B. B. Jana · R. N. Mandal
P. Jayasankar *Editors*

Wastewater Management Through Aquaculture

Springer

Wastewater Management Through Aquaculture

B. B. Jana • R. N. Mandal • P. Jayasankar
Editors

Wastewater Management Through Aquaculture

Springer

Editors
B. B. Jana
International Centre for Ecological Engineering
University of Kalyani
Kalyani, West Bengal, India

Centre for Environmental Protection & Human Resource Development (Kalyani Shine India)
Kalyani, West Bengal, India

R. N. Mandal
Central Institute of Freshwater Aquaculture
ICAR
Kolkata, West Bengal, India

P. Jayasankar
Central Institute of Freshwater Aquaculture
ICAR
Bhubaneswar, Odisha, India

ISBN 978-981-10-7247-5 ISBN 978-981-10-7248-2 (eBook)
https://doi.org/10.1007/978-981-10-7248-2

Library of Congress Control Number: 2017962306

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword

The efficient use of freshwater is an important concern for the future, because many areas in the world are facing water scarcity on a continual basis or during drought years. The major use of freshwater globally is for food production. Aquaculture is a particularly water-intensive activity, and it competes with traditional agriculture for freshwater in many areas. There is urgent need to improve water use efficiency in all types of agriculture – aquaculture included.

One way of improving water use in aquaculture is by increasing the intensity of production. The largest production sector is pond aquaculture, in which fertilizers are applied to increase the availability of natural feed or manufactured feeds are applied. Fertilized ponds already tend to be managed for the highest level of production possible. The production of aquaculture feed requires a large amount of water for producing plant meals included as ingredients. The water embodied in feed often greatly exceeds the direct water use in ponds. Thus, the opportunities for reducing water use in conventional pond culture through intensification are limited.

Wastewater aquaculture provides a means to lessen water use in ponds. By adding wastewater to ponds, an equal amount of freshwater is conserved. Wastewater also contains nutrients and this lessens fertilizer requirements in ponds. Thus, both water and nutrients are conserved. There is another benefit of wastewater aquaculture; natural processes in ponds remove nutrients, suspended solids, and organic matter from the wastewater. This improves the quality of the wastewater when it is ultimately discharged downstream.

Previous studies have revealed that fish from wastewater aquaculture are safe for human consumption. Nevertheless, there are areas of the world where consumers will not eat fish produced in wastewater. There are other areas where consumers will accept fish grown in wastewater, and wastewater aquaculture has considerable potential in these areas.

Considerable research has been conducted on wastewater aquaculture, but much remains to be done in order to realize the full potential of this resource. This book *Wastewater Management Through Aquaculture* provides a thorough, in-depth assessment of previous findings on the use of wastewater in aquaculture. It covers issues such as integrated planning and design of projects, health risks, production techniques, case studies, results of ongoing projects, and future research needs. The chapters have been prepared by respected scientists who have considerable experience with wastewater aquaculture. The coverage is quite complete, and I believe that this book will be of great interest to all who are involved in wastewater aquaculture or seek information about its potential.

Auburn, Alabama, USA
17 January 2017

Claude E. Boyd

Preface

It is needless to say that the demand for freshwater has been tripled during the last 50 years and is projected to increase by 70% in terms of surface water by 2025. Heavy demand of freshwater results in much depletion of groundwater level accompanied by withdrawal-driven groundwater pollution especially arsenic contamination in drinking water sources in many countries as well as pollution in surface water resources. As a result, concern has been raised about the quality and quantity deterioration of freshwater. Discharge of untreated or partly treated municipal wastewater causes contamination and eutrophication of inland water sources particularly in water-scarce and economically poor countries where facilities for conventional wastewater treatment are inadequate. Climate change has further aggravated the situation with its major implications on ecosystems and human life. It is most urgent to protect and conserve inland water resources to accomplish the ecosystem functionality and sustainable development processes. Hence, the present volume *Wastewater Management Through Aquaculture* has been a noble attempt which is the need of the hour.

