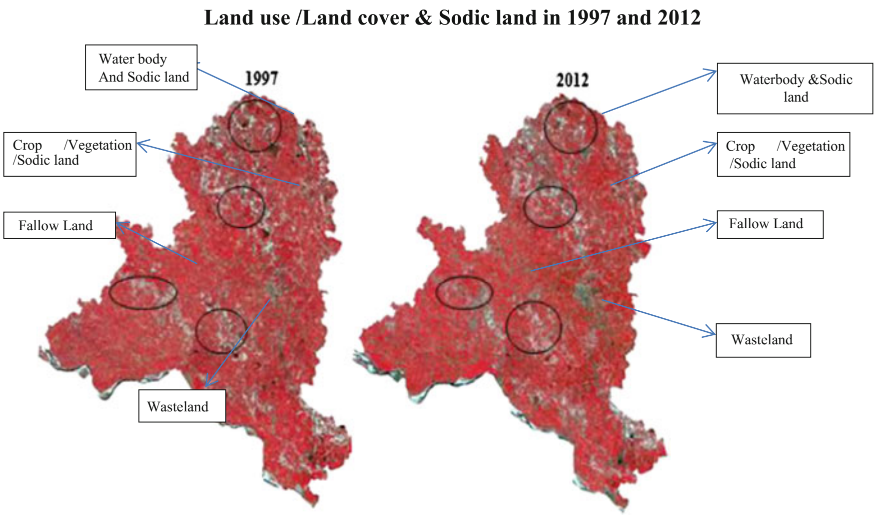


Fig. 3 Land use/land cover and sodic land in 1997 and 2012

The process of georeferencing of different multi temporal remote sensing data has been done using georeferenced Survey of India (SOI toposheet number 63B/12, 63B/16, 63F/3, 63F/4, 63F/6, 63F/7, 63F/8, 63G/5) topographical map of year 1972 by identifying the ground control points (GCP's) from the map and the corresponding points on the satellite images and finally applying the map-image transformation model. On screen digitization of different land use features from the SOI maps and satellite data was done to transfer the same on the georeferenced image using ARC GIS 10.1 software.

In this study two different image processing classification methods were used i.e., unsupervised and supervised classification. Unsupervised classification is the identification of natural groups, or structures, within multispectral data. Supervised classification is the process of using training samples, samples of known identity to classify pixels of unknown identity. Broadly area is divided into seven classes, mainly forest, water bodies, agricultural land/vegetation, fallow land, waste land, etc. (Figs. 4 and 5).

Final result showing the changes in sodic land and various plantations in Raebareli district using two years LISS III satellite data of Rabi season (Fig. 6).

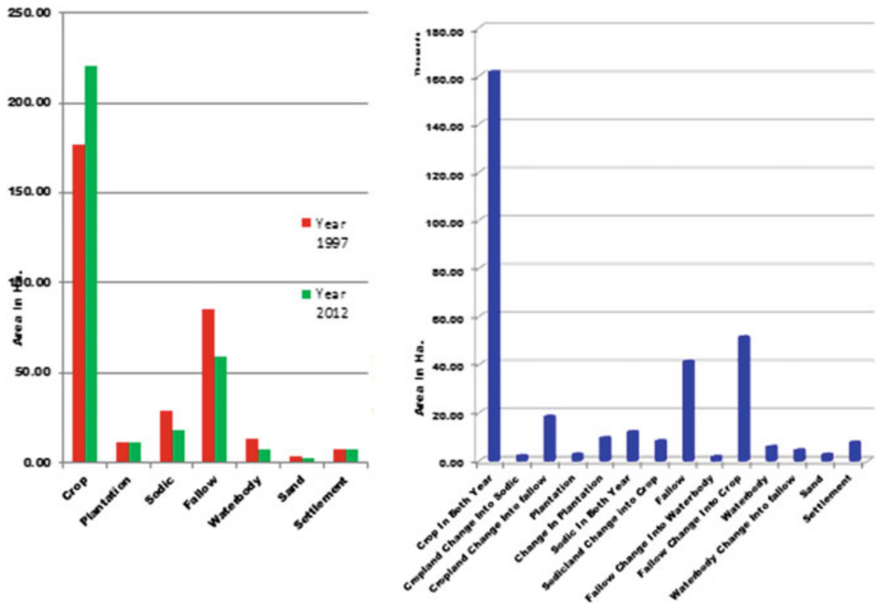
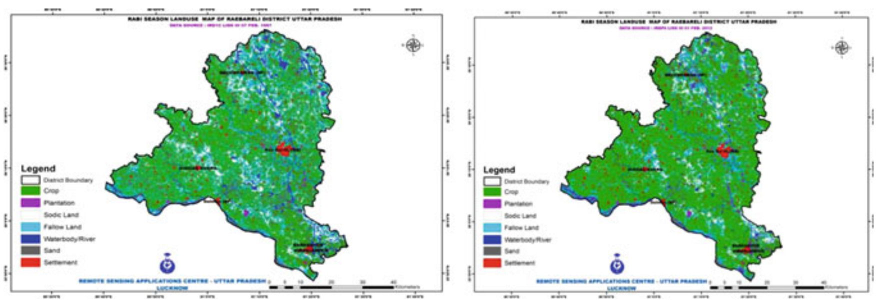


Fig. 4 Land use change distribution from year 1997, 2004 and 2009 respectively both using onscreen digitization and unsupervised classification method



Year 1997 Year 2012

Fig. 5 Land use map of Raebareli district of year 1997 and 2012

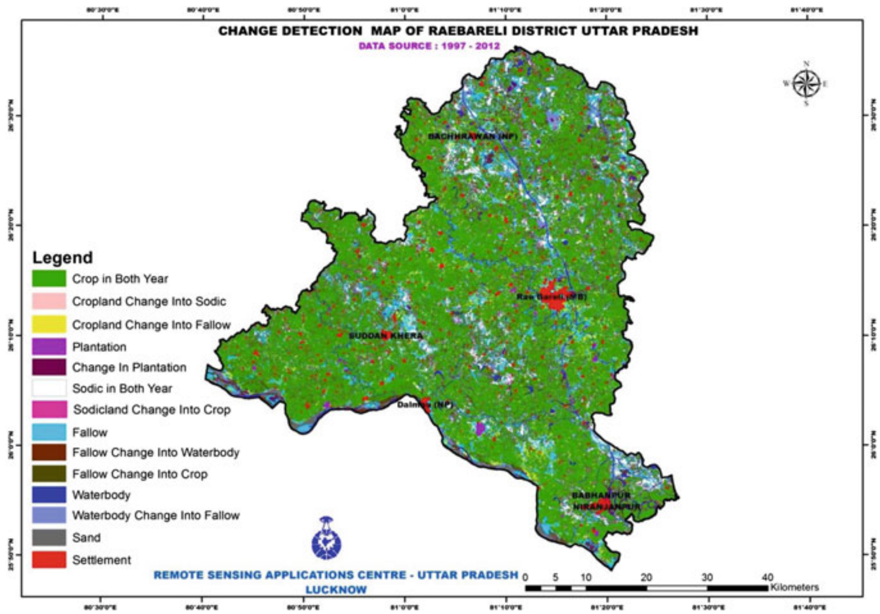


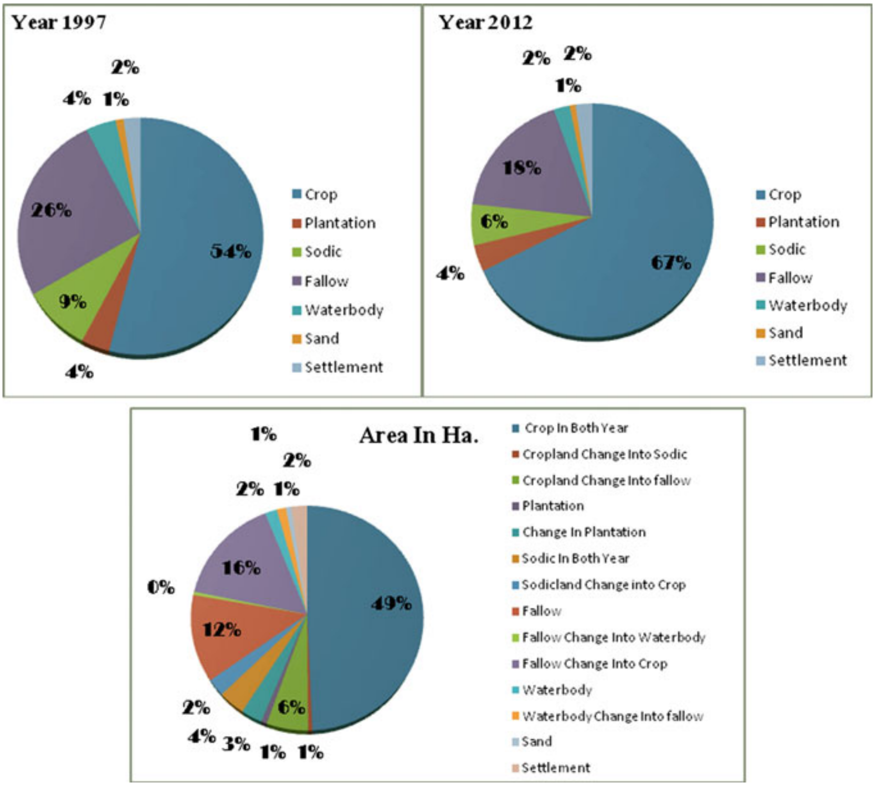
Fig. 6 Change detection map of sodic land from 1997 to 2012 year

Conclusion

In Raebareli district, sodic land covers 45286.19 ha area in 1997, which is 10.14% of the total geographical area of the district. At present the total area of sodic lands have been decreased by 12650.56 ha, which covers 32635.63 ha area in 2012, which is 7.31% of the total geographical area of the district. The major changes have taken place in wastelands, fallow land and sodic land areas, which have decreased over the years. However, the fallow lands have converted into cultivated lands, some wastelands have also converted into cultivated lands.

From this study it was concluded that remote sensing technique and GIS is an important tool to mapping and monitoring of sodic/wasteland. It is cost-effective and saves time as compared to other methods of survey/monitoring due to synoptic view and repetitivity of remote sensing satellites. This study is also helpful in evaluating the different soil reclamation projects running by government and private bodies. It is highly recommended to the government that they should include those areas for reclamation processes which are left due to some reasons and remain sodic till date. This study help us in many ways like identification of sodic land areas, calculate the available land resources for the purpose of policy and planning for proper land utilization in various sectors, i.e. infrastructure, development, etc. of Raebareli district.

This research also help for the site suitability of the environmental issues like waste land, sodic land, solid waste management, energy development site like solar power plant, thermal power plant, etc. As, the district boundary of the Raebareli attached to metropolitan city as well as capital of Uttar Pradesh, i.e. Lucknow “City of Nawabs”, its importance increased daily due to fast growing economy.



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Part V
Water Quality Modeling

Process Modelling of Gas–Liquid Stirred Tank with Neural Networks

Neha Phukon, Mrigakshee Sarmah and Bimlesh Kumar

Abstract Stirred tank reactors are widely used as the major processing unit in environmental and waste management engineering. It also finds its applicability in many chemical, pharmaceutical and petroleum industries. Due to the dynamic nature of the chemical reactions involved and the non-linear functional relationship between the input and output variables, it is difficult to correctly predict a universal empirical correlation for the process variables, i.e. mass transfer coefficient and gas hold-up rate. As such, intelligent modelling using neural networks was adopted in the present experimental work. Experiments were conducted with two types of impeller such as Rushton and curved blade to observe the mass transfer rate and gas hold-up characteristics. The Levenberg–Marquardt optimization algorithm was used to train the neural network so that the error between the desired output and actual output is reduced. The predictive capability of the model has been found satisfactorily and also independent of the impeller type.

Keywords Stirred tanks · Rushton impeller · Mass transfer rate · Gas hold-up

Introduction

A stirred tank reactor has a cylindrical or curved base along with a mixer such as a stirrer or propeller to facilitate the mixing of the reactor contents. When air is bubbled through the reactor it is called sparged stirred tank or a gas-liquid stirred tank (Gracia-Ocha and Gomez 1998). Air sparging is required for effective oxygen transfer in liquid volumes greater than 3 L.

A stirred tank as a chemical reactor is one of the most important unit operations in the chemical industry. It is used primarily in homogenous liquid phase flow reactions requiring constant agitation. A continuous stirred tank reactor is used in

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the pharmaceutical industry as a loop reactor. Stirred tank is also used as a bioreactor (Shewale and Pandit 2006) in which biochemical transformation of raw materials like microbial plant, animal or human cells are carried out to yield specific products, individual enzymes etc.

A bioreactor provides the optimal conditions like temperature, pH, substrate, salts, vitamins, oxygen etc. for achieving the desired product. Bioreactors are used for the manufacture of vaccines, production of proteins, organic acids and amino acids, antibiotics, etc. It is further used in the process of bioremediation in which living organisms, especially microorganisms are used to degrade environmental contaminants to less toxic forms. It has many industrial applications like waste water treatment, hydrogenation, dissolution, etc. (Fig. 1).

The process variables of a sparged stirred tank bioreactor, i.e. mass transfer coefficient and gas hold-up are closely related to each other. Mass transfer is the net movement of mass by processes such as absorption, evaporation, adsorption, precipitation, membrane filtration, distillation, etc. from one location to another. The oxygen mass transfer is a function of many variables. These include physical properties, concentration and composition of the liquid, geometrical and operational characteristics of the vessel, as well as the type of sparger used. The oxygen transfer

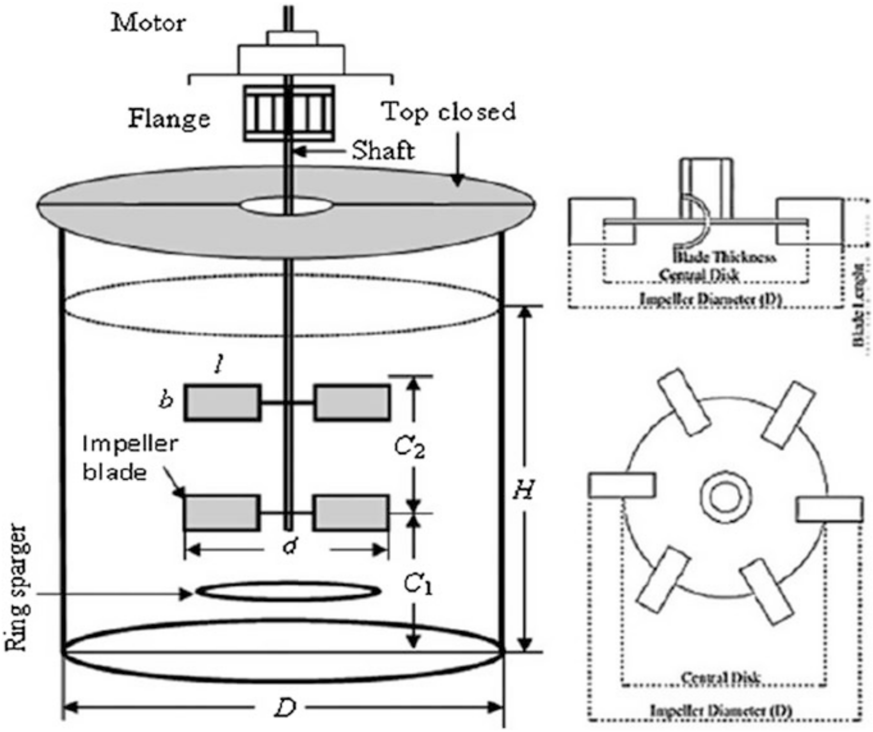

Fig. 1 Schematic diagram of an unbaffled sparged stirred tank

area is greatly increased when bubbles are introduced into the culture fluid by sparging. Bubbles are broken up by agitation which further increases the mass transfer coefficient. Gas hold-up is another important parameter and defined as the total volume of large or microscopic gas bubbles in the liquid at any instant during the gas-liquid contact process. Sometimes when gas hold-up is prolonged there is a tendency for all the gas bubbles to coalesce forming a very big bubble and giving the appearance of a static void within the broth. When the system is sparged with a particular gas, the broth around the impeller becomes less dense and hence requires less power than an ungassed system. Impellers play a very important role as they perform the task of solid suspension, mixing and dissolution of oxygen to liquid phase and maximizing the interfacial area between liquid and gaseous phases. The design and speed of the impeller, the velocity of the gas used and the physical properties of the liquid are the factors which influence the rate of gas hold-up in an impeller agitated reactor.

It is necessary to be able to correctly predict the mass transfer coefficient and gas hold-up rate in a sparged stirred tank in order to optimize its performance. However the empirical correlations predicted for these parameters take into account only the experimental conditions. Hence, these empirical formulae are valid only in its experimental range, which limits its applicability outside the range and in other engineering applications. Thus, recent advancement such as intelligent modelling has been adopted in the present work. Intelligent modelling is a discipline which merges mathematical approach and computer technology. It uses technologies such as neural network, automatic modelling and verification, computer calculating, simulation etc. It comprises of appropriate learning algorithms, which is useful in learning complicated relationships from a set of related input–output vectors.

Artificial neural network (ANN) is designed based on the biological equivalent of the human brain. The system consists of a large number of highly interconnected neurons which send messages to each other, working in parallel to solve a specific problem. Conventional computers follow a specific set of instructions which is given by the user in order to solve a problem. This is known as the algorithmic approach. As opposed to this, neural networks learn by example. As such, there is no need to devise an algorithm to understand the internal mechanisms of the task. A learning process configures an ANN for a specific application, such as pattern recognition and data classification. Hence the problem solving capability of neural networks is enhanced as they can analyse data and detect trends that are too complex to be noticed by either humans or other computer techniques. ANN has the following characteristics:

- Nonlinearity
- Ability to learn
- Input–output mapping
- Ability to adapt
- Fault tolerance.