In fact, municipal wastewater is the storehouse of fertilizers due to its immense nutrient potentials of phosphorus, nitrogen, and potassium and increasingly high rates of wastewater generation resulting from increased population and urbanization. Hence, wastewater has been rightly called as a resource out of place, and a huge sum of money in the form of chemical fertilizers is not only lost through unmanaged drainage of municipal wastewater every day, but it also causes environmental pollution and eutrophication of water bodies. Municipal wastewater poses a triple-win climate-smart agri-aquaculture strategy toward conservation of water for multiple uses, environmental protection, as well as food and nutritional security by turning wastes into wealth in the form of fish biomass and allied cash crops. Therefore, it is pertinent to respect society's discarded materials as resource. Lack of proper management of wastewater may result in triple losses – environmental degradation, monetary loss from fertilizers, and loss of valuable water source.

As the present and future scenarios of water crisis have been conceived worldwide, the cutting-edge researches and tailor-made solutions are in progress not only to protect and conserve valuable freshwater resources but also to use, reuse, and promote multiple uses of wastewater generated from various anthropogenic activities. Wastewater-fed aquaculture is a unique integrated biosystem in which organic wastes generated by the first system are used by the next subsystem for fish production as means of food and nutritional security mediated through an ecosystem resilient dependent self-purification process and microbial-autotrophic-heterotrophic complex food web mechanism. Though wastewater-fed aquaculture using more than 45 species of indigenous and exotic fishes has been practiced by farmers for a long time in a traditional way as self-wisdom, its scientific exploration and application of proven technologies have been focused in recent years for harnessing the resources in a sustainable way for water conservation and protection of biodiversity in wetlands.

Altogether 16 chapters have been compiled in the present volume, and the contents of this book have been broadly divided into four parts: (a) Understanding the Fundamentals of Soil-Water Interactions and Biogeochemical Nutrient Dynamics, (b) Culture Practices of Wastewater-Fed Aquaculture, (c) Strategies Toward Wastewater Reclamation Using Green and Sustainable Technologies, and (d) Economic Perspectives of Wastewater, Environmental Impact Assessment, and Environmental Law and Regulations.

Healthy soils are of utmost importance to a variety of ecosystem services they provide in aquatic systems. Pond soils act as a source or as a sink of nutrients depending upon the nutrient input and pond metabolism. In view of global cycling of carbon and climate change, the wetland ecosystem has a key role to control the balance of carbon, whether the system becomes a net carbon source or sink. An enhanced, holistic understanding of interactions between soils and overlying water and primary ecosystem drivers in mixed aquatic and soil systems is paramount to developing adaptive strategies to mitigate climate change and strategies for guiding their future construction and management to maximize their beneficial use while minimizing negative environmental impacts. The roles of different biogeochemical cycling bacteria such as heterotrophic, nitrifying and denitrifying, phosphate-solubilizing, and cellulose-decomposing bacteria as well as their activities on degradation and nutrient cycling of carbon, nitrogen, and phosphorus and autotrophic and heterotrophic food chain have been elucidated in a series of sewage-fed ponds placed in a waste stabilization pond system. Dominance of detritus food chain over the grazing food chain in all ponds within a waste stabilization pond system (anaerobic, facultative, and maturation) has been focused. The supremacy of facultative ponds has been reported to be most dynamic than the remaining ponds investigated. The importance of such basic understanding for encouraging healthy conditions and animal associations of the pond bottom particularly in wastewater-fed systems has been highlighted in the first part.

Wastewater-fed-aquaculture-related responses to counteract negative driving forces, pressures, and impacts associated with inadequate sanitation and wastewater treatment and to enhance the state of systems are systematically reviewed with the DPSIR framework. Prospects for a rational design-based approach to safe wastewater reuse using treatment lagoons and cutting-edge biorefinery approaches have been highlighted. Conditions required to support and promote safe wastewater-fed aquaculture are assessed using the STEPS (social, technical, environmental, political/institutional, and sustainability) framework. A SWOT (strengths, weaknesses, opportunities, and threats) assessment is presented concerning the future development of safe wastewater reuse through aquaculture. It is predicted that widespread adoption of wastewater reuse through aquaculture could contribute to achieving targets specified for sanitation and safe wastewater reuse by 2030 in accordance with the United Nations' Sustainable Development Goals. This demands the large-scale and rational uses of municipal wastewater worldwide especially in developing countries with enormous potentials of wastewater.