Back-propagation (Irie and Miyanki 1988) is the most adaptable algorithm for the feed forward layered network. Neural networks can find any nonlinear relationships between input and output (Hornik et al. 1989) without having any knowledge of the system beforehand. In the back-propagation algorithm, the neural network computes the error derivative of the weights. The weights are adjusted so that the error between the desired output and the actual output is reduced.

One of the major drawbacks of back-propagation is that it is affected by local minima. Many modifications to back-propagation have been proposed and one of the significant modifications is given by Levenberg–Marquardt (Hagan and Menhaj 1994). This algorithm is based on the assumption that the underlying function which is modelled by the neural network is linear. Here the minimum is determined exactly in a single step. The calculated minimum is now tested. If the error is lower the weights are moved to a new point. This process of iteration is repeated for each generation.

Estimation of the volumetric oxygen transfer coefficient (k_La) from the gas balance and using a neural network technique was carried out by Cruz et al. (1999). The use of gas balance and dynamic methods to obtain an estimate of the volumetric oxygen transfer coefficient (k_La) in a conventional reactor is reported in this paper. This experiment is done during the growth phase of the microorganism *Cephalosporium acremonium.* The parameter measurements of the related variables were taken as the inputs. The training of the feed forward neural network was done with the calculated values of k_La. The gas balance method was comparatively less useful than the neural network technique which proves effective, predicting the values of k_La accurately from input data not used during the training phase. Estimation of oxygen mass transfer coefficient in stirred tank reactors using artificial neural networks was carried out by Garćia-Ochoa and Castro (2001). Volumetric mass transfer coefficient k_La was estimated in stirred tank reactors using ANN. The factors taken into account were the operational conditions, properties of fluids and geometrical parameters. Stirred tank reactors of different volumes were taken and the learning sets of input–output patterns were obtained. Neural network was combined with an empirical equation forming a hybrid model which provides a better representation of estimated parameter values. The predicted output by the hybrid ANN was compared with experimental data and some correlations previously proposed for tanks of different sizes. Model-based control of a yeast fermentation bioreactor using optimally designed artificial neural networks was carried out by Nagy (2006). In this paper the use of feedforward neural networks for dynamic modelling and temperature control of a continuous yeast fermentation bioreactor is described. The back-propagation learning algorithm was used to train different ANNs. A pruning algorithm was proposed to avoid overfitting of the data and achieve the best prediction ability with the simplest structure possible. The control performance of the structure was tested by testing the resulting ANNs.

Investigation of experiments in unbaffled gas-liquid stirred tank using Rushton and curved blade impellers has been used to explore the process modeling of the system through ANN. In the present work, data obtained from experimentation was fitted in the empirical correlations proposed by different researchers for calculation of mass transfer coefficient and gas hold-up rate. Alternatively, neural network was used to predict the values of the same. The overall performance of both the methods adopted was compared.

Experimentation

Two sizes of circular unbaffled tank of diameter (*D*) 200 and 150 mm was tested under laboratory conditions. Rushton and curved blade impellers were used in the experiment. The blade height (*b*), the blade length (*l*) and the disc thickness were set as *d*/5, *d*/4 and 0.035*d* respectively. The central disc diameter was 0.5*d*. The liquid depth (*H*) in the stirred tank was maintained equal to the tank diameter in all experiments. Water was taken as the working fluid with density, ρ_w, of 1000 kg/m^3. For maximum gas hold-up, a ring sparger of diameter 0.8d is required was observed by Rewatkar et al. (1993). Smaller number of holes and holes of smaller size gives a larger gas hold-up (Rewatkar et al. 1993). For supplying air, 0.8*d* with holes of 2 mm was used. Air was supplied to the ring sparger by a compressor fitted with a valve to control the supply. To measure the volumetric flow rate (1 and 5 L/min) a rotameter was fitted before the valve. In each experiment the location of the sparger was fixed at 0.09*d* from the bottom of the tank.

To measure the volumetric mass transfer rate, the standard dynamic method was used. For this, the liquid phase was flushed with nitrogen to deoxygenate. After replacement of nitrogen with air, measurement of the variation in dissolved oxygen concentration with time takes place until saturated. It was assumed that the liquid phase was well mixed and gas absorption is liquid phase controlled, the volumetric mass transfer coefficient at *T* °C was determined using the empirical formulae:

$$\mathrm{k_L a}_T = [\ln(C_s - C_0) - \ln(C_s - C_t)]/t \quad (1)$$

where, ln represents natural logarithm and the concentrations C_s, $C_{0,}$ and C_t are dissolved oxygen (DO) concentrations in parts per million (ppm), C_s = the saturation DO concentration at time tending to very large values, C_0 is at $t = 0$ and C_t is at time $t = t$.

Gas hold-up was measured by visual method. A graph paper with graduation was pasted on the outside of the vessel. The difference in level, with and without aeration was noted and the hold-up was found out using empirical formulae:

$$\varepsilon = (H - H_0)/H_0 \quad (2)$$

H_0 is the ungassed column height (m) and H is the column dispersion height due to the presence of gas bubbles (m).

The statistical data of the experiment are tabulated in Table 1.

Table 1 Experimental observations

S. No.	Variable	Mean	Maximum	Minimum
1	Fl	0.016098	0.082656	0.002218
2	*l*/*D*	0.25	0.25	0.25
3	*b*/*D*	0.2	0.2	0.2
4	*t*/*D*	0.035	0.035	0.035
5	*C*	0.55	0.85	0.25
6	*R*	39732.98	104969.3	7511.286
7	P_v	6.421859	18.30709	0.979772

Fl is the flow number, *R* is the Reynolds number and P_v is power per unit volume

where Fl is the flow number, *R* is the Reynolds number and P_v is power per unit volume.

Methodology

The critical step in building a robust ANN is to create an architecture, which should be as simple as possible and has a fast capacity for learning the data set. The robustness of the ANN will be the result of the complex interactions between its topology and the learning scheme. The choice of the input variables is the key to insure complete description of the systems, whereas the qualities as well as the number of the training observations (experimental data) have a tremendous impact on both the reliability and performance of ANN (Bose and Liang 1996).

The Transfer function used in the neural network is bipolar sigmoid. The idea behind choosing bipolar sigmoid functions as transfer functions is that it bears a greater resemblance to the biological neurons (Pignon et al. 1996). Entire modelling and analysis has been done by the use of neural network toolbox of MATLAB® software. The aim of the analysis is to get a good correlation between predicted by neural network *K* and experimental *K*. The criteria set during neural modelling can be summarized as follows.

- $R \geq 0.9$
- Least numbers of neurons in the hidden layer.

In order to determine the optimum number of hidden nodes, a series of topologies was used, in which the number of nodes in hidden layer was varied from 5 to 20. Each topology was repeated three times to avoid random correlation due to the random initialization of the weights. Back-propagation searches on the error surface by means of the gradient descent technique in order to minimize the error. It is very likely to get stuck in local minima. Various other modifications to back-propagation to overcome this aspect of back-propagation have been proposed and the Levenberg–Marquardt modification (Hagan and Menhaj 1994) has been found to be a very efficient algorithm in comparison with the others like Conjugate gradient algorithm or variable learning rate algorithm. Levenberg–Marquardt works by making the assumption that the underlying function being modelled by the neural network is linear. Based on this calculation, the minimum can be determined exactly in a single step. The calculated minimum is tested, and if the error there is lower, the algorithm moves the weights to the new point. This process is repeated iteratively on each generation. Since the linear assumption is ill-founded, it can easily lead Levenberg–Marquardt to test a point that is inferior (perhaps even wildly inferior) to the current one. The clever aspect of Levenberg–Marquardt is that the determination of the new point is actually a compromise between a step in the direction of steepest descent and the above-mentioned leap. Successful steps are accepted and lead to a strengthening of the linearity assumption (which is approximately true near to a minimum). Unsuccessful steps are rejected and lead to a more cautious downhill step. Thus, Levenberg–Marquardt continuously switches its approach and can make very rapid progress. The Levenberg–Marquardt algorithm performs very well and its efficiency is found to be of several orders above the conventional back-propagation with learning rate and momentum factor.

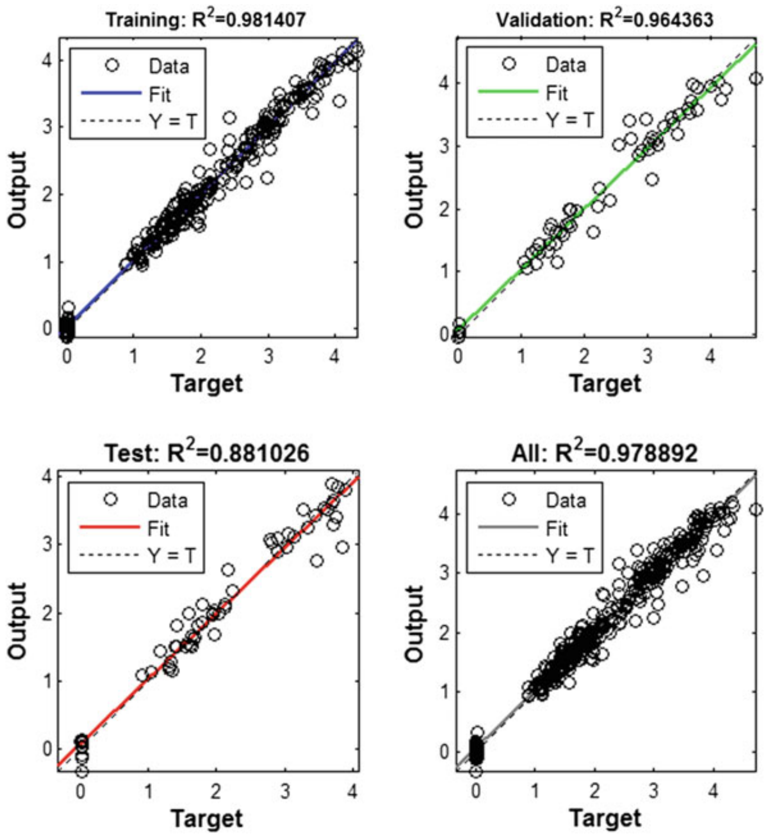

Fig. 2 Results of ANN model for mass transfer

Results and Discussions

All the experimental data points collected were used to build and validate the ANN correlations. In the training algorithm of the back-propagation neural networks, the mean squared error (MSE) was minimized for each epoch, i.e. iteration. The number of epochs was set 10,000, and a termination rule was maintained as MSE of 0.0001 or maximum epoch. Weights are updated though batch learning. The performance of the modelling has been given in the Figs. 2 and 3 for mass transfer and gas hold-up, respectively.

It can be clearly seen from Figs. 2 and 3 that the linear coefficient of correlation is very high between observed experimental data and values predicted through neural nets. This shows the learning and generalization performance of the network is good. Present experimental observations have been tested with the empirical equations available in the literature as given in Table 2. Thus it can be said that aeration phenomena can be modelled through neural networks. Therefore, instead

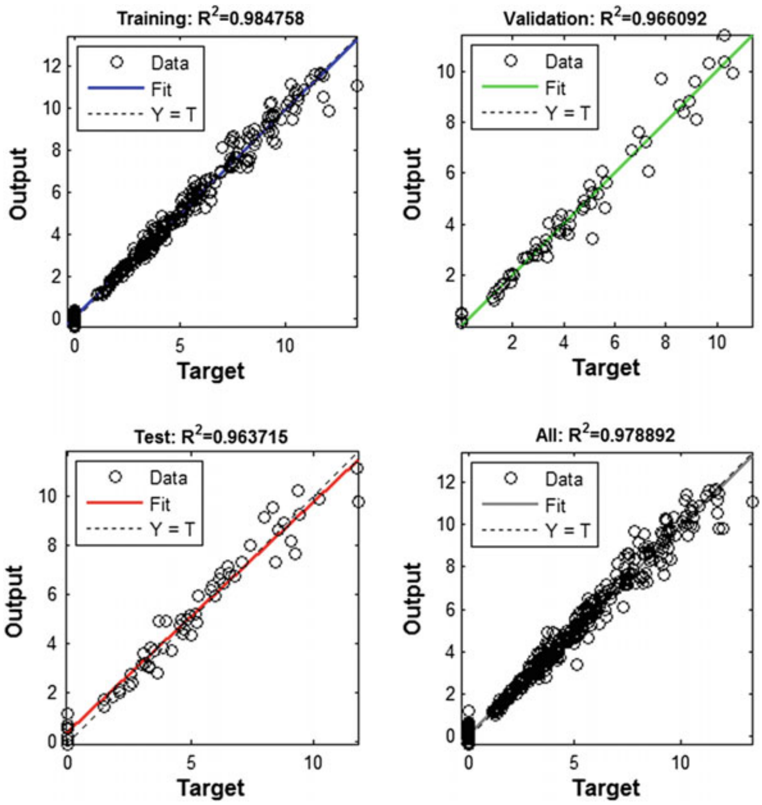

Fig. 3 Results of ANN model for gas hold-up

Table 2 (a) Empirical correlation for mass transfer. (b) Empirical correlation for gas hold-up

S. No.	Researchers	Correlation	Range
(a)			
1	Linek et al. (1987)	$K_La_T = 4.95 \times 10^{-3} (P_g/V)^{0.593} (v_g)^{0.4}$	Single disc turbine, $D = 0.29$ m, $N = 4.17$–14.17 rps, $v_g = 2.12$–4.24 mm/s
2	Nocenti et al. (1993)	$K_La_T = 0.015 (P_g/V)^{0.59} (v_g)^{0.55}$	Single Rushton, $D = 0.232$ m, $Q_g = 0.1$–0.7 vvm, $d/D = 1/3$, $R_e > 1000$
3	Moucha et al. (1995)	$K_La_T = 0.0177 (P_g/V)^{0.58} (v_g)^{0.588}$	Four Rushton, $D = 0.19$ m, $d = D/3$, $v_g = 2.12$–8.48 mm/s, $N = 5.5$–18.8 rps
4	Arjunwadkar et al. (1998)	$K_La_T = 0.00204 (P_g/V)^{0.68} (v_g)^{0.58}$	One Disc turbine and one pitched-blade down flow, $D = 0.18$ m, $v_g = 0.98$–3.3 mm/s, $N = 6.6$–12.5 rps
5	Smith (1991)	$K_La_T = 1.25 \times 10^{-4} (d/D)^{2.8} (Fr)^{0.6} (Re)^{0.7} (\mathrm{Fl})^{0.45} (d/g)^{-0.5}$	Single Rushton, $D = 0.6$ m
(b)			
1	Zhengming et al. (1996)	$\varepsilon_G = 0.195 (P_g/V)^{0.28} (v_g)^{0.56} (D)^{0.45}$	Baffled, single Rushton, $D = 0.287$, 0.495 and 1.1 m, $H = D$, $d = D/3$, $v_g = 0.003$–0.0344 m/s, $P_g/V = 0.15$–5.2×10^3 W/m^3
2	Moucha et al. (2003)	$\varepsilon_G = 0.01686 (P_g/V)^{0.6241} (v_g)^{0.5669}$	Baffled Rushton, $D = 0.29$ m, $d = D/3$, $C = C_1 = d$, $C_2 = D$, $v_g = 2.12$, 4.24 and 8.48 mm/s, $N = 4.17$–14.17 rps
3	Fadavi and Chisti (2007)	$\varepsilon_G = 2.47 (v_g)^{0.97}$	$D = 0.148$ m, $V = 0.01625$ m^3, $v_g \leq 0.04$ m/s

Table 3 Performace comparison

S. No.	Using empirical formulae	R^2	
		Mass transfer	Gas hold-up
1	Linek et al. (1987)	0.1775	
2	Nocenti et al. (1993)	−1.206	
3	Moucha et al. (1995)	−1.156	
4	Arjunwadkar et al. (1998)	−0.97	
5	Smith (1991)	−1.596	
6	Zhengming et al.(1996)		−4.308
7	Moucha et al.(2003)		−1.073
8	Fadavi and Chisti (2007)		−0.561
	Using neural network		
1	Training	0.981407	0.984758
2	Validation	0.964363	0.966092
3	Testing	0.881026	0.963715
4	All	0.976361	0.978892

of proposing a compact correlation for modelling the re-aeration rates, a neural net with weights can be supplied for the modelling.

These correlations have been tested on the basis of R^2, which are tabulated in Table 3.

Thus it can be said that stirred tank process dynamics can be modelled through neural networks. Therefore instead of proposing a compact correlation for modelling the system, a neural net with weights can be supplied for the modelling.

Conclusion

Values obtained from regression analysis from empirical correlations proposed in previous studies indicate variation in regression coefficient value. It reveals that direct relation is not possible between theoretical and experimental values of the process variables. However, it has been observed that these correlations are valid only in their experimental range and cannot be used outside that range. It can be concluded that a universal correlation is not present to predict the values of mass transfer coefficient and gas hold-up. The ANN method has been used to predict the values of mass transfer coefficient and gas hold-up. It has the ability to develop a relation between complex variables and consequently detect better trends. On application of this method, it has been observed that the value of regression coefficient is nearly equal to one. It reveals that learning and generalization performance of ANN is better as compared with previous studies.

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Identification and Planning of Water Quality Monitoring Network in Context of Integrated Water Resource Management (IWRM)

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Abstract Hydrological system is a quite complex and dynamic in nature because of the heterogeneity of the earth crust and surrounding atmosphere. Water exists on the earth in all three forms of liquid, solid and gas. The scarcity of its liquid freshwater has resulted because of increasing demand in response to growing population, contamination and pollution of freshwater bodies due to urbanization and industrialization. Precise measurement of water quality, in present time, has become the necessity because of increasing scarcity of this precious resource. In a global perspective, organizations dealing with water supply and monitoring are ever concerned about precise assessment of water quality. Researchers are focusing on the assessment of surface and ground water quality on spatial scale rather than point scale, which needs strengthening of monitoring networks time-to-time. The design of a hydrometric network starts ideally with a minimum number of stations, and increases gradually until an optimum network is attained when the amount and quality of data collected and information processed is economically justifiable and it meets the user's needs to make specific decisions. In hydrology, monitoring of data is mostly site-specific and proper representation of this data on spatial scale requires proper network planning. Since the drivers of water quality vary in space and time, the quality of water also varies in space and time. It is therefore imperative to monitor the quality of water under heterogeneous space-dependent conditions for which a specialized water quality monitoring network is essential. The present paper is in the context of identifying and planning of water quality monitoring network for data acquisition for Integrated Water Resources Management (IWRM).

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Introduction

The monitoring of hydrologic system is known from the ancient times, whereas the first description of the rain gauge and its use is contained in the Arthashastra by Chanakya (300 BC). Varahamihira's (AD 505–587) Brihatsamhita contains descriptions of the rain gauge, wind vane and prediction procedures for rainfall. Egyptians knew the importance of the stage measurement of rivers and records of the stages of the Nile dating back to 1800 BC have been located. The knowledge of the hydrologic cycle came to be known to Europe much later, around AD 1500 (Subramanya 2010).

In recent times, the issues related to the optimal design of water quality monitoring networks and efficiency improvements have been the subject of research since 1970s (Ning and Chang 2002) and the basic principles of monitoring network design and site selection criteria for individual monitoring stations have been evaluated and applied by many researchers (Skalski and Mackenzie 1982; Lettenmaier et al. 1986; Smith and McBride 1990). Later studies have focused greater attention on the effective design of water quality monitoring networks using various types of statistical and/or programming techniques, such as integer programming, multi-objective programming, Kriging theory and optimization analysis (Hudak et al. 1995; Dixon and Chiswell 1996; Timmerman et al. 1997).

In India, various water monitoring and water supply organizations and institutions are more concerned to monitor the water resources more accurately and on wider geographic region, and thus strengthening their monitoring network from time-to-time. Such agencies and researchers are monitoring precipitation (in the form of rainfall and snow), stream flow (CPCB 2009; Sargaonkar and Deshpande 2003; Samantray et al. 2009; Jindal and Sharma 2011), groundwater (Krishan et al. 2013, 2014, 2015, 2016a; Lapworth et al. 2015; MacDonald et al. 2015), lakes and reservoirs, as well as water quality of various water bodies (Krishan et al. 2016b; Rao et al. 2016).

The design of a hydrometric network starts ideally with a minimum number of stations and increases gradually until an optimum network is attained when the amount and quality of data collected and information processed is economically justifiable and it meets the user's needs to make specific decisions. Network planning is the backbone of any monitoring system. In hydrology, monitoring of data is mostly site-specific and proper representation of this data on spatial scale requires proper network planning. The present paper is in the context of identifying and planning of water quality monitoring network for data acquisition for Integrated Water Resources Management (IWRM).

Water Quality Monitoring Network

Water sample collection network is quite general in nature which may include a network for collection of wide variety of samples. The samples collected under this network may be used for various hydrological analysis, viz. water quality, isotopic analysis, sedimentation, etc.

There are several approaches to water quality monitoring. Monitoring can be done through a network of strategically located long-term stations, by repeated short-term surveys, or a combination of these two. In addition to the basic objectives of the water quality monitoring programme, the location of stations should take into account the following factors:

- Existing water problems and conditions;
- Potential growth centres (industrial and municipal);
- Population trends;
- Climate, geography and geology;
- Accessibility:
- Available manpower, funding, field and laboratory data handling facilities;
- Inter-jurisdictional considerations;
- Travel time to the laboratory (for deteriorating samples); and
- Safety of personnel.

Water Quality Parameters

The parameters that characterize water quality may be classified in several ways, including physical properties (e.g. temperature, electrical conductivity, colour, turbidity), inorganic chemical components (e.g. dissolved oxygen, chloride, alkalinity, fluoride, phosphorous, metals), organic chemicals (e.g. phenols, chlorinated hydrocarbons, polycyclic aromatic hydrocarbons and pesticides), and biological components, both microbiological, such as faecal coliforms, and macrobiotic, such as worms, plankton and fish, which can indicate the ecological health of the aquatic environment (WMO 1994).

A second classification is done according to the importance attached to the parameter. This will vary with the type of water body, the intended use of the water and the objectives of the monitoring programme. Water quality variables are sometimes grouped within following two categories:

(a) Basic variables (given in Table 1).
(b) Use-related variables:

  - Drinking water supplies
  - Irrigation, and
  - General quality of aquatic life.

Table 1 Water quality basic variables

S. No.	Parameters	River	Lake and reservoir	Groundwater
A	*General water quality*			
1	Water level/discharge	X	X	X
2	Total suspended solids	X	–	–
3	Temperature	X	X	X
4	pH	X	X	X
5	Electrical conductivity	X	X	X
6	Dissolved oxygen	X	X	X
7	Transparency	–	X	–
B	*Dissolved salts*			
8	Calcium	X	X	X
9	Magnesium	X	X	X
10	Sodium	X	X	X
11	Potassium	X	X	X
12	Chloride	X	X	X
13	Fluoride	–	–	X
14	Sulphate	X	X	X
15	Alkalinity	X	X	X
C	*Nutrients*			
16	Nitrate plus Nitrate	X	X	X
17	Ammonia	X	X	X
18	Total phosphorous, dissolved	X	X	–
19	Total phosphorous, particulate	X	X	X
20	Total phosphorous, unfiltered	X	X	–
21	Silica reactive	X	X	–
D	*Organic matter*			
22	Chlorophyll *a*	X	X	–

Note ‘X’ = Required; ‘–’ = not required

USDA (2007) has suggested the following general groups of indicators for groundwater quality monitoring programmes:

1. Field measurements (temperature, specific conductance, pH, Eh (redox potential), dissolved oxygen, alkalinity, and depth to water).
2. Major inorganic ions and dissolved nutrients (total dissolved solids (TDS), Cl^-, NO_3^-, SO_4^-, PO_4^-, SiO_2, Na^+, K^+, Ca^{++}, Mg^{++}, NH_4^+).
3. Total organic carbon (TOC).
4. Pesticides (AlphaBHC, betaBHC, gammaBHC, Chloropyriphos, Acetanilide, Triazine, Phthalate, Dinitrophenol, Carbamate, Halocarbon, etc.).
5. Volatile organic carbon (VOC).
6. Metals and trace elements (Fe, Mn, Zn, Cd, Pb, Cu, Cr, Ni, Ag, Hg, As, Sb, Se, Be, B).

7. Bacteria (Coliform bacteria, *E. coli*, Entrococci, etc.).
8. Radionuclides (Radium Radon, Uranium).
9. Environmental isotopes (H, O, N, C, S).

Techniques for Water Quality Monitoring Network Design

Following factors need to be considered for planning of the water quality monitoring network:

1. Monitoring of bedrock and superficial aquifers
2. Depending on hydrological structures
3. Based on water use and site condition
4. Based on mixing of water
5. Based on specific yield
6. Based on flow capacity of river
7. Based on water surface area of lake and reservoir
8. Parallel to coastline
9. Based on land use
10. Based on areal extent

Monitoring of Bedrock and Superficial Aquifers

The proposed network must reflect the diverse hydrogeological, soil and land-use conditions. Therefore, both bedrock and superficial aquifers should be monitored in a variety of soil conditions. The network should continue to include different types of sources, although less emphasis should be given to wells, which are generally poor monitoring points. The nature of water quality in these two types of aquifers generally differs significantly, and hence water quality monitoring is essential.

Depending on Hydrological Structures

The number of sampling points on a river depends on the hydrology and the water uses. The greater the water quality fluctuation, the greater the frequency of measurement required. In humid regions, where concentrations of dissolved matter are low, fewer observations are needed than in dry climates, where concentrations, particularly of critical ions such as sodium, may be high. At many locations, the water quality sampling stations may be coupled to the stream gauging stations and structures such as barrage, dams, etc. Similarly, the gauging sites of the spring flow may also be used for the water sampling purpose.

Based on Water Use and Site Condition

For establishing water sampling stations on water use and site conditions, the areas need to be sampled to assess the extent and severity of contamination on the basis of sources such as anthropogenic or geologic water quality pollution or contamination due to particular rock formations. If any water supply scheme or any waste water disposal site exists there, then such sites need to be critically mapped.

Based on Mixing of Water

On rivers, the sampling stations should be established at places where the waste water is sufficiently well mixed with it. Since the lateral and vertical mixing of a wastewater effluent or a tributary stream with the main river can be rather slow, particularly if the flow in the river is laminar and the waters are at different temperatures and complete mixing of tributary and main stream waters may not take place for a considerable distance, sometimes many kilometres, downstream of the confluence, therefore, the zone of complete mixing may be estimated from the values shown in Table 2 (UNEP/WHO 1996). In the case of doubt, the extent of mixing should be checked by measurements of temperature or some other characteristic variables at several points across the width of the river (Krishan et al. 2016b). If there

Table 2 Estimated distance of complete mixing in streams and rivers

Average river width (m)	Mean depth of river (m)	Estimated distance for complete mixing (km)
5	1	0.08–0.7
	2	0.05–0.3
	3	0.03–0.2
10	1	0.3–2.7
	2	0.2–1.4
	3	0.1–0.9
	4	0.08–0.7
	5	0.07–0.5
20	1	1.3–11.0
	3	0.4–4.0
	5	0.3–2.0
	7	0.2–1.5
50	1	8.0–70.0
	3	3.0–20.0
	5	2.0–14.0
	10	0.8–7.0
	20	0.4–3.0

are rapids or waterfalls in the river, the mixing will be speeded up and representative samples may be obtained downstream. Sampling for the determination of dissolved oxygen, however, should take place upstream of the rapids or waterfall because the turbulence will cause the water to be saturated with oxygen. In such a case, several samples should be taken across the width of the river to allow for the possibility of incomplete mixing.

A bridge is an excellent place to establish a sampling station (provided that it is located at a sampling site on the river). It is easily accessible and clearly identifiable location. Furthermore, a bridge is often a hydrological gauging station and, if so, one of the bridge piers will have a depth gauge marked on it, thus allowing the collection of stream flow information at the time of sampling. Usually, a sample taken from a bridge at mid-stream or in mid-channel, in a well-mixed river, will adequately represent all of the water in the river.

To verify that there is complete mixing at a sampling station it is necessary to take several samples at points across the width and depth of the river and to analyse them. If the results do not vary significantly one from the other, a station can be established at mid-stream or some other convenient points. If the results are significantly different it will be necessary to obtain a composite sample by combining samples taken at several points in the cross section of the stream. Generally, the more the points that are sampled, the more representative the composite sample will be. Sampling at 3–5 points is usually sufficient and fewer points are needed for narrow and shallow streams. Suggestions are provided in Table 3 for the number of points from where samples should be obtained in streams or rivers of different sizes and with different flow rates.

Based on Specific Need

Water quality sampling stations may also be required to be fixed based on the need. Such needs may arise due to any or some of the reasons mentioned below:

1. Occurrence of health problems in a particular area.
2. Drinking water supply scheme.
3. Research needs.
4. Waste water disposal in a stream.
5. Just before an international boundary, if the river is draining outside the country.
6. Just after an international boundary, if the river is entering into the country.
7. Just before or after the inter-state boundary, if the river is draining in more than one state.
8. Above the points of withdrawal for irrigation, or domestic, or industrial purpose under a major scheme.
9. Outlets of lakes and reservoirs.

Based on Flow Capacity of River

Lakes and reservoirs can be subjected to several influences that cause water quality to vary from place to place and from time-to-time. It is, therefore, prudent to conduct preliminary investigations to ensure that sampling stations are truly representative of the water body. Where feeder streams or effluents enter lakes or reservoirs, there may be local areas where the incoming water is concentrated, because it has not yet mixed with the main water body. Isolated bays and narrow inlets of lakes are frequently poorly mixed and may contain water of a different quality with the rest of the lake. Wind action and the shape of a lake may lead to a lack of homogeneity; for example, when wind along a long, narrow lake causes a concentration of algae at one end. Table 3 suggests the sampling regimes for composite samples in the flowing water.

In India, a vast river quality monitoring data has been accumulated over the years but it has not been properly utilized for reasons of limited ability to communicate the data to the common man. Some researchers have tried to use the river water quality indices with limited success (Sargaonkar and Deshpande 2003; Samantray et al. 2009; Jindal and Sharma 2011).

Based on Water Surface Area of Lake and Reservoir

A number of sampling locations vary with the size and depth of any water body. If the water surface area of lake or reservoir is large enough, multiple sampling locations are necessary. To allow for the size of a lake (UNEP/WHO 1996) has suggested that the number of sampling stations should be the nearest whole number to the log10 of the area of the lake in km^2. Thus, a lake of 10 km^2 requires one sampling station, 100 km^2 requires two stations, and so on. For lakes with irregular boundaries, it is advisable to conduct preliminary investigations to determine whether and where differences in water quality occur before deciding on the number of stations to establish.

The most important feature of water in lakes and reservoirs, especially in temperate zones, is vertical stratification, which results in differences in water quality at different depths (UNEP/WHO 1996). Stratification at a sampling station can be detected by taking a temperature reading at 1 m below the surface and another at

Table 3 Suggested sampling regimes for composite samples in flowing water (UNEP/WHO 1996)

Average river discharge (m^3/s)	Type of stream/river	Number of sampling points	Number of sampling depths
<5	Small stream	2	1
5–140	Stream	4	2
150–1000	River	6	3
$\geq$ 1000	Large river	$\geq$ 6	4

1 m above the bottom. If there is a significant difference (e.g. >3 °C) between the surface and the bottom readings, there is a "thermocline" (a layer where the temperature changes rapidly with depth) and the lake or reservoir is stratified and it is likely that there will be important differences in some water quality variables above and below the thermocline. Consequently, in stratified lakes, more than one sample is necessary to describe the water quality. For lakes or reservoirs of ≥ 10 m depth it is essential, therefore, that the position of the thermocline is first investigated by means of regularly spaced temperature readings through the water column (e.g. metre intervals). Samples for water quality analysis should then be taken according to the position and extent (in depth) of the thermocline. As a general guide, the minimum samples should consist of

- m below the water surface,
- just above the determined depth of the thermocline,
- just below the determined depth of the thermocline, and
- m above the bottom sediment (or closer if this can be achieved without disturbing the sediment).

If the thermocline extends through several metres depth, additional samples are necessary from within the thermocline in order to characterize fully the water quality variations with depth. Whilst the position of the thermocline is stable, the water quality for a given station may be monitored by fewer samples but, in practice, the position of a thermocline can vary in the short- (hours) or long-term (days) due to internal seiches (periodic oscillations of water mass) and mixing effects. In general, in tropical climates where the water depth at the sampling site is <10 m, the minimum sampling should consist of a sample taken 1 m below the water surface and another sample taken at 1 m above the bottom sediment.

Parallel to Coastline

Sea water intrusion is the most common problem in the coastal aquifers. Without salinity monitoring of groundwater in the coastal aquifers, it is not impossible to decide on the sea water intrusion. It is thus imperative to have a good network of observation wells in the coastal aquifers particularly parallel to the coastline. The groundwater table is very shallow near the coast and goes down below the land surface on moving away from the coast. For monitoring the dynamics of saline and fresh water interface, at least 03 observation wells should be placed perpendicular to the coastline at regular intervals, either fixed or depending on rock formations susceptible to the sea water ingress, withdrawal patterns in the aquifers, etc. The 03 observation wells shall be placed at 2, 4 and 6 km away from the coastline for the salinity monitoring.

Table 4 Recommended minimum density of water quality stations (WMO 1994)

S. No.	Physiographic unit	Minimum density per station (km^2/station)
1	Coastal	55,000
2	Mountainous	20,000
3	Interior plains	37,500
4	Hilly/Undulating areas	47,500
5	Small islands	6,000
6	Polar/Arid regions	200,000

Based on Land Use

The effluents from the domestic, industrial and agricultural activities pose large influence on the surface and groundwater resources in the surrounding areas. Many times, land use has a large influence on the nitrate concentrations in arable areas, cultivation of both arable and grassland, and areas where dairy, pigs and poultry contribute to the highest nitrate concentrations. Thus, proper monitoring network is required under such nitrate pressured areas. Thus one sampling site should be located in each land-use class which is representative of that class for the region.

Similar kinds of monitoring networks are also required to other industrial areas where the industrial effluents may affect the water resources depending on the nature of the industries.

Based on Areal Extent

For small streams, a sampling procedure becomes necessary as it is impracticable to establish gauging stations on all of them. The discharge of small rivers is strongly influenced by local factors. In highly developed regions, where even the smallest watercourses are economically important, network deficiencies are keenly felt even on streams draining areas as small as 10 km^2. WMO (1994) has recommended the minimum density of water quality stations as given in Table 4.

Conclusions

Quantity and quality of surface and groundwater vary from place to place depending on several morphological and hydrogeological factors. The quality of water may further be subjected to various anthropogenic activities and transport of pollutants varies both in space and time. Proper monitoring of such phenomena requires well-organized and optimized monitoring network that is the true representation of the water quality of that region. Therefore, proper monitoring network must be dependent on spatial hydrogeological factors with due diligence to the anthropogenic sources including the intended use of the monitoring network. Thus a well-planned water quality monitoring network for Integrated Water Resources Management (IWRM) can be achieved (i) if goals are clear, defined and well developed; (ii) the hydrogeology and geology of the aquifer formation is well understood and taken into consideration; (iii) the budgetary constraints are looked into; and (iv) some statistical techniques for optimization of network. Various techniques for planning and identification of the monitoring points and water quality parameters to be included are presented and discussed in the paper.