In developing countries, sewage-fed aquaculture has immense potential to develop into an effective alternate system of fish production in the backdrop of freshwater scarcity and increased farm income. Importance of nutrient harvesting from liquid wastes through aquaculture production in vertically integrated systems has been elucidated along with dominance of heterotrophic microbial pathway. High fish yield to the tune of 5 ton/ha/year at the downstream of the waste stabilization pond system testifies the ecological efficiency of wastewater in the conversion of wastes to wealth through aquaculture. This has been possible by the application of different aspects of management that has been developed through long-term dedicated researches of the country. However, urbanization pressure, improved economic condition, and betterment in the health quality standards warranted imposition of different safety standards in wastewater aquaculture and quality of the produce with respect to microbial load and other pollutants.

The significance of wastewater-fed aquaculture with unique case studies of the East Kolkata Wetlands, an important Ramsar site and one of the largest and oldest wastewater aquaculture systems of the world, has been focused that renders livelihood opportunity to a large section of local people through production of cheap protein food source – fish. However, maintenance of proper ecological conditions is of utmost importance in a wastewater-fed system as enhancement of fish production is often limited by suboptimal water quality and chemical stressors that cause manifestations of different diseases. However, such stress-sensitive manifestation of fish diseases often occurs in farmed ponds under the prevalence of suboptimal ecological conditions.

Sustainable production of fish yield or biomass in a wastewater system contaminated by inorganic and organic pollutants warrants the effective management of wastewater. As a part of enhanced treatment mechanism, application of ecological engineering is highly preferred in developing countries in view of low cost for natural, green, and sustainable technology based on nature's library in the tropical and subtropical zones, where the concept of an engineered resilient ecosystem is being applied to treat partially treated municipal wastewater for beneficial reuse and multiple uses. Macrophytes, microalgae, probiotics, annelids, mollusks, crustaceans, fishes, etc. have been rightly designated as living machines due to their immense beneficial biofilter potentials for remediation/reclamation of eutrophic water bodies, heavy metal-contaminated perturbed aquatic habitats, etc.

Various methods for bioremediation such as biostimulation, bioaugmentation, plant-based assisted bioremediation, phytoremediation, biofilm, periphyton-based bioremediation, biofloc technology, biodegradation, biotransformation, enzymatic bioremediation, recombinant DNA technology, biosorption, and nutriremediation have been presented in the third section. Apart from different basic methods employed for wastewater treatment, recent techniques such as cavitation, high-rate algal pond system, and biotechnology have also been elucidated. Application of nanomaterials such as carbon-based nanoadsorbents, metal-based nanoadsorbents, polymeric nanoadsorbents, nanomaterial-based membranes, and nanofiber membranes for water and wastewater treatment has been elaborated.

Among the technologies available, adsorption has widely been used for the removal of various contaminants from aqueous media, and accordingly different adsorbents have already been prepared over the years. The comprehensive, up-to-date, and critical information on the adsorption of different heavy metal pollutants by various types of biosorbents and polymer-based synthetic adsorbents has been documented. Nevertheless, the waste stabilization pond (WSP) system has gained its importance as an integral tool for treating wastewater as well as for linking with economic-driven activities of fish culture and culture of vegetable crops in aquaponic systems.

Aquaponics is a green and sustainable eco-technological approach integrating aquaculture in a hydroponic system and can play a pivotal role in harnessing nutrients from wastewater resources; it has been focused in the third section of the present volume. Concurrent production of fish crops and green vegetables or other medicinal aquatic plants can also fetch high income from wastewater that will lead to protection and conservation of wastewater by controlling the water loss through surface evaporation and promoting aquatic production through vegetable crops.