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An Updated Review on Quantitative and Qualitative Analysis of Water Pollution in West Flowing Tapi River of Gujarat, India

Shreya Gaur

Abstract A river plays an important role in development of any society or even the country, being the solitary source of water supply to meet our domestic, industrial, agricultural, aquatic and even the power generation needs. It is agonizing to see that some of the rivers used to pass through big cities, and their huge water resources are utilized for disposal of domestic and industrial wastes too, which ultimately leads to multifarious pollution hazards towards land, water, vegetation and nearby living society. Tapi is one of the three major rivers in central India which flows from east to west with a length of 724 km, encompassing the contributing catchment to the tune of about 30,000 km^2. It passes through Surat, a mega city of Gujarat, compromising with multiple land use complexes. Historical importance as well as peculiar characteristics of this river and its water body are reviewed and presented to show the updated status in regards to degree and extent of contamination. Write-up presents an updated review on status of prevailing water quality, encircling indicators like heavy metals (Fe, Cu, Zn, Pb, As, Hg, Ni, Cd, etc.), suspended sediments, bed loads and other pollutant with their causes and effects. Efforts are made to critically review some of the updated status and estimates in regards to overexploitation of water and river reaches, riverbank erosion, channel geomorphologic constituents, sedimentation (erosion, transport and deposition) and their varied patterns with ever increasing human and natural interferences. Influences of ritual functions like dipping of Lord Ganesha Idol and other associated activities are also visited, revealing that these manmade causes contributed significant deteriorations in river water quality, in particular the physiochemical parameters (pH, Temperature, Dissolved Oxygen, free CO_2, Hardness, Alkalinity, BOD, COD, etc.). The available field data and findings of previous researchers are critically viewed and analysed providing a better understanding on quantitative variability of annual runoff, sedimentation patterns, flood inundations and flood-based threats in and

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around study river. Critical limits in regards to above cited indicators (quantitative, qualitative) are offered, to provide a better understanding of river water management meeting the prevailing demands in sustainable manner.

Introduction

Rivers play an important role in the life of the people because these are mostly used as a source of water for drinking, bathing, irrigation, recreation and other miscellaneous purposes. Accordingly, it governs the overall development of the country and people as well. River water happens to be the only important surface water source which obtains its input from rains. The history of ancient civilization and industrial growth in India very well depicts the factual scenarios, that how this imperative volume of surface water gets uncertain both in quantity as well as quality. At one hand, it is highly influenced by drastic changes in climate and rainfall patterns, while on other hand it is severely prejudiced in its qualitative aspects. The even changing pattern of rainfall, both with respect to location as well as time, have made river water discharges very much uncertain. Some times at some locations there are floods while other time there exits droughts leading to declined volumes of water in rivers. If we consider the changing scenarios in respect of quality of river water, it is emerging as another burning issue for people and society. The ever-changing land use patterns, industrial and agricultural interventions have contributed a lot to degrade the quantity as well as quality of river water. It includes many processes as well as versions like, pesticides and fertilizers in agricultural runoff water, human and animal wastes in sewage, industrial pollutants/waste and many other point source or non-point source pollutants. This altogether is releasing many adverse impacts on human life, including deficit water availability, water borne diseases, overall deterioration in soil and water, complex scenarios of floods and droughts, and many such adverse effects which directly or indirectly influence living and nonliving settings situated in and around the rivers. The deteriorated quantity and quality of water in these rivers is having close correlation with prevailing state of social, economical and technological problems at micro and macro scales.

Indian River System

In India, rivers are classified mainly of two types based on their geographical locations and origin viz. Himalayan rivers and Peninsular rivers. The Himalayan rivers are glacier fed and perennial, while peninsular rivers remained altogether monsoon fed. A broad sketch of major Indian rivers with their basins is shown in Fig. 1. Among peninsular rivers, majority of them are east coast rivers (e.g. Mahanadi, Krishna, Godavari and Cauvery) and empty their water in Bay of

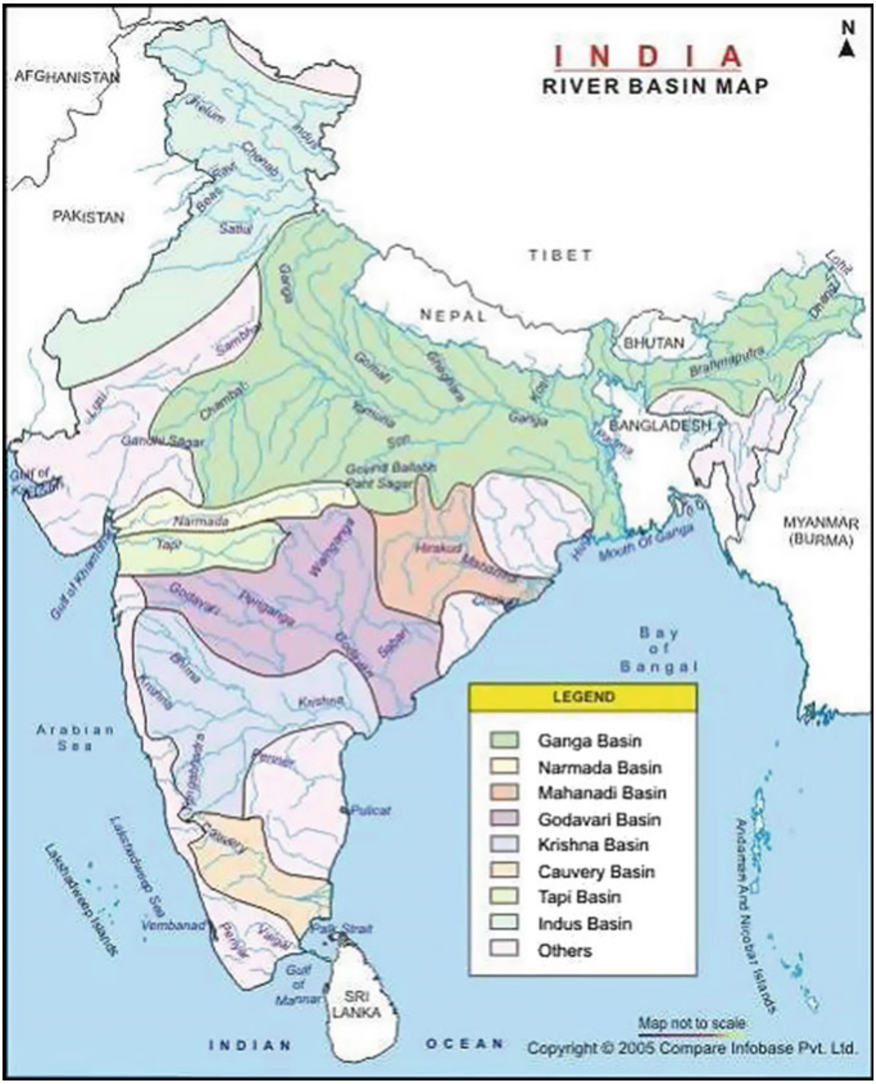

Fig. 1 Relative location of west flowing Tapi river under major river basins of India

Bengal; while a few others, i.e. west coast rivers (e.g. Narmada, Tapi, Sabarmati and Luni) are west flowing and drain out in Arabian sea. All the peninsular rivers are entirely dependent on monsoonal rhythm and display from very poor water flow to heavy flood and accordingly exhibit the fluctuating ecological and biological conditions.

Above rivers are indeed the life line of country, but during prevailing conditions are suffering from enormous number of pollution, which is being caused by below given two reasons,

- Untreated urban sewage, industrial effluents, agricultural runoff, mining wastes, religious ceremonies and navigational operations.
- Indiscriminate destruction of drainage basin because of clearing of riparian zone vegetation which, in turn, is responsible for elevated load of suspended solid and increased magnitude and frequency of flood changing the level of interaction between land and water; and hence affects all inputs of energy source.

Among these rivers, three are exceptionally explicit (Mahi, Narmada, Tapi) which flows from east to west and directly drain into sea. All these passes through Gujarat state of India, which happens to be most the industrialist and developed state in the country, encompassing an area of approximately 196,000 km^2 and is enclosed within the North Latitude 20° 10′ to 24° 50′ and East Longitude 68° 40′ to 74° 40′. Obviously, the course of these rivers remains via many urban settings as well as cities. Present paper incorporates one of these rivers namely 'Tapi' which is the most peculiar and passes through Surat—the Diamond city of Country, famous for world class industries on diamonds, textiles, and chemicals. Paper presents an updated review towards prevailing scenario of Tapi river in and around Surat city of Gujarat, by incorporating certain quantitative as well qualitative aspects. The spectrum of findings by various researchers in regards to causes and effects of various activities to create river water pollution, reported values of pollution indicators, logical interpretations and discussions on relevant issues are discussed. The contents of this write-up remains only a work review by other researchers only, with an aim to visualize the issue of river water pollution and offer certain food for thought for this specific study region. This could be vital utilities towards framing suggestions for futuristic R&D and other development plans/strategies to cope up the problem and evolve suitable site specific preventive measures and action plans.

Methodology

While conducting an updated review on water pollution, a specific river namely Tapi is adopted in this write-up. Review and discussion are presented by adopting common hypothesis as emerged and well established, based upon findings of several researchers. According to these, the physicochemical purity of water in the river Tapi, as well as, ground water available in nearby wells on both banks of river is greatly deteriorated due to two basic reasons, (1) release of excessive polluted substances from nearby industries and (2) excessive use of organic and inorganic fertilizers and use of pesticides and insecticides in agricultural lands which travels down underground towards wells and river water bodies. This all together affected the water quality in river and total hygiene/health of population living near to rivers.

Owing to complexity of problem, it has been a difficult era of research, to project and present the level of water pollution for rivers like Tapi. The reasons remained enormous, like, that environmental pollutants from anthropogenic sources affect the aquatic ecosystem in a synergistic manner, which cannot be detected comprehensively by determination of selected physiochemical parameters alone. On the other hand, the biological system can integrate all environmental variables over a long period of times, the effects of which could be only relatively measured and quantified with ease. The reach of Tapi river is considered for the purpose. All the associated information in relation to this specific reach and the Tapi river basin as whole is critically searched and reviewed for its physiographic, hydrologic and river water pollution related objectives. The findings of several researchers as well as basic information in regards to quantitative as well as qualitative parameters of Tapi river water are looked so as to provide prevailing scenario in this regard. The spectrum of river water pollution agents, end indicators of water quality and various causes and effects of human activities are too sought by traversing through the available literature. The gist of reported results by researchers is reviewed, analysed and presented herein, being adhered to standard sets of methods, as reported by these researchers.

Description of Study Area

The focus of present study remained in and around the Tapi river reaches. Moreover, attempts are made to encompass limited important findings of similar nature in a few other parts of Tapi basin too. The river Tapi is the second largest west flowing inland river of the Indian peninsula, which rises near Betul district of Madhya Pradesh at an elevation of 752 m and ends in Arabian Sea near Surat. If we look into the Mythology of this peculiar river, it is also known as Tapti, who was believed to be the daughter of Sun God, and it rises from the sacred tank of Multai (Mulatapi, i.e. the source of Tapi). The Tapi has its name derived from tapa (i.e. heat). The main reason of contamination of the river Tapti by the heavy metals is due to drainage discharge from all villages and cities on both the banks of the river and its tributaries. Similarly heavy metals contamination also takes place due to small brick industry, small scale industries and farming runoff water containing fertilizer and pesticides. The study river Tapi flows through the Surat city (334 km^2, 28.77 lakhs population as per 2001 census, average annual rainfall 1894 mm) and meets the Arabian Sea at about 16 km from Surat. The city is located at 90 km in downstream of Ukai Dam over river Tapi.

Basic Characteristics of Tapi River Basin: The basin is situated in the northern part of the Deccan Plateau. It extends over an area of 65145 km^2, and lies between East longitudes of 72° 38′ to 78° 17′ and North latitudes of 20° 5′ to 22° 3′. It is bounded on the three sides by the hill ranges (north by the Satpura range, East by Mahadeo hills, South by Ajanta range and Satmala hills) and the West by Arabian Sea (Fig. 2). Culturable area of basin is about 4.29 Mha with forest cover to the

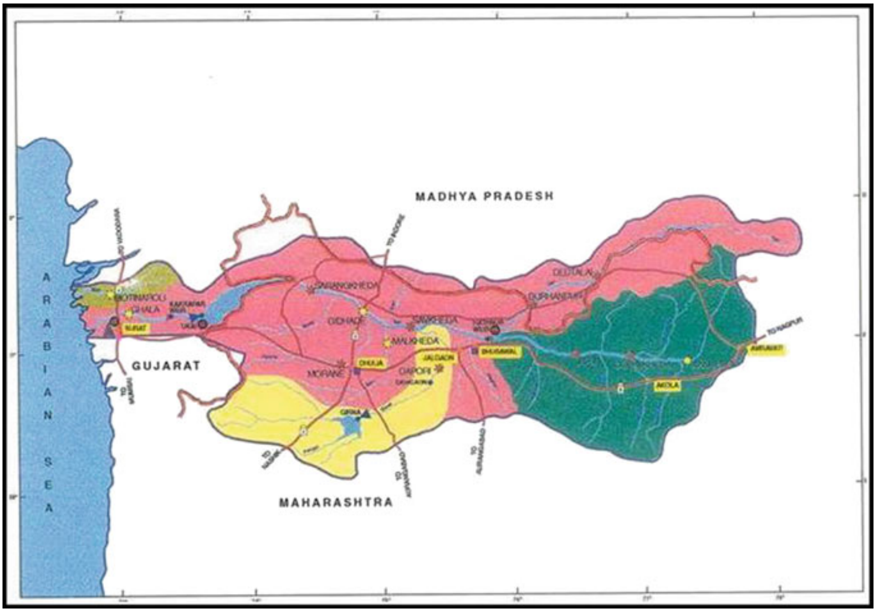

Fig. 2 Entire view of Tapi river basin (*Source* www.wrmin.nic.in)

tune of about 25%. Physiographically, the area is a basaltic landscape with major physiographic units of plateau lands, hills, and valley plains. Basin has two well-defined physical regions, viz., the hilly regions and the plains. The plains cover the Khandesh plains which are broad and fertile areas suitable for cultivation. The drainage area of the Tapi basin up to Ukai dam is reported as 62,225 km^2 out of which 9804 km^2 falls in Madhya Pradesh, 51,504 km^2 in Maharashtra and 917 km^2 in Gujarat.

Tapi basin has vast water potential, comprising surface water potential to the tune of 14.88 km^3 and the ground water potential as of 8.27 km^3. Though good water potential prevails, still there remains a plethora of problems in relation to water resources development of the basin. During monsoons, the Tapi River frequently projects floods, which occasionally cause havoc in the plains of lower reaches. In post-monsoon period, the discharge in the river remains quite low (300 m^3/s or so). In the basin, rain storms typically move from east to west, which use to be the general runoff flow direction too. Most floods occur during the period of July to September with maximum number of floods in August. Heavy floods were observed 1944, 1945, 1958, 1959, 1968, 1969, 1970, 1994 and 1998 causing considerable damage to the Surat city and other low lying areas on the downstream. Entire view of Tapi river basin is illustrated in Fig. 2, where dense morphological constituents of river could be speculated being major factors for its flood prone nature at extreme downstream ends (Fig. 3).

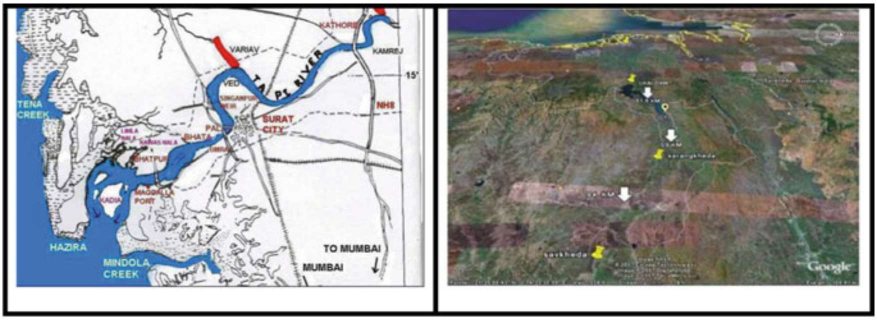

Fig. 3 Schematic view of Tapi river within Surat city showing biological effects

Methods for Physiochemical Assessments: Most of the researchers (APHA 2005; Prasad and Gaur 1992) have analysed the physiochemical parameters of water quality using standard methods usually in accordance to APHA (American Public Health Association), with below given findings,

- Physiochemical characterization of river water, sediments and nearby soil sample such as pH, conductivity, hardness, total alkalinity bicarbonates, phosphate, chloride, calcium, magnesium, sodium, potassium, etc.
- Heavy metal concentration in water (Fe, Cu, Zn, Cd, Pb, As, Hg, Ni)
- Sediment dynamics and nearby soil sampling
- Detection of some organic compounds such as BHC, DDT
- Data processing for statistical analysis
- Effect of river water on Ground Water Quality and Soil Quality

If we look into the general/specific methods as adopted by researchers, for various parameters, it is evident that in most of the studies, the pH metre was adopted for recording values of pH, conductivity metre EC, standard EDTA method for determining hardness parameter, volumetric methods for assessing total alkalinity, spectrophotometric method for phosphates, Mohr's method for chloride, standard AAS methodologies (AAS, Flame photometry) for heavy metals and Gas Chromatographic techniques for pesticides and similar pollutants.

River Pollution Causes

Approximately 75% of urban waste in India ends up in the country's rivers. The unchecked urban growth across the country combined with poor government oversight escort the problem in getting it worse and shoddier. This situation has arisen despite the huge investments made by subsequent governments in river cleaning efforts/strategies. The end results are still to be visualized. The more recently launched National Ganga Cleaning Mission by Govt of India is being looked by everybody with great hope, because as on now our own survival and that of rivers is almost at stake.

Major Sources of Pollution

According to the Centre for Science and Environment, approximately 75–80% of the river's pollution is the result of raw sewage, industrial runoff and the garbage thrown into the river and it totals over 3 billion litres of waste per day. This remains true for rivers like Tapi, where domestic waste water/industrial pollutants are bound to be dumped in intensive magnitudes, giving manifold higher ammonia concentration (even 0.5 mg/L or more). There are not only the formal or documented sources of pollution of river water, but there remains enormous other sources which are not easy to be controlled and thus demanding a strategic planning and implementations by involving technocrats, society and government agencies all together. Description of all such sources/processes of pollution is avoided here, moreover some of the relevant ones are being described below in brief to reflect the prevailing scenario in and around the study area of present study.