The fourth part deals with economic perspectives of water reuse potentials of treated wastewater in different economic-driven activities such as agricultural and landscape irrigation; industrial processes; athletic fields, schoolyards, and playgrounds; edges and central reservations of highways; irrigation of landscaped areas around public, residential, commercial, and industrial buildings; and many others. Partially reclaimed wastewater is used for decorative and ornamental purposes such as fountains, reflecting pools and waterfalls, etc. It is frequently used for fire protection and toilet and urinal flushing in commercial and industrial buildings. In general, low-quality wastewater is widely used for agriculture and aquaculture, whereas treated wastewater is exploited in high-income countries. Industrial water consumption was up to 22% of global water use. Industrial water use in Europe and North America accounted for half of their total water use, whereas in developing countries, it is about 4–12% of national water use. In the process of reusing wastewater in aquaculture, the externality costs are social costs incurred for public health protection as the system is associated with health risk. In order to perform a comprehensive cost-benefit analysis, it is necessary to evaluate all these environmental, social, and ecological impacts by valuing them in monetized way by eliciting people's willingness to pay (WTP), shadow price, and opportunity cost. Recycled water is often more expensive than existing water supply. Efficiency of wastewater recycling in developed countries should be increased to reduce the cost of supply of recycled water so that it can compete efficiently with alternative sources of water. Proper planning, management, and regulation are necessary for effective reuse of municipal wastewater for different activities.

The environmental impact assessment of the East Kolkata Wetlands (EKW) has been discussed using six generic steps. It also focused on the process of "initial environmental examination" (IEE) and "strategic environmental assessment" (SEA) which are recognized as the outcome of Agenda 21. Finally, impact analysis of cultured fishes through histological, histochemical, topological, and enzymological studies has been elucidated.

So far as the environmental law and regulations are concerned within the framework of the United Nations Conference on the Human Environment (1972), it laid emphasis on protection and improvement of environment for inter- and intra-generational equity. India as a participatory nation by 42nd amendment of the constitution incorporated provisions under Art. 48A and Art. 51A (g) for protection and improvement of natural environment. Consequently, by considering alarming effects of solid, liquid, or e-wastes on the environment, various rules are framed by the central government for establishment of regulatory authorities to manage the situation.

It is anticipated that the contents of the book will be useful to students, teachers, researchers, administrators, planners, farmers, and entrepreneurs who make a strong effort on the profitable use of wastewater within the framework of wastes into wealth for the welfare of human society and multiple uses of water in the hour of inevitable freshwater crisis. Further, this would help in achieving targets specified for sanitation and safe wastewater reuse by 2030 in accordance with the United Nations' Sustainable Development Goals.

We urge the readers to consider different innovative technologies and to utilize the low-tech traditional knowledge of the locals to explore the tailor-made appropriate solution to counter the negative impact of environmental pollution caused by discharge of untreated wastewater and promote the safe multiple uses of treated wastewater for societal sustainable development, especially for food and nutritional security and allied economic activities toward conservation of water and protection of our invaluable biodiversity as well as sustaining the clean and green Earth.

Kalyani, West Bengal, India B. B. Jana
Kolkata, West Bengal, India R. N. Mandal
Bhubaneswar, Odisha, India P. Jayasankar

Acknowledgments

The editors would like to thank the director of ICAR-CIFA, Bhubaneswar, for initiating the proposal of the present volume. We thankfully acknowledge the management of Springer Nature, especially their office in Delhi, India, for their helpful cooperation and kindly agreeing to publish the manuscript of the present book. We also record our sincere thanks to all the contributors for their timely submission of the respective manuscripts.