Pollution from Industrial Units: Industrial units located along or nearby to rivers, often discharges their wastes and effluents directly or indirectly into the river water bodies, irrespective of time and water flowing conditions. Majority of these industrial wastes are toxic to life forms that consume the polluted river water. Certain industries which are extremely chronic from this point of view, which includes electroplating industrial units, textile industries, diamond industries, chemical and fertilizer industries, etc. There exists a dense population of such industries near study river reach which are releasing pollutants very intensively. The released loads of varied pollutants use to be the greatest source of contamination in river water, with multiple adverse influences on environment, human life and many other on-site/off-site impacts. This all together creates the water resource management of region as one complex issue, which needs its proper realizations/solutions.

Pollution from Agricultural Lands: It happens to be another major source to create and accelerates river contamination, by directly or indirectly affecting the water quality of Tapi river, through ground and surface water runoff. It is getting placed from agricultural land through monsoon/non-monsoon precipitation and seepage of irrigation water, which is composed of artificial fertilizer residues/insecticides/herbicides/pesticides/farm yard waste.

Pollution from Urban and Rural Settings: Dumping of Solid waste and Garbage is another polluting agents as well polluting action by society, whose proper management is inevitable in rivers particularly for the one which is considered in this write-up. The main reason for it remains the high density of the population living in Surat city, dumping of untreated water and solid waste (human faecal matter, cow dung) into river, demanding optimum managerial solutions.

Other Sources of Pollution: Being country of intensive rituals/festivals, the annual occasions like large number of festivals, thousands of peoples take a dip in the river and leave behind worship materials, polythene bags, clay idols, human excreta, account books and floral offerings in the river water, which increases the suspended materials and other pollutants inside the river water. The superstitious mindset of the peoples has contributed, and still contributing and escalating the Tapi river pollution. Further large number of villages and small towns are located all along the river, majority of which do not have adequate/proper sanitation facilities. Hence, people uses river catchment areas for defecation, which causes pathogenic and organic contamination in the river. Also, peoples have the habit of dumping un-burnt bodies of human beings and animals into the river. According to superstition, bodies of those who die from certain diseases (asthma, tuberculosis, leprosy, snake bite, poisoning, etc.) and those of newborn babies, unmarried persons and holy men are consigned to the river. Poor people also dump bodies into the rivers to save the costly wood cremation.

River Sediments and Their Detrimental Effects

Soil erosion by natural process increases sediments in river water. Sediments, being soil and mineral particles, are washed away from the land by flood waters and creates extensive pollution of surface water. It is well established by scientists that they are the prime sources of organic and inorganic matter in the streams, fresh water river, estuaries, oceans and other water supply systems. From quantitative point of view too, the extent of sediment yields remained an alarming situation. Subramanian (1996) gave a realistic scenario in this regards, while reporting erosion and sediment yielded from global and regional perspectives and with extremely large variability of river sediments as transported by Indian rivers, even to the tune of more than 1200 tonnes per km^2 per year for rivers like Ganges. The available literature clearly reveals this fact in regards to present study area too, where higher levels of organic matter in sediments are believed in comparison to even the soils. These sediments are highly harmful and their physical presence inside the Tapi river water bodies remained extremely dynamic. Owing to river flows and other reasons, sediments have differential positions with respect to time as well as space, and accordingly, their concentration remained highly variable. One does not easily predict or estimate that at what point of time and at what exact location the sediments are being added to river water and in what quantity and quality. It depends upon several associated parameters, say for example in case of Tapi river, one of the dominating parameter was found the meandering and poor river banks characteristics of the river. Considering physiographic attributes, the placement of sediments gets highly influenced. The relative quantity and concentration of sediment in river water in different layers of flow governs the ultimate influences of sediments on water pollution. In case of Tapi river, many researchers (Vyas et al. 2008; Varsani 2010; Dinakaran and Krishnaiyya 2011) have found that the sediments located at bottom of river flows, i.e. nearby to river beds are often subjected to anaerobic conditions, when they undergo continuous leaching. These sediment masses have higher capacity to exchange cautions with the surrounding water medium and also facilitate deposition of trace elements of metals such as As, Sb, Hg, Cd, Cu, Cr, Mo, Ni, Co, Pb, Mn, etc. Some of the prominent effects of these sediment masses could be enumerated as follows:

- Sediments destroy aquatic organisms, as it is often believed that bottom sediments are held to decreases fish population by blanketing fish nests, spawn and food supplies. Also, some of the previous works very well projects a fact that Toxic metals (Hg, Cd, Pb) as present in sediments, attack sulphur bonds in enzymes causing immobilizing effect of transportation through cell membrane of aquatic organisms.
- Sediments reduce light penetration in water, as presence of suspended sediments in river water reduces direct penetration of sunlight which lowers photosynthesis in aquatic plants, offering decreased evolution of inadequate oxygen for aquatic animals.
- Sediments gets water turbid as suspended solids which are greater from surface runoff than that from sewage discharge, deteriorate the water quality badly.
- Sediments facilitates water bodies to get easily flooded and thus make the river to overflow by drastic changes in rates and depths of flowing water systems and adversely influencing the operations and the overall life of downstream reservoirs.

Factors Controlling Sediment Loads: Sediment use to be an important cause of stream degradation and also the river water pollution. Factors such as relief, channel slope, basin size, seasonality of rains and tectonic activities control sediment loads in rivers. Similarly, land use patterns also had their effects on sediment flux to the oceans. Sedimentation in various stage like, erosion, transport and deposition, remained the global burning issue, as environmental impacts of sedimentation includes many sensitive factors like loss of benthic aquatic habitat, changes in photosynthesis and visibility, and impacts from several contaminants attached to and transported by sediments. Gray and Gartner (2009) and many other researchers in past have revealed their results on characterization of suspended sediment using backscatter and attenuation of acoustic signals in water for these purposes.

Anticipated Influences of Sediments: The recent activities of people in changing river courses and setting obstacles against natural river flows have significantly altered natural mechanical erosion rates and sediment fluxes. Such interventions can have severe consequences for agriculture by loss of fertile soils. Accordingly, the subject of sediment transport and flow in rivers or streams are gaining importance with the increasing utilization of water resource. Transportation of sediments in the river often comprised two phases, the suspended sediments and the bed load sediments. Yadav and Samtani (2008) presented their scientific findings in regards to such sediment transportations inside the Tapi river near Surat. An important effort for observing, assessing and devising solutions for estimation of sediment load in

Table 1 Probable influences of sediments on environmental and engineering concerns

Sediment size	Environmental issues	Associated engineering issues
Silts and clays	Erosion, especially loss of topsoil in agricultural areas; gullying	
	High sediment loads to reservoirs	Reservoir siltation
	Chemical transport of nutrients, metals and chlorinated organic compounds	Drinking-water supply
	Accumulation of contaminants in organisms at the bottom of the food chain (particulate feeders)	
	Silting of fish spawning beds and disturbance of habitats (by erosion or siltation) for benthic organisms	
Sand	River bed and bank erosion	River channel deposition, navigation problems, instability of river cross-sections
	River bed and bank erosion	Sedimentation in reservoirs
	Habitat disturbance	
Gravel	Channel instability when dredged for aggregate	Instability of river channel leads to problems of navigation and flood control
	Habitat disturbance	

Tapi river was reported by them, by incorporating non uniform bed material considering the various variables like discharge, hydraulic mean depth, flow velocity, bed slope, etc. by collecting the field data of Tapi River for 10–15 years duration. Bed load was found to be a dominating part of sediment transport with significant influences of non-uniformities of river-bed materials. Sediments of varied sizes have its own impact and greater control on many environmental and engineering concerns, specifically from managerial point of view, as pin pointed below in Table 1.

Idol Immersion and Other Ritual Activities

India is the country of rituals and people used to believe and deeply follow these. Most of these rituals are performed near the bank of river and water bodies. The 'Ganesh Chaturthi' or 'Durga Ashtami/Navratri' use to be important festivals of Hindu and during these festival thousands of Idols having various sizes are immersed every year in different water bodies of the cities. In Gujarat, the Idol immersion of Lord Ganesha happens to be a grand celebration in each year, where large number of Idols got immersed in rivers after 10 days worship during the months of August or September. If we consider the area of present study, only in

Tapi river, on an average about 3000–4000 idols were being immersed during each such festival in recent years. These idols are constructed by plaster of paris, clay, cloths, small iron rods, bamboo and decorated with different paints such as varnish, water colours, etc. and when immersed in the water, leads to significant alteration in the water quality (Dhote et al. 2001; Swain et al. 2005; Vyas et al. 2008; Dhote and Dixit 2011 and Bhat et al. 2012). The input of biodegradable and non-biodegradable substances found to be responsible for greatly deteriorating the water quality and enhancing silt load in the river. The floating materials released through idol in the river or lake after decomposition results in eutrophication too. Thakre et al. (2013) reported certain important findings on environmental impacts of Idol immersion at foremost upstream reaches of river Tapi and found it as a major cause for river water contamination. The immersion practices resulted in degradation of water quality apart from siltation. After immersion of the idols, the river water quality parameters like turbidity, total hardness, chemical oxygen demand (COD), biochemical oxygen demand (BOD), dissolved oxygen (DO), oil and grease depicted higher values well beyond their maximum permissible limits as prescribed by standard agencies.

Reported Results/Findings on Tapi River Pollution

Surat is the only major city in the state to have been blessed by a perennial river. But, the river is being stabbed by citizens. A Delhi-based firm engaged by the Surat Municipal Corporation (SMC) found that there are more than 7000 illegal drains emptying their contents into the Tapi, making it more polluted than the Sabarmati when it comes to faecal bacteria content. An analysis of Tapi waters done in February by SVNIT in the upstream of causeway (Sarthana, Varachha, Katargam and Rander) from where the city draws its drinking water, records a pH factor of 9.06, suggesting that the water has turned highly alkaline. Its coliform bacteria content peaked to 1.6 lakh in litre by the time it crossed Varachha and Jehangirpura areas instead of the required 500 per 100 ml. Coliform is the main indicator of faecal content in water. The biochemical oxygen demand (BOD) has always remained above 30 mg/L. In the downstream of the causeway, the total coliform content peaks to as high as 1.1 crore per litre at Singanpore, where the city drains its sewage. The dissolved oxygen is reported as 'zero' at Ginger hotel, Sardar Bridge and Ved hotel. The BOD levels are as high as 315 mg/L while the standards are 30 mg/L. Even the chemical oxygen demand (COD) levels exceed desirable levels at Sardar bridge, Vivekanand bridge and the Singanpore areas and hovers between 520 and 800 mg/L—the standard being 250 mg/L. Excessive sand mining has also played its part in changing the contours of the river. Encroachments on both the side within the civic limit area has also resulted in the carrying capacity coming down from 8.5 lakh cusecs to merely 3.5 lakh cusecs. "Weir-cum-causeway has actually blocked the passage of impurities on Tapi, when both organic and inorganic impurities accumulate at the causeway, decomposition leads to birth of more microorganisms. We need to get rid of these accumulated impurities". Siltation is the major problem for Tapi river today, as high tides bring in a lot of impurities from the sea to the river, but does not pull it back. This raises the river-bed level of Tapi through the last 35 km of its journey which passes through the city. The scope of this updated review remained to assess some of the dominating physiochemical parameters on the course of water in the river Tapi, based upon available literature. Presenting reviewed results of all water quality attributes, remained out of scope here, moreover some of the significant ones are attempted herein with their reported values/causes/effects in study area.

Status of Quantitative Discharges/Floods

City of Surat is located between Mumbai and Ahmedabad on banks of river Tapi, which originates from Multai in MP and merge into Arabian Sea at Dumas. Though there remained many recent estimates of river discharges for study locations, but the same could not find place here owing to large variations even in short span of time, in particular the recent years, when climate and rainwater are showing totally unpredictable and non-homogeneous results. If we see some of the historical records for Tapi river discharges for Surat location, the total annual runoff volume was used to be projected as 12,000 Million Cubic Metres (MCM) which was considered to be an assured flow for 75% of years. Out of this, Maharastra had allocated 6000 MCM quota for its use, while the Gujarat had created reservoir at Ukai (about 100 km upstream of Surat) for storage of 8600 MCM. Floods in and around Surat and villages remained the chronic issues for all the past years and thus they remained as an active part of flood drainage of Tapi River. Some of the historical estimates (as evident from Ukai dam data using indirect sources) clearly revealed the facts that the Tapi river can contain about 6 lakhs cusecs of flood within banks in major areas of Surat city and around. Since 1882, many extreme floods/high discharges are recorded, and most of them occurred in the months of August and September. Major floods (1933, 1959, 1968, 1970, 1998 and 2006) gave a situation when recorded floods even crossed 9 lakhs cusecs capacity.

One of the recent estimation (Patel and Gundaliya 2014) for calculating the discharge carrying capacities of River Tapi was found to be of great relevance and importance for this write-up. Massive floods of 2006, as occurred in Surat, remained the centre of focus, where greater damage to personal and properties were seen in 2006, and authors had presented estimated discharge capacities of Tapi river for more than 300 cross sections across lower Tapi basin. Table 2, presents some historical peak discharge values as observed during few important floods in Surat. The carrying capacity of river Tapi, is being drastically deteriorated and needs suitable modifications. Agnihotri and Patel (2011) provided ways and means of improving carrying capacities of river Tapi, which has its own importance to current scenario.

Table 2 Comparison of different floods in Surat flood

Year	Peak inflow (lakh cusec)	Max outflow (lakh cusec)	Rose level at hope bridge (m)	Outcome
1968 (no dam)	–	15	12.01	Major flood
1978	<8	4.4	–	No flood
1979	<8	3.3	–	No flood
1994	8.9	6	10.2	Flood
1998	10.5	7	11.5	Flood
2006	10.6	9	12.01	Major flood

Source People Committee on Gujarat Flood 2006: A Report

Status of Sediment Characteristics

For Tapi river the suspended sediment loads as well as the bed load of sediments, both were found to be equally important and sensitive. This is due to the fact that the river reaches are located at most downstream side near to the sea. Majority of findings have clearly established the facts that the sediment transport remains the direct function of water movement. Chakrapani (2005) reported excellent findings on variety of factors which ultimately control the variations in sediment loads inside the rivers. Looking the physics of sediment transport inside the river, it is quite evident from physical observations that during floods, sediment particles gets separated into suspended material (silt + clay + sand) and bed load (some part moving along bed and other getting deposited on bed). Bed load as reported for Tapi is usually stony material, such as gravel and cobbles, that moves by rolling along the river bed being too heavy to be lifted into suspension by flowing water.

A baseline study was conducted by Marathe et al. (2011) to determine the basic physical and chemical characteristics of the sediments of Tapi river, being concentrated on whole river length at about 10 different locations along its course. The overall ranges of certain sediment related characteristics revealed following factual ranges of variations,

- Texture of sediments—sandy to loamy (muddy) sand soils with pH 7.01–8.05
- Organic carbon in Sediments—0.16–0.54%
- Electric Conductivity (EC) of sediments—3.11–5.05 ds/m
- Available Nitrogen (N), Potassium (K) and Phosphorous (K) in sediments—71.8–244.3; 6.7–20.7; and 168.2–367.0 kg/ha, respectively
- Exchangeable Ca and Mg in sediments—13.97–16.07 and 20.01–20.40 me/100 mg

The Physicochemical characteristics of Tapti river sediments, particularly for Surat station were too reported, according to which the representative values of pH, Organic carbon (%), EC (ds/m), Exchangeable Ca (me/100 gm), Exchangeable Mg (me/100 gm), Available N (Kg/ha), Available P (Kg/ha), Available K (Kg/ha) were reported to be 7.01, 0.38, 3.99, 15.0, 20.11, 170.2, 190.0 and 367.2, respectively. Dinakaran and Krishnayya (2011) presented an interesting spectrum on organic carbon and grain size distribution in certain ephemeral river sediments in western India. Total Organic Carbon (TOC) and grain size distribution (sand, silt and clay) in the ephemeral Mahi River (western India) sediments were measured to look at their effectiveness in understanding the late Quaternary monsoon conditions. Four sites spread across the alluvial zone and three sites from the estuarine zone were sampled. TOC concentration in the sediments of the alluvial and estuarine zone sites ranged between 0.04 and 0.39% and 0.04 and 0.23%, respectively. It was observed that grain size differed significantly at alluvial zone sites, while a uniform trend was found in estuarine zone sites.

Status of River Water Quality

Earlier, works done on Tapi Water resources are said to be polluted because of man's action resulting in the addition of matter to the water or altering the physical, chemical or biological characteristics of water to such an extent that its utility for any reasonable purpose or its environmental value is demonstrably depreciated. The quality of physicochemical and biological characterizations of water is an index to provide a complete and reliable picture of the conditions prevailing for tropic status in the water bodies. For present study following published literatures have been reviewed viz Heavy Metal are considered as major environmental pollutants, which is consistently increasing through effluents, sedimentation of rocks and mining activities. High concentrations of all heavy metals are toxic to biological systems and affect the growth and differentiation of a blue green and green algae. Researchers have studied and reported a lot to assess the pollution load of Tapi River adopting standard methods (APHA 2005) with below given major steps/efforts,

- Survey and selection of sites for river water samples for certain confined sections.
- Physiochemical characterization of river water sediments and nearby soil samples for pH, conductivity, hardness, total alkalinity, bicarbonates, phosphate, chlorides, calcium, magnesium, sodium, potassium, etc.
- Heavy metal concentration in water, sediments and soil nearby soil samples such as Fe, Cu, Zn, Cd, Pb, As, Hg, Ni.
- Detection of some organic compounds such as BHC and DDT in river water.
- Water Analysis in pre-monsoon and post-monsoon season.
- Long term comparison and statistical analysis of data between river water and sediment.
- Ground water quality and soil quality in nearby land and water bodies.
- Prevailing and projected awareness among the public/society living nearby.

Table 3 Salient water quality parameters at Tapi river (downstream of Ukai Dam)

Parameters	Units	Maximum permissible limits	Minimum	Maximum	Mean
Temperature	°C	35	18	25.0	21.4
Turbidity	NTU	10	15	41.5	23.8
pH	–	8.5	7.7	8.6	8.27
Conductivity	ms	1	0.2	0.8	0.29
Dissolve oxygen	mg/L	7	1.2	7.2	4.95
BOD	mg/L	2	2	7.2	5.45
COD	mg/L	250	16	232.0	79.5
Nitrate-n	mg/L	9	0.019	1.4	0.53
Ammonia	mg/L	0.1	0	1.7	0.61
Total hardness	mg/L	500	100	202.0	137.67
Fluoride	mg/L	1.5	0.01	0.0	0.02
Chloride	mg/L	250	23	65.0	36.08
Total alkalinity	mg/L	600	28	112.0	77.67
Phosphate	mg/L	0.1	0	1.0	0.67
Sodium	mg/L	200	8.8	50.0	20.59
Potassium	mg/L	50	39	98.0	56.5

River Water Quality Parameters: Description of each and every findings and reported results (as cited above) is not feasible to get accommodated here. Moreover, a sincere effort is made to incorporate the gist of salient findings and common results, as reported by various researchers on pollution of Tapi river reaches, being confined to segments located nearby to Surat. The water quality deterioration in Tapi River at different locations due to salient activities as described in preceding segments of this write-up, are well studied by Variya (2010); Varsani (2010); Azahar and Multani (2011); Malik et al. (2010); Ujjania and Multani (2011) and Malik et al. (2012). Based upon their consolidated findings, the overall scenario in regards to quantitative indicators of river water for study area, are illustrated in Table 3, where numerical values of water quality standard parameters are reflected with their relative comparisons in contrast to standard maximum permissible limits as set by World Health Organization (WHO) or various pollution control boards at national or regional level. Heavy metals and their concentrations in river water use to be another serious concern while controlling river pollution (Prasad and Gaur 1992; Bajpai et al 2002).

Status of Human Induced Pollution

Influences of Municipal Waste: Prior to 1995, the Tapi river near Surat was merely a tidal river, which is converted to a fresh water body by the construction of a weir across it. The stagnant part of the water body is now within the reach of human habitat and accumulates waste load (organic pollutant and nutrients) turning it to be eutrophic. Due to the federal system of governance prevalent in India, both the Central and State governments exploit rivers as a national natural resource and the water is transported to meet people's needs at remote places beyond the river basin. Besides this orderly use, the river is also exploited by those living on the riverbanks forming a user group usually not documented. These users draw water, discharge wastewater and sometimes over exploit the aquatic resource. The activities that fall under this unorganized category include washing clothes, cattle farming, religious activities, cremation, open defecation, recreation, fishing and agriculture. Surat Municipal Corporation carried out a survey in 2001 to identify the major wastewater discharges into the river. The survey revealed that the population of 2,811,614 individuals within the municipal limit, living in 7 villages along the river bank, 15 km upstream of the weir, accounts for wastewater discharge of 5204 m^3 per day through 28 inlet points. If we see on animal sides, in some of the reports/news papers of past, it was reported that at least 35 cattle farmers with more than 100 cattles were occupying the Tapi river bank, which might have grown to many fold by now. Moreover, its an established and reliable estimate that about 400 kg of animal dung is wasted every day, assuming that each cattle generate 4 kg of dung per day. Anyone can visualize the pollution scenario, when such a large quantity of dung is being discharged into Tapi river. The results as reported by Dubey and Ujjania (2013) indicated that most of the physicochemical parameters (pH, Turbidity, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), phosphate, ammonia and potassium) from Tapi River were beyond the WHO and BIS limits for drinking water and even not suitable for domestic purposes.

Influences of Idol Immersion on Water Quality: Tapi river is investigated by many researchers, in this regard, encompassing varied locations along river course. It is difficult to incorporate all such results here, moreover certain confined results, as observed for its tail end locations (near Surat) are being reported herein. Mohini et al. (1991) gave very comprehensive findings based upon their observed water samples at idol immersion sites on Tapi River, revealing the fact that values of most of the water quality parameters gets adversely affected during the immersion which later recovered in the post-immersion period. For example, the value of temperature during the pre-immersion, immersion and post-immersion period was stated as 32.5, 30.2 and 30 °C, respectively. Turbidity of water during immersion period was reported highest (126 NTU) while it was shown comparatively low during the pre-immersion (98 NTU) and post-immersion (54 NTU). Conductivity was reported 12.2 ms during immersion period while it was 4.6 and 0.5 ms during pre-immersion and post-immersion, respectively. High value of total solids 1260 mg/L was observed during the immersion period that was comparatively low 930 mg/L during pre-immersion and 650 mg/L during post-immersion period. Similarly total dissolved solid was shown 650 mg/L during immersion period while pre-immersion and post-immersion period, it was found low 370 and 480 mg/L, respectively. Total suspended solids was found high 610 mg/L during immersion period compare to pre-immersion 569 mg/L and post-immersion period 170 mg/L, respectively. The pH of river water was found alkaline 8.5 during immersion period while it was 8.2 and 8.8 during pre-immersion and post-immersion period, respectively. In their study, total alkalinity was found 224.0 mg/L during pre-immersion period compare to immersion and post-immersion period 96.0 and 104.0 mg/L, respectively. Total hardness was observed as 1510.0 mg/L during immersion period while 340 mg/L during pre-immersion and 160 mg/L in post-immersion period. The calcium hardness was observed as 310 mg/L during immersion period while 100 mg/L during pre-immersion period and 50 mg/L during post-immersion period, respectively. During immersion period, DO was observed 4.35 mg/L while it was observed comparably high during the pre-immersion 1.62 mg/L and post-immersion 3.24 mg/L. BOD was observed 32.4 mg/L during the immersion period that was significantly high when compared to pre-immersion 20.2 and 12.2 mg/L during post-immersion period. High value of COD 63.2 mg/L was observed in the immersion period and was comparatively low 27.8 mg/L during pre-immersion and 34.5 mg/L during post-immersion period. Oil and grease was observed high 0.90 mg/L during immersion period while in pre-immersion and post-immersion period, these were reported low 0.70 and 0.54 mg/L, respectively.

Ujjania and Mistry (2012) categorically assessed the environmental impact of Ganesh idol immersion activity on water quality of Tapi River with significant changes in physicochemical properties of river water. It was found that the pH of water notably affects the solubility of nutrients. The pH was noted acidic or high (7.5–7.9) during the immersion period, while it was reported low during the pre-immersion (6.9–7.4) and post-immersion (7.6–7.7) periods. The range of temperature during the pre-immersion, immersion and post-immersion period were reported as 27.0–31.0, 28.0–31.0 and 28.0–30.0 °C, respectively. Such rising in temperature was stated as a reason to speed up chemical reaction and biological activity that reduce the solubility of gases in water. Similarly, DO during immersion period was observed very low (2.8–4.4) mg/L while it was observed comparably high during the pre-immersion 4.8–6.8 mg/L. High value of carbon dioxide (12.32–14.08 mg/L), total hardness (166.0–178.0 mg/L) and total calcium (126–134 mg/L) were detected during the immersion period in comparison to other time periods. Other researchers too supported and supplemented similar inferences from their findings on different reaches of Tapi river.

The influences of ritual activities like Idol immersions were intensively studied and reported by many other researchers too in different alike river segments (Malik et al. 2010; Ujjania and Multani 2011 and Malik et al. 2012). If we look into two specific reaches of Tapi river viz. (a) Multai (Madhya Pradesh) an extreme upstream location from where the river originates and (b) Surat (Gujarat) an extreme downstream location where the river almost finishes its course; the relative quantitative status of river water pollution owing to idol immersions is reflected in Table 4, where the reported results are concisely presented. Same are self explanatory to reflect the adverse influences of Idol immersion activities in the river, showing varied quality of river water during pre-immersion, immersion as well as post-immersion periods.

Table 4 Reported river water quality parameter as influenced by Idol immersions at two extreme specific reaches of Tapi river

Quality parameter	Time of observations		
	Pre-immersion	Immersion	Post-immersion
a. At upstream location (Multai, Madhya Pradesh) of Tapi river			
Turbidity	23–30	25–50	30–48
Total hardness	35–52	42–59	39–65
Dissolved oxygen	5.2–7.2	5.8–8.8	5.4–7.4
BOD	5.8–6.6	5.8–7.4	7.8–9.4
COD	29–36	36–42	44–52
Oil and grease	Nil	0.009–0.049	0.019–0.065
Source Thakre et al. (2013)			
b. At downstream location (Surat, Gujarat) of Tapi river			
pH	6.9–7.4	7.5–7.9	7.6–7.7
Temperature (°C)	27.0–31.0	28.0–31.0	28.0–30.0
Dissolved oxygen (mg/L)	4.8–6.8	2.8–4.4	2.8–5.2
Free CO_2 (mg/L)	7.04–15.84	12.32–14.08	8.8–14.08
Total hardness (mg/L)	110.0–120.0	166.0–178.0	120.0–166.0
Total alkalinity (mg/L)	230.0–270.0	310.0–360.0	230.0–310.0
BOD (mg/L)	3.6–4.8	3.2–6.0	3.2–4.0
COD (mg/L)	21.14–35.42	42.28–49.14	14.00–35.42
Oil and grease (mg/L)	0.33–0.65	0.69–1.20	0.53–0.80
Total calcium (mg/L	72.0–100.0	126.0–134.0	80.0–124.0

Source Ujjania and Mistry (2012)

Futuristic Inferences/Suggestions

Climate change is emerging as a biggest challenge for engineers, researchers, managers of natural resources, and planners and policy makers. Under such circumstances, the rivers are the water bodies which are going to be extremely sensitive and accordingly influencing the life on globe in variety of ways. Varghese et al. (2011) had performed a case study in regards to evaluate a few probable measures to achieve an effective water protection plan for Tapi river. Considering all the reviewed literature and so gained understanding, it looks to be more important to describe the futuristic suggestions in this aspect. Author, being merely a graduate student, considered herself not fully competent to provide appropriately logical expressions in this regard, moreover, based upon surface reviewing and findings of esteemed researchers, following important suggestions or inferences are offered for the readers of this review paper,

- Secrets of past monsoons and associated sediment loads in rivers, clearly gives a warning for being sensitive towards rivers, so that their health (qualitative) and geometry (physical state) could be properly taken care by involving all segments of society.

- The river systems do respond to climatic changes but the response is not overnight, it may take hundreds of years to show a lasting change, hence more intensive research studies are of great importance in today's context when more and more habitats are coming up on the river banks or along the flood pathways of the rivers.
- Rivers should not be taken for granted. Planning course of action on them in any of the desired ways/means, just to fulfill the vested interest (political, commercial, popularity stunt, forceful obligations, long term business/benefits, etc.), needs to be avoided. Merely translation of river into cosmetic beautification in the name of river fronts development or other catchy projects, looks beautiful in its first catch, but technologically they could release harms rather benefits for river water bodies/river system in totality, as it invites only the real estate for concrete structures to attain the end target of recreational/commercial activities. Do we really need river front development models? Is it a true river restoration? Such questions could be considered as a big food for thought for us, being inclined towards ecological and climatic adjustment of river eco systems.
- The water pollution of Tapi river has gained large heights, and now it became imperative to yield a plan, identifying viable remedial options and strategies for its effective clean up. Efforts needs to be made to resort to a bottom-up approach rather than a top-down one to help this highly polluted river, which is the major life-supporting artery of Surat city. We need to develop awareness among masses, education, and improved watershed management that can improve the overall water quality of this holy river.
- Huge quantity of waste water discharges into river, which needs proper management and treatment to remove or at least reduces the organic matter, solids, nutrients, disease-causing organ isms and other pollutants from the river water body.
- Looking into ever increasing shortage and uncertainties of water both in urban and rural areas, conservation of water must be given top priority, which could be well achieved by adopting several strategies like, promoting wastewater treatment/technologies, drainage water management/treatment, recycling/reuse of waste water, improving sewerage system, upgrading of sewage treatment plant, effective disposal of sewage, agricultural practices improvement with reduced applications of chemicals/fertilizes, better environmental management of rivers considering interactions among ecology/hydrology/water quality/climate/flooding/droughts, afforestation, canal developments, integrated watershed management in river catchments, etc.
- Strong awareness among the people and creation of proper legislation and fines is another critical needs of time, where different organizations/groups of common people, and even the youth and students must take active part controlling visible/invisible abuses to rivers and river water bodies. This could evolve some simple and innovating ways and means to tackle this alarming situation where river water pollution is touching greater heights.

- A better and deep understanding of causes and effects of river water pollution needs to be made available to common people using social media, showing the anticipated on-site and off-site impacts. River water pollution not only remains confined to visible water bodies of the rivers, but could have multiple adverse impacts/deteriorations towards invisible soil columns, ground water bodies which are sensitive sources to gets easily polluted.
- Relocation of religious activities and crematoria along rivers looks to be a need, but from practical considerations it is not at all feasible to totally avoid it. Moreover, certain alternative plans and thinking needs to be evolved at this juncture, to reduce the extent of problem. This objective could be attained by educating the concerned people, by providing alternate disposal facility for the waste, properly relocating the cause points of pollution like cattle shed, water supply, biogas energy generation plants, outlets for marketing of dairy products, alternate water sources for washermen making cloth washing as organized activity by identifying a suitable locality and dedicated source of water with pumping station.

Conclusion

Rivers are the lifeline for human beings on the globe as they use to be the only reliable source of water for domestic, industrial, agricultural and all other activities of life. Owing to fast developments, the river water quality is getting deteriorated in an alarming fashion, which altogether demands for a proper understanding of its causes and effect to evolve suitable solutions. The rivers located nearby to urban areas are more severely influenced and need special attention.

Present study reflects an updated review of river water pollution in regards to an important west flowing Tapi river of India, by incorporating reported findings or results by various researchers, considering the major water quality parameters which includes Temperature, Turbidity, pH, Conductivity, Dissolve Oxygen, BOD, COD, Nitrate-n, Ammonia, Total Hardness, Fluoride, Chloride, Total alkalinity, Phosphate, Sodium, Potassium, Free carbon dioxide, Oil and grease, Total calcium, etc.

The values of these sensitive indicators were found to be significantly deviating from the standard prescribed safe limits as established by agencies like WHO or pollution control boards at regional or national scales. The deep analysis of several predominant causes of river water pollution, showed an alarming situation for river under study, where activities under three specific categories (1) Domestic/Human induced (2) Industrial (3) Agricultural; have released sizeable inputs to deteriorate the river water bodies physically as well as chemically. Influences of ritual activities like Idol immersion are specifically screened which showed high influences on leading water quality parameters and demands for framing alternative regulations and strategies to cope up with the issue.

The extent of sediment and its detrimental effects on river water quality were found to be the leading concern, which remains the sole ingredients towards river water pollution. The in depth reading and analysis of more than 50 research papers/publications, made the author educative and a bit capable to draw certain specific conclusions and inferences on the subject, which are mentioned in preceding sub section namely “Futuristic Inferences/Suggestions”, hence not being repeated here.

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Ensemble MCDM Approach to Determine Priorities of Parameters for WQI

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Abstract Priorities of different water quality parameters are required to be determined for the calculation of Water Quality Indices. The procedures of determining priorities (importance) to the parameters are often subjective and preferential. The present study proposes an objective and non-preferential method to determine the priorities of water quality parameters to calculate Water Quality Index. Relative importance of the parameters were determined on the basis of important criteria like hazard potential, utility, cost, and citation frequency using Multi-Criteria Decision-Making methods like Analytic Hierarchy Process, Fuzzy Logic Decision-Making, and their combinations. Different Water Quality Indices (MCDM WQI) were developed from the priority values of the parameters, determined by each of the methods applied. A case study was performed in Tripura, India to validate those Water Quality Indices. Sensitivity analysis, statistical analysis, and comparison with an established Water Quality Index (NSF WQI) were performed for each of the indices developed. The MCDM WQIs were found to be close to NSF WQI (less than 2% deviation) and also follow similar patterns. The Hybrid AHP-FLDM method was found to be closest to NSF WQI (0.29% deviation) among the methods used. Thus, the MCDM WQI is successful in representing the overall water quality.

Keywords Water quality index · WQI · Objective · Non-preferential Multi-criteria decision-making · MCDM · Ensemble · Analytic hierarchy process · AHP · Fuzzy · Tripura · India

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Introduction

In recent years, *Multi-Criteria Decision-Making* (MCDM) methods like *Analytical Hierarchy Process* (AHP) (Saaty 1977, 1980) and *Fuzzy Logic Decision-Making* (FLDM) (Zadeh 1965) are being widely used to support decision-making in complex situations, where multiple factors are involved (Triantaphyllou 2000). In the present study, MCDM is used to determine the priorities of the Water Quality Parameters (WQP) in an objective and non-preferential way. Water Quality Index (WQI) is a concise numerical representation of overall water quality of a water body, which is convenient to interpret and widely used (Tyagi et al. 2013). WQI of water is essentially a function of the water quality parameters and their concentrations.

Equation 1 WQI is a function of parameters and their concentration

$$\mathrm{WQI} = f(P, C) \tag{1}$$

where

P Water quality parameter
C Concentration of that parameter.

$$P \in \mathbb{R}|P > 0 \text{ and } C \in \mathbb{R}|\ C > 0$$

Not all the WQP are equally important in assessing the overall quality of water. A fewer parameters with greater importance may be enough to represent the overall quality. As different water quality parameters have different importance in assessing overall water quality, the priorities of the parameters are required to be determined for calculation of WQI. In initial (Horton 1965; Brown et al. 1970; Dunnette 1979) and later works (Bhargava 1983; House and Ellis 1987) on WQI, the importance of the parameters were determined from subjective opinions of the experts (Avvannavar and Shrihari 2008). The number of experts surveyed was very small in comparison to the huge pool of experts throughout the globe. Moreover, only the experts' opinions were considered, but the criteria on which the importance of the parameters were determined, were out of the scope of those WQIs.