Contents

Contributors

S. Adhikari ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar, Odisha, India

S. K. Bag International Centre for Ecological Engineering, University of Kalyani, Kalyani, West Bengal, India

J. N. Bhakta International Centre for Ecological Engineering, University of Kalyani, Kalyani, West Bengal, India

V. S. Bharti Aquatic Environmental Management Section, Aquatic Environment & Health Management Division, ICAR-Central Institute of Fisheries Education, Versova, Mumbai, India

Stuart W. Bunting Bunting Aquaculture, Agriculture and Aquatic Resources Conservation Services, Suffolk, UK

P. P. Chakrabarti Regional Research Centre, ICAR-Central Institute of Freshwater Aquaculture, Kolkata, India

D. N. Chattopadhyay Regional Research Centre, ICAR-Central Institute of Freshwater Aquaculture, Kolkata, India

A. Das Regional Research Centre, ICAR-Central Institute of Freshwater Aquaculture, Kolkata, India

Manas Kr. Das Fisheries Resource and Environmental Management Division, ICAR-Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India

Shamik Das Directorate of Fisheries, Government of West Bengal, Meen Bhavan, Kolkata, West Bengal, India

S. K. Das Department of Aquaculture, Faculty of Fishery Sciences, West Bengal University of Animal and Fishery Sciences, Panchasayar, Kolkata, West Bengal, India

S. Datta ICAR-Central Institute of Fisheries Education, Salt Lake, Kolkata, India

Peter Edwards Asian Institute of Technology, Bangkok, Thailand

A. R. Ghosh Ecotoxicology Lab, Department of Environmental Science, The University of Burdwan, Burdwan, West Bengal, India

Debarati Ghosh International Centre for Ecological Engineering, University of Kalyani, Kalyani, West Bengal, India

Sasidulal Ghosh Bidhannagar Agro & Fisheries Projects Pvt. Ltd., Kolkata, West Bengal, India

S. Gita Aquatic Environmental Management Section, Aquatic Environment & Health Management Division, ICAR-Central Institute of Fisheries Education, Versova, Mumbai, India

Ken Gnanakan William Carey University, Shillong, Meghalaya, India

ACTS Group of Institutions, Bangalore, India

Johannes Heeb Seecon International GmbH and Cewas, Willisau, Switzerland

A. Hussan Regional Research Centre, ICAR-Central Institute of Freshwater Aquaculture, Kolkata, India

B. B. Jana International Centre for Ecological Engineering, University of Kalyani, West Bengal, India

Centre for Environmental Protection & Human Resource Development (Kalyani Shine India), Kalyani, West Bengal, India

S. Jana Department of Fisheries Economics & Statistics, West Bengal University of Animal & Fishery Sciences, Kolkata, West Bengal, India

Centre for Environmental Protection & Human Resource Development (KSI), Kalyani, West Bengal, India

P. Jayasankar ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar, Orissa, India

D. Kole Ecotoxicology Lab, Department of Environmental Science, University of Burdwan, Burdwan, West Bengal, India

Kishore K. Krishnani ICAR-National Institute of Abiotic Stress Management, Baramati/Pune, Maharashtra, India

Kundan Kumar Aquatic Environmental Management Section, Aquatic Environment & Health Management Division, ICAR-Central Institute of Fisheries Education, Versova, Mumbai, India

Neeraj Kumar ICAR-National Institute of Abiotic Stress Management, Baramati/Pune, Maharashtra, India

Saurav Kumar Aquatic Environmental Management Section, Aquatic Environment & Health Management Division, ICAR-Central Institute of Fisheries Education, Mumbai, India

S. Lahiri International Centre for Ecological Engineering, University of Kalyani, Kalyani, West Bengal, India

B. K. Mahapatra ICAR-Central Institute of Fisheries Education, Kolkata, India

A. Mandal Department of Aquaculture, College of Fisheries, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab, India

R. N. Mandal Regional Research Centre, ICAR-Central Institute of Freshwater Aquaculture, Kolkata, India

S. Mandal International Centre for Ecological Engineering, University of Kalyani, Kalyani, West Bengal, India

K. K. Meena ICAR-National Institute of Abiotic Stress Management, Baramati/Pune, Maharashtra, India

S. Mondal Ecotoxicology Lab, Department of Environmental Science, The University of Burdwan, Burdwan, West Bengal, India

B. N. Paul Regional Research Centre, ICAR-Central Institute of Freshwater Aquaculture, Kolkata, India

G. Rathi Bhuvaneswari Aquatic Environmental Management Section, Aquatic Environment & Health Management Division, ICAR-Central Institute of Fisheries Education, Versova, Mumbai, India