In later phase, the trend was to develop a method which is more general and objective in nature (BCWQI—Rocchini and Swain 1995; CWQI—CCME 2001; WAWQI—Chauhan and Singh 2010). However, in these cases, the WQIs were calculated by quantification of the failure of the parameters to meet the objective values, rather than their individual importance. Also, the selection of parameters and objective values depends upon the consideration of the users. Therefore, these indices are rather subjective and biased (Terrado et al. 2010) in nature. Another disadvantage of these indices is they are quite time consuming to calculate as a large number of data are required.

In some recent works, use of MCDM methods like AHP (Karbassi et al. 2011), FLDM (Lermontov et al. 2009; Semiromi et al. 2011; Sahu et al. 2011; Mourhir et al. 2014) and their combinations (Ocampo-Duque et al. 2006; Carbajal-Hernándeza et al. 2012) was found to be successful in the determination of importance of the parameters in objective and non-preferential manner. In the present study, multiple significant criteria were selected first from experts' opinions. Expert survey is replaced by literature survey in the selection of WQP to integrate the views of a large number of experts. On the basis of those selected criteria, the relative importance of the parameters was determined in an objective and non-preferential way using different MCDM methods and their combinations. Novelty of the study is that hazard potential, utility, and cost were considered together for the determination of weights of importance of the parameters. So, the weights, determined by the proposed method, were able to represent the impact on the cost of mitigation, utilities, and hazards of the parameters considered. Again, MCDM methods like AHP, FLDM, and their combinations were used to determine the priorities of the parameters.

Objective

The objective of this study was to determine Priority Values (PV) of different WQPs for WQI in an objective and non-preferential way on the basis of important criteria, so that the index can be more realistic and holistic.

Methodology

The PV of different WQP were determined on the basis of some important criteria, using different MCDM methods and their aggregation. The method was then validated through a case study where different WQIs were calculated from the samples using those PV. Sensitivity analysis, statistical analysis, and comparison with an established WQI were then performed on those WQI for that validation.

Selection of Criteria

Four important criteria, viz., *hazard potential, utility, cost* and *citation score*, were selected on the basis of expert survey. A brief description of those criteria is given here:

Hazard Potential (H): Hazard potential is a relative estimation of the potential extent of hazard caused by each of the specific water quality parameters. The most hazardous (or least beneficial) parameter gets the lowest score.

Utility (U): Utility is a relative estimation of how useful is each of the water quality parameters to assess the overall quality of the water. The most useful parameter gets the highest score.

Cost (C) of Mitigation: It is a relative estimation of how expensive the mitigation of the negative impact imposed by each of the specific water quality parameters. The most expensive parameter gets the lowest score.

Citation Score (F): Citation frequency is the percentage of frequency of using of parameters in related studies. The most used parameter gets the highest score and *vice versa*.

Selection of Parameters

The parameters were selected from the metastatic analysis of extensive literature survey. Citation scores of the parameters found in literatures were calculated by their frequencies of use in the related studies (Eq. 2) (Debnath et al. 2015; Ghosh et al. 2016).

Equation 2 Citation score of parameters from Literature Survey

$$S = \frac{P}{C} \times 100 \tag{2}$$

where

S Citation score of a parameter
P Number of times a particular parameter was found in literature
C Total number of times all the parameter was found in literature.

The WQP which have at least 5% presence in literature, were selected for this study (Craparo 2007). Citation score being fractional values, the WQP which have scores greater than 4.5 were taken as selected, following the rule of approximation.

Scoring of Parameters

Selected WQP were scored on the basis of each of the selected criteria from a metastatic literature survey.

Hazard Potential (H): When the importance of the parameters was determined on the basis of hazard potential, their benefits and negative effects were assessed from the literature qualitatively. The qualitative values were then converted to quantitative values using a scale of 1–5 (Table 1).

Table 1 Scale of hazard potential of the parameters

Criteria	Most hazardous/least beneficial	Hazardous/less beneficial	Neither hazardous nor beneficial	Beneficial/less Hazardous	Least hazardous/most beneficial
Scale	1	2	3	4	5

The scoring of hazard potential was calculated by combining the quantitative values from all the literature surveyed (Eq. 3).

Equation 3 Scoring of hazard potential of the parameters

$$I_H = \frac{\sum H_i}{N} \quad (3)$$

where

I_H Relative importance score of a hazard potential of a parameter
H_i Importance value (scale of 1–5) of hazard potential in *i*th literature for that parameter
N Number of literature surveyed.

For example, the parameter Dissolved Oxygen (DO) found to be very beneficial as per some related literature. The qualitative importance of DO was assigned in the following manner for each of the papers surveyed:

Paper	Hazard potential	Score
1	Most beneficial	5
2	Beneficial	4
3	Most beneficial	5
4	Most beneficial	5
5	Most beneficial	5

Then the hazard potential score of DO is (5 + 4 + 5 + 5 + 5)/5 = 24/5 = 4.8. The hazard potential of all the parameters was calculated in the similar way.

Utility (U): When the importance of the parameters was determined on the basis of their utilities, their usefulness was assessed from the literature qualitatively. The qualitative values were then converted to quantitative values using a scale of 1–5 (Table 2).

Table 2 Scale of utility of the parameters

Criteria	Most useful	Very useful	Moderately useful	Less useful	Least useful
Scale	5	4	3	2	1

The scoring of utility was calculated by combining the quantitative values from all the literature surveyed (Eq. 4).

Equation 4 Scoring of utility of the parameters

$$I_U = \frac{\sum U_i}{N} \quad (4)$$

where

I_H Relative importance score of a hazard potential of a parameter
U_i Importance value (according to the scale of 1–5) of utility in ith literature for that parameter
N Number of literature surveyed.

For example, the parameter temperature was found to be moderately useful as per some related literature. The qualitative importance of temperature was assigned in the following manner for each of the papers surveyed:

Paper	Hazard potential	Score
1	Moderately useful	3
2	Moderately useful	3
3	Very useful	4
4	Moderately useful	3
5	Less useful	2

Then the utility score of pH is (3 + 3 + 4 + 3 + 2)/5 = 15/5 = 3. The utility of all the parameters was calculated in the similar way.

Cost (C): Cost of mitigation of native impacts of each of the WQP was also determined in the similar way.

Citation Frequency (F): The citation frequencies of the parameters were determined from their citation scores (Eq. 5).

Equation 5 Citation frequency of parameters from Literature Survey

$$F = \frac{S}{100} \quad (5)$$

where, F = Citation frequency and S = Citation score.

Determination of Weights of the Criteria

The opinions of five experts were taken to assess the relative importance of the criteria. The scale of importance is given in Table 3.

The importance values of the criteria were calculated by multiplying the scale value with the number of experts, given that importance scores (Eq. 6).

Table 3 Scale of importance of the criteria

Importance	Most important	Important	Moderately important	Less important	Not important
Scale	5	4	3	2	1

Equation 6 Calculation of Relative Importance of the Criteria

$$I = \frac{\sum S \times E}{N} \tag{6}$$

where

- I Relative importance score of a parameter
- S A Scale value (1–5)
- E Number of Experts, given that value to that parameter
- N Number of Experts.

For the criterion utility, the evaluations of the experts were as follows:

Expert No.	Evaluation	Score
1	Moderately important	3
2	Important	4
3	Moderately important	3
4	Important	4
5	Moderately important	3

So, the Relative Importance Score of utility is ((3 × 3) + (4 × 2))/5 = (9 + 8)/5 = 17/5 = 3.4. The Relative Importance Score of all the criteria was calculated in the similar way.

Determination of Weights of the Parameters

The weights of the parameters were determined using MCDM methods like Analytical Hierarchy Process (AHP) and Fuzzy Logic Decision-Making (FLDM) and their combinations.

Weights by AHP

For the determination of weights by AHP method, the comparison matrix of the selected criteria was prepared from their citation frequencies (Eq. 2) and the criteria score was calculated. Then comparison matrices of all the parameters were prepared for each of the criterion, using Saaty scale (Saaty 1977). After that, the scores were worked out my multiplying the matrix of criteria scores with that of parameter scores. The normalized values of the importance scores were taken as the weights of the parameters.

Weights by FLDM

Similarly, the weights of fuzzy comparison matrices of the criteria and the parameters were prepared using FLDM. The multiplication of matrices of the importance scores of the criteria and parameters was performed to find out the final importance scores of the parameters. The normalized values of the importance scores from FLDM process were taken as the weights of the parameters in the similar manner.

Weights by Combination of AHP and FLDM

The weights of the parameters were determined in another way. The scores of the qualitative criteria (i.e., whose comparison was done qualitatively) were determined by FLDM and that of quantitative criteria (i.e., whose comparison was done quantitatively) were determined by AHP. The similar procedure was followed to find out the scores of the parameters. Then the fuzzy values were converted to crisp values to form the matrices. Again, the normalized values of the matrices were taken as the weights of the parameters.

Weights by Hybrid of AHP and FLDM

Yet another method was applied—the standard AHP procedure was followed, but the comparison of the criteria and parameters was performed using FLDM. In this case also, the matrices of the importance scores of the criteria and parameters were multiplied to obtain importance scores. The normalized values of the importance scores were taken as the weights of the parameters as usual.

Aggregated Weight

Finally, the mean values of the weights of each of the parameters, worked out by different procedures, were calculated. These values were named as Aggregated

Table 4 Key differences among the methods used

	AHP	FLDM	Combined AHP-FLDM	AHP-FLDM hybrid	Aggregated score
Procedure followed	AHP	FLDM	AHP	AHP	Mean values of the scores from these four methods were taken
Comparison procedure	Crisp	Fuzzy	Crisp for Quantitative criteria, Fuzzy for Qualitative criteria	Fuzzy	

Weight of the parameters. The key differences among the methods used for the determination of the priorities of the parameters are summarized in Table 4.

Validation of the Proposed Method

A WQI was developed from the priority values of the parameters, determined by the proposed method. For validation of the proposed method, sensitivity analysis and scenario analysis on different landscape patterns were performed. The WQI was also compared with NSF WQI.

Case Study

Samples were collected from 38 different water bodies of South and West of Tripura, a state located in the north eastern part of India. The WQIs of the samples were calculated using the different indices, developed by applying different MCDM methods.

Developing WQI with the Determined Priorities of the Parameters

Different WQIs (MCDM WQI) were developed using the weights of the parameters calculated by the MCDM method to verify its applicability. The sub-index values were calculated by multiplying the weights of respective parameters with their Q values (Eq. 7) (Brown et al. 1970).

Equation 7 Calculation of AHP WQI

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \tag{7}$$

where

Q_i Q value for ith water quality parameter
W_i Weight associated with ith water quality parameter
n Number of water quality parameters.

Sensitivity Analysis

Sensitivity analysis of the parameters was performed in respect to WQI using tornado model (Eschenbach 2006). The importance scores of the parameters were compared with their sensitivity to verify whether the most important parameters are the most sensitive also.

Comparison of the MCDM WQI with NSF WQI

WQIs of the same samples were calculated using the National Sanitation Foundation Water Quality Index (NSF WQI) (Brown et al. 1970). The values of MCDM WQI were then compared with that of NSF WQI. The difference between the MCDM WQI and NSF WQI was assessed by Mean Absolute Percentage Deviation (MAPD) (Eq. 8) (Hyndman and Athanasopoulos 2013).

Equation 8 Calculation of MAPD of WQI from NSF WQI

$$\mathrm{MAPD} = \frac{100}{n}\sum_{i=1}^{n}\frac{N_i - M_i}{\mathrm{N}_i} \tag{8}$$

where,

N_i NSF WQI of ith sample
M_i WQI of ith sample by proposed methods
n Number of samples.

Result and Discussion

Selection of Parameters

In the 182 literatures surveyed, 51 water quality parameters were found. The total numbers of times all those parameters used were found as 765. Now, the parameter pH was found 49 times in those literatures. Therefore, the citation score of pH is

Table 5 Citation scores of various water quality parameters found in the literature

SL	Parameters	Citation score	SL	Parameters	Citation score
1	DO	7.71	27	Cadmium	1.18
2	BOD	7.06	28	Selenium	1.18
3	pH	6.41	29	Zinc	1.18
4	Phosphate	5.62	30	Sodium	0.78
5	Temperature	5.36	31	Hardness	0.78
6	Nitrate	4.84	32	Iron	0.78
7	TS	4.71	33	Barium	0.78
8	Turbidity	4.58	34	Anionic Surfactant	0.78
9	Conductivity	3.86	35	Alkalinity	0.39
10	Ammonia	3.62	36	Salinity	0.39
11	Nitrite	3.13	37	Boron	0.39
12	Chloride	2.98	38	Carbonate	0.39
13	Sulfate	2.89	39	Calcium	0.39
14	TDS	2.87	40	Magnesium	0.39
15	COD	2.88	41	Manganese	0.39
16	Fecal Coliform	1.96	42	TOC	0.39
17	Arsenic	1.96	43	Cryptosporidium	0.39
18	Chromium VI	1.96	44	Aluminium	0.39
19	TKN	1.77	45	Silver	0.39
20	Total Coliform	1.67	46	Cyanide	0.39
21	Lead	1.67	47	Nickel	0.39
22	Copper	1.57	48	TA	0.39
23	Fluoride	1.28	49	SAR	0.39
24	TS	1.21	50	Oil & Grease	0.39
25	Color	1.18	51	Oxidation Ability	0.39
26	Mercury	1.18			

$\frac{49}{765} \times 100 = 6.41$. The citation scores of all the parameters were calculated in the similar way. The selected parameters and their citations scores are given in Table 5.

The first eight parameters (Dissolved Oxygen, pH, Temperature, Biochemical Oxygen Demand, Phosphate, Nitrate, Total Solids, and Turbidity) were selected for the present study.

Determination of the Priorities of the Parameters

The priorities of the selected parameters were determined, using AHP, FLDM, and their combinations. The hierarchy of the criteria and the parameters are described schematically in Fig. 1.

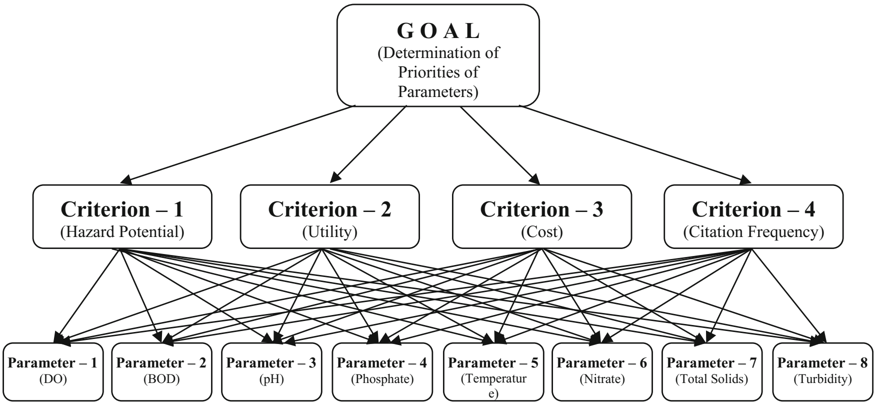

Fig. 1 Hierarchy diagram for criteria and parameters

Weights of the Criteria

The weights of the selected criteria were worked out first by pair-wise comparison of their Relative Importance Score (Eq. 4). The normalized eigenvectors of the comparison matrix were taken as the scores of the criteria. The ranking of the criteria is given in Table 6.

The relative importance of hazard potential was found to be maximum, and that of citation frequency was found to be minimum.

Weights of the Parameters

The weights of the parameter were done on the basis of the selected criteria using different methods—AHP, FLDM, Combined AHP-FLDM, AHP-FLDM Hybrid and their Aggregated Score. The ranking of the parameters, found by the different methods, is given in Table 7.

It was observed that DO ranks highest and Turbidity and Total Solids tend to be in lower ranks for all the criteria.

Table 6 Ranking of criteria

	Criteria score	Rank
Hazard potential	0.5872	1
Utility	0.2179	2
Cost	0.1228	3
Citation frequency	0.0722	4

Table 7 Ranking of the parameters with respect to the criteria

Parameters	Hazard potential (qualitative)	Utility (qualitative)	Cost (quantitative)	Citation frequency (quantitative)
DO	1	1	1	1
pH	2	3	8	3
BOD	6	4	2	4
Temperature	7	2	4	5
Phosphate	5	5	6	2
Nitrate	3	6	5	7
Turbidity	4	7	7	8
Total solids	8	8	3	6

Case Study

A case study was performed for the validation of the proposed method for determining the PV of WQP.

MCDM WQI

WQIs were developed from the PV of the different MCDM methods and collectively called as MCDM WQI. The MCDM WQIs were calculated similarly as NSF WQI as it is an established and widely used one. Now, there are nine parameters, recommended for NSF WQI and their weights are in a scale of 1 (i.e., the sum of the weights of all the parameters is 1). In the present study, eight parameters were selected and their weights are also in the scale of 1. As there is a mismatch in the number of parameters, a correction factor (Eq. 9) was used to scale both the indices similarly.

Equation 9 Calculation of the Correction Factor

$$\text{Correction Factor} = \frac{\sum P_{\text{NSF}}}{\sum P_{\text{MCDM}}} \tag{9}$$

where

P_{NSF} Weights of the common parameters in NSF and
P_{MCDM} Weights of the common parameters in Proposed.

The Correction Factor was found to be 0.84 (Eq. 8) which is the sum of the weights of common parameters in NSF WQI. Therefore, 0.84 was multiplied with each of the weights of the selected parameter for the purpose of scaling (Table 8), so that the sum of weights of all the common parameters in both of the methods is

Table 8 Weights of the parameters

Parameters	Corrected weights of the parameters					NSF WQI weights
	AHP	FLDM	Combined AHP-FLDM	AHP-FLDM hybrid	Aggregated score	
Dissolved oxygen	0.17	0.16	0.12	0.16	0.15	0.17
pH	0.10	0.10	0.09	0.10	0.10	0.11
BOD	0.12	0.11	0.14	0.12	0.12	0.11
Temperature	0.09	0.09	0.11	0.09	0.10	0.10
Total phosphate	0.10	0.11	0.11	0.10	0.11	0.10
Nitrates	0.10	0.10	0.09	0.10	0.10	0.10
Turbidity	0.09	0.09	0.07	0.08	0.08	0.08
Total solids	0.07	0.08	0.11	0.08	0.09	0.07

equal. The scaled scores were taken as the weights for the WQI of the proposed method.

The WQI was then calculated using these weights of the parameters. Q values were determined as per the method of NSF WQI.

Sensitivity Analysis

The relative sensitivity of all the input parameters toward the WQI was calculated by the single factor analysis using Tornado technique (Eschenbach 2006). The results show that the first three most prioritized parameters (DO, BOD, and pH) are also the first three most sensitive parameters. Again, the least important parameter (Total Solids) was found to be least sensitive also. Thus, weights of importance, as given by the MCDM methods, were found to support the results from sensitivity analysis (Table 9).

Table 9 Sensitivity analysis of the parameters

Parameters	Sensitivity	AHP weights	FLDM weights	Combined AHP-FLDM weights	AHP-FLDM hybrid weights	Aggregated weights
Dissolved oxygen	0.39	0.20	0.19	0.19	0.20	0.20
pH	0.14	0.12	0.12	0.12	0.11	0.12
BOD	0.38	0.14	0.14	0.14	0.14	0.14
Temperature	0.01	0.11	0.11	0.11	0.13	0.11
Total Phosphate	0.03	0.12	0.13	0.13	0.12	0.12
Nitrates	0.02	0.12	0.12	0.11	0.11	0.11
Turbidity	0.03	0.10	0.10	0.10	0.11	0.10
Total solids	0.01	0.09	0.10	0.11	0.09	0.10

Table 10 Analysis of the water quality of the samples

METHODS	AHP	FLDM	Combined AHP-FLDM	AHP-FLDM hybrid	Aggregated	NSF
Mean value of WQI	64	64	64	64	64	64
Mean interpretation	Medium	Medium	Medium	Medium	Medium	Medium
Standard deviation	7.16	6.86	6.92	7.03	6.98	6.94
Skewness	−0.40	−0.33	−0.29	−0.39	−0.35	−0.43
Kurtosis	0.34	0.41	−0.27	0.31	0.18	0.39
85th percentile	70	70	70	70	70	70

Statistical Analysis

Water quality of most (78%) of the samples was found to be medium. The mean water quality was also found medium with the WQI value of 64 (Table 10). A low standard deviation (about 7) of the WQI values of the samples shows that there are little variations in water quality among the samples (Table 10). The low skewness and kurtosis values of the WQI values also support the fact by indication that the values are close to each other (Table 10). However, negative values of skewness suggest that the water quality spreads a little bit toward bad rather than good (Table 10). Only 15% of the samples have good water quality as the 85th percentile of the values is 70—the threshold value of good water quality (Table 10).

Comparison of MCDM WQI with NSF WQI

The graphical representation of the WQI, by all the methods, shows similar patterns (Fig. 2). The graphs were prepared by plotting the WQI points in an increasing order and joining them with smooth lines.

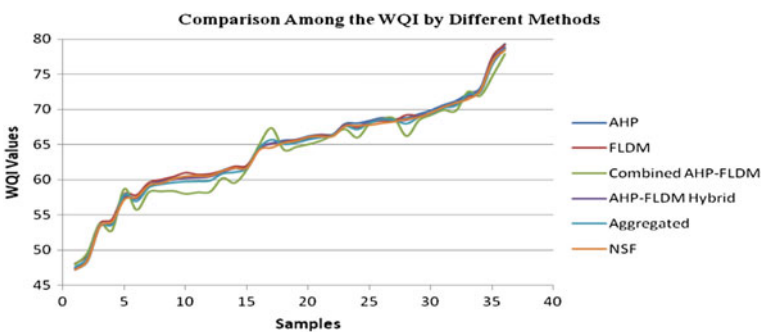

Fig. 2 Comparison graph of the WQI values of different methods

Table 11 MAPD of the WQI by proposed methods from NSF WQI

	AHP WQI	FLDM WQI	Combined AHP-FLDM WQI	AHP-FLDM hybrid WQI	Aggregated WQI
MAPD (%)	0.42	0.57	1.81	0.29	0.59

All the WQI were found to be very close to NSF WQI, except the APH-FLDM Hybrid WQI, which exhibits more conservative values (MAPD = 3.49%) than NSF WQI (Table 11). The reason of such behavior seems to be contributed by fuzzy method, as it is known to give conservative output values. Among the other methods, AHP WQI was found to be the closest (MAPD = 0.42%) to NSF WQI, followed by Combined AHP-FLDM WQI (MAPD = 0.44%) and FLDM WQI (MAPD = 0.57%) (Table 11). The Aggregated WQI was also fairly close (MAPD = 0.64%) to the NSF WQI (Table 11).

Thus, it was found that among the outputs of the different methods, the Hybrid AHP-FLDM method is closest to the outputs of NSF method (MAPD = 0.29%). Therefore, the **Hybrid AHP-FLDM** method seems to be more appropriate than the other MCDM methods used in this study.

Conclusion

The present investigation attempted to determine the priority values of water quality parameters in agricultural runoff for estimation of WQI on the basis of hazard potential, utility, cost of mitigation, and citation frequencies of the parameters. The method was developed in such a manner that subjective and preferential treatment may get minimized. The weights of parameters were determined by the output of AHP, FLDM, Combined AHP-FLDM and AHP-FLDM Hybrid methods, which help to estimate the weights as a direct representation of the importance of parameters in depiction of overall quality of water. The MCDM WQI was compared with NSF WQI for validation. The most important PV were also found to be the most sensitive toward the respective WQI and *vice versa*.

All these methods of validation showed accuracy (close to NSF WQI), applicability (found by sensitivity analysis) and reliability (found by statistical analysis) of the indices. According to the results, DO and Total Solids were found to have the highest and lowest priorities respectively, among the eight parameters considered, in assessing the overall water quality. The sensitivity analysis showed that the most important parameters are the most sensitive also, toward the WQI. Among the methods used, the AHP-FLDM Hybrid WQI was found to be the closest (MAPD = 0.29%) to NSF WQI, followed by Combined AHP WQI (MAPD = 0.42%), FLDM WQI (MAPD = 0.57%) and Aggregated WQI (MAPD = 0.59%). However, AHP-FLDM Combination WQI deviates more (MAPD = 1.81%) from NSF WQI and tends to give comparatively extreme outputs.

In the present study, the criteria considered were the hazard potential, cost, utility, and citation frequency of the parameters. In future studies, more different criteria such as effects of the parameters on aquatic (e.g., insects, fishes, algae, planktons) and terrestrial biodiversity (both plants and animals), crop type, crop yield, human health, etc., may be included while estimating their priorities. Also, other MCDM methods (e.g.. Analytic Network Process, Weighted Sum Method, Weighted Product Method, Simple Additive Weight, Grey Relational Analysis, etc.) and their combinations may be used to determine the priorities in similar studies.

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Aerosol Optical Depth Variation During a Recent Dust Event in North India

Manu Mehta, Vaishali Sharma and Gaurav Jyoti Doley

Abstract Aerosols play a vital role in influencing the climate both by cooling and warming up the Earth's surface and also by altering the cloud properties. Due to natural and large amount of anthropogenic factors, Indian region observes high variability of loadings in aerosols both in terms of space and time in the planetary boundary layer. Dust storms in India exert momentous influences on weather, air quality, and climate of the country. Detection and monitoring of aerosol optical depth (AOD) at the time of dust storms is challenging, especially in case of short life time of events, and strong interaction with climatic parameters. This paper addresses the study of a dust storm event which hit Indian (North) region on June 13, 2015 parts of Haryana, Punjab, Delhi, UP were affected. AOD variations over the North Indian region has been studied using MODIS level 2 data (MOD04) obtained NASA Terra platform at a spatial resolution of 10 km × 10 km.

Keywords AOD · Dust storm · MODIS

Introduction

Satellite-based remote sensing estimations permit precise way of retrieval of aerosol optical properties on both local and global rate (Kaufman et al. 2005; Kahn et al. 2010). Dust storms are one of the major sources of aerosols in Northern India;

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especially in spring and summer seasons. Aerosol loading is increased during the pre-monsoon season (summer season, April–June) in the Indo-Gangetic plains because of large influx from higher range transport of mineral dust aerosols from the western arid zone (Dey et al. 2004; El-Askary et al. 2004, 2006; Singh et al. 2004; Prasad and Singh 2007). A firm convection in summer took after by a deeper boundary layer, and addition of dust events results in higher aerosol optical depth (AOD) during summer (Singh et al. 2004). Dust particles can directly modify the surface radiation budget in both visible (VS) and infrared (IR) spectral regions that leads to temperature variation of earth's surface and therefore impacting the exchange processes between the earth's surface and atmosphere, as well as climatic dynamics (Alpert et al. 2004) and chemical and biological environment (Singh et al. 2004). Detection of dust storms is challenging because of the short-life existence, multiple scales and strong bonding with the local surface and meteorological conditions. Because of specific optical features of dust storms, satellite-observed radiances having the spectral signatures of dust particles are different from those of other atmospheric components (Zhao 2012). This paper presents the aerosol optical depth (AOD) variation during a dust storm event that hit over northern part of India, i.e., Delhi, NCR, Haryana regions during June 13, 2015. The satellite data at a spatial resolution 10 km × 10 km is taken from Moderate resolution Imaging Spectro-radio-meter (MODIS) onboard Terra platform.

Study Area, Data, and Method

Study area includes parts of Haryana, Himachal Pradesh, Punjab, U.P., and the Union Territories of Delhi, NCR, and Chandigarh. This region lies in Indo-Gangetic plains covering 28°N–35° N and 70°E–78°E. According to Indian Meteorological department (IMD), temperature frequently rises above 35 °C over the significant part of the Indo-Gangetic plain during summer. During winter, the lowest temperature on the plains falls to below 5 °C at some places (Fig. 1).

The AOD data before the dust storm (June 7, 11, 12, 2015), during the dust storm (13th June 2015) and after the dust storm (June 14, 15, 16, 19, 20, 2015 and July 1, 2, 2015) is visualized to have clear idea of the impact of the storm.

MODIS is a near-polar satellite sensor which is on board NASA's Terra platform. It has a swath of 2,330 km (cross track) by 10 km (along track at nadir) orbiting at an altitude of 705 km and measures reflected solar radiance and global emission in 36 spectral bands (wavelength ranges from to 0.415–14.5 μm) with resolution varying between 0.25 and 1 km at nadir. The MODIS retrieval algorithm considers a lookup table methodology, in which arranged aerosol types, loadings, and geometry are expected to, span the range of global aerosol conditions (Remer et al. 2005, 2010; Levy et al. 2010). The algorithm matches the lookup table with the measured spectral reflectance.

In this paper MODIS level 2 daily aerosol data (MOD04_L2) (http://laadsweb.nascom.nasa.gov), at a spatial resolution of 10 km × 10 km at nadir, collected

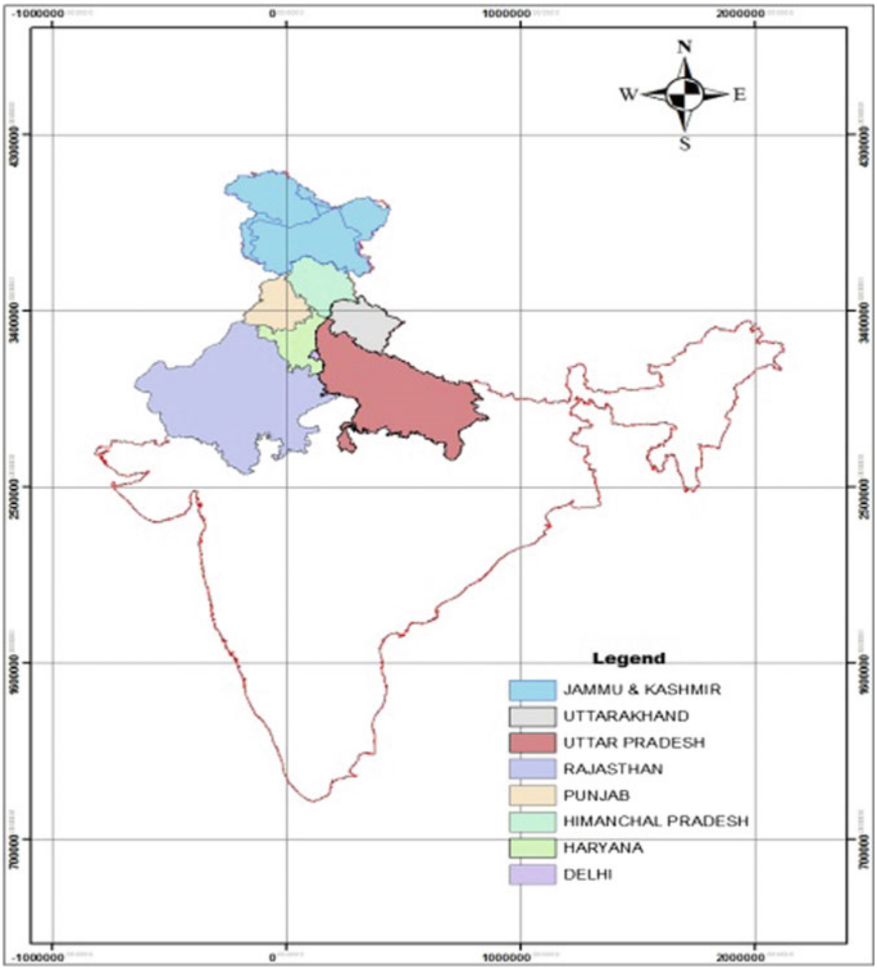

Fig. 1 Study area

from Terra V005 daily 0.55 µm AOD are used to study the AOD variation. Study of AOD variations due to dust storm from the study area before, during and the prevalence of the AOD over the area is performed. The study area undergoes some rainfall during this period making loss of data in some bits from the data obtained. The product used here is generally accessible as scaled integer (SI) value which has been converted to the value of optical depth, i.e., optical depth land and ocean, using a standard conversion formula with a given scale factor of 0.001.

Results and Conclusions

From Fig. 2, it can be seen that the area affected during dust storm covers the regions of Northern India, mainly Rajasthan, Haryana, Delhi and Punjab and later the AOD value increase over the Indo-Gangetic plain. Before the storm the values of the AOD in the region varied from 0.4 to 0.7 i.e. from the period of June–June 7–11, 2015. The AOD values increases to 1.0 at some portion of the study area during the storm period i.e., June 12–14, 2015. It is interesting to note that even after 6 days, (19 June 2015), the AOD values remain high in the considered study regime. This indicates

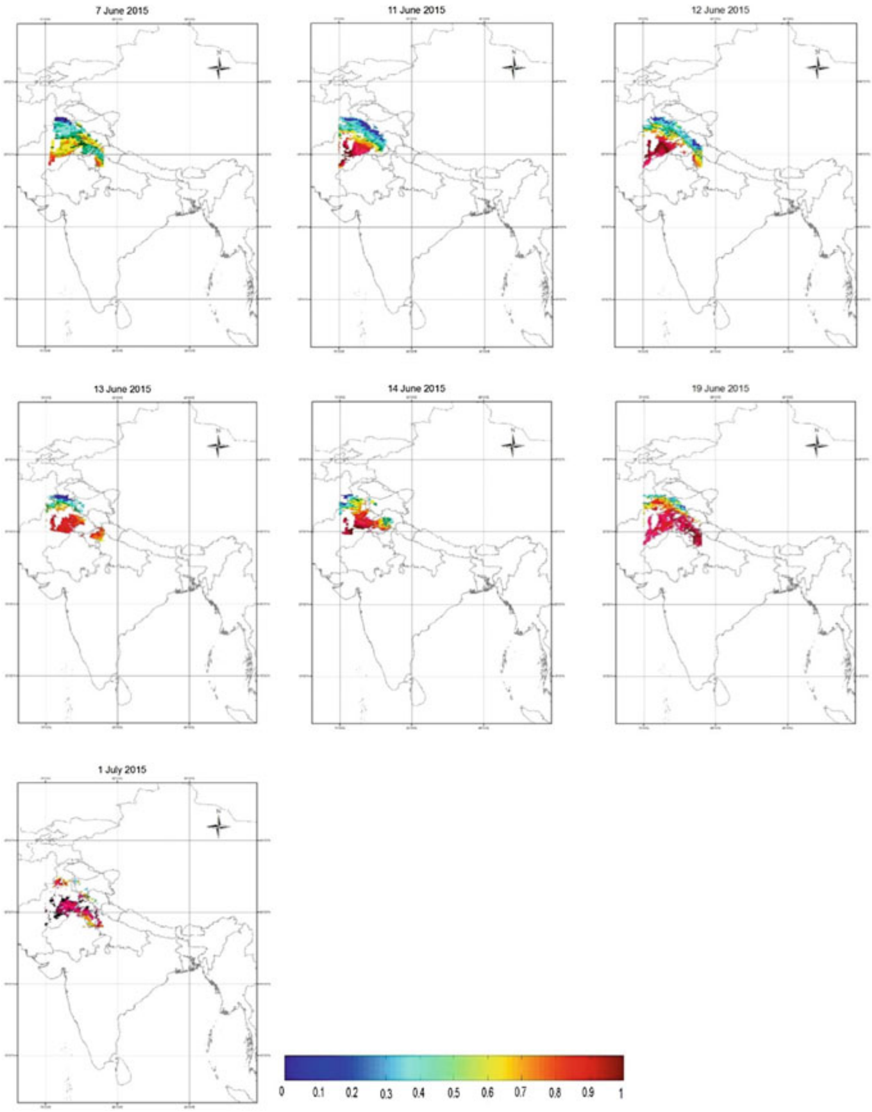

Fig. 2 AOD variations before, during and after dust storm

the longer stay times of dust particles in the atmosphere. A much later image of July 1, 2015 also depicts higher AOD values in the North West India. The variation shows the accumulation of mineral dust over the study area for long time duration.

The future work in the allied area can also include a detailed trajectory analysis for the source and sink identification of dust storm affected areas, along with quantified analysis of aerosol loading.

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