S. K. Sadhu Department of Law, University of Burdwan, Burdwan, West Bengal, India

Dipanwita Sarkar (Paria) Department of Zoology, Chandernagore College, Chandannagar, Hooghly, West Bengal, India

Subhas Sarkar ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar, Odisha, India

S. P. Shukla Aquatic Environmental Management Section, Aquatic Environment & Health Management Division, ICAR-Central Institute of Fisheries Education, Versova, Mumbai, India

N. P. Singh ICAR-National Institute of Abiotic Stress Management, Baramati/Pune, Maharashtra, India

About the Editors

B. B. Jana a fellow of the National Academy of Agricultural Sciences, New Delhi, as well as some other prestigious academies in India and recipient of the Joy Govinda Memorial Award of the Asiatic Society, is emeritus fellow and academic advisor in the International Centre for Ecological Engineering, University of Kalyani, West Bengal, India. He did his doctorate on aquatic ecology and microbiology and worked as postdoctoral fellow of the then USSR and DAAD visiting fellow in the University of Hamburg, Germany. He has published several monographs, books, and contributed chapters in the UNESCO Encyclopedia and over 235 papers in peer-reviewed journals and supervised 32 Ph.D. students. As a principal investigator, he is the recipient of many national and international projects funded by the European Commission, GTZ and TTZ, ICAR, UGC, CSIR, DST, DBT, DOEn, the government of India, etc. His domain of research includes wastewater aquaculture, ecological sanitation, eco-restoration, ecological engineering, microbial nutrient cycling, integrated organic farming, impact of global warming and climate change in aquaculture, water conservation, etc. A board member of the International Ecological Engineering Society, Switzerland, and editorial board member of several important journals, Professor Jana has extensively traveled abroad and chaired and/or participated and invited speakers in many international conferences held in many countries of the world. At present, his passion is eco-sanitation particularly for the use of human urine as alternative chemical fertilizer. One of his papers published in *Ecological Engineering* has been highlighted in News@Nature.com (doi: https://doi.org/10.1038/news070625-13). His another current publication on human urine has also been highlighted and covered in the *IndUS Business Journal* (http//indusbusinessjournal.com), August 28, 2016, which reads as "Now human urine as an organic alternative to chemical fertilizers" (http//indusbusinessjournal.com/2016/08/now-humanurine-organic-alternative-chemical-fertilizers/). As a secretary, his mission has been focused on outreach programs and extension activities at the grassroots level which are being implemented through his own founded NGO, Kalyani Shine India (www.kalyanishineindia.org), also known as the Centre for Environmental Protection and Human Resource Development, aimed at alleviating rural poverty and ensuring protection and conservation of biodiversity, environment, and water resources.

R. N. Mandal did his M.Sc. and Ph.D. in Botany from the University of Calcutta. Presently, Dr. Mandal has been in the position of principal scientist in the Aquaculture Production and Environment Division (APED), Indian Council of Agricultural Research-Central Institute of Freshwater Aquaculture (ICAR-CIFA), Rahara, Kolkata, West Bengal, India. Dr. Mandal is now working on wastewater-fed aquaculture as the principal investigator in a sewage-fed aquaculture farm in Rahara and deals with different aspects of sewage-fed aquaculture in farmers' field in East Kolkata Wetlands (EKW). He has been working on the management of both aquatic and wetland plants, including utility of beneficial flora and removal of nuisance ones, in the perspective of aquaculture. He has also guided students for their master's dissertation. He has published a number of articles in refereed scientific journals of high repute.

P. Jayasankar has spent 31 years as a researcher in fisheries, including fishery biology and fish stock assessment, phenotypic/genotypic stock structure analysis, evaluation of genetic heterogeneity and molecular taxonomy/DNA barcoding (fish, shellfish, and cetaceans), genetic linkage mapping and QTL, genomic selection, molecular marker-based fish hybrid identification, and transgenics. Recently, Dr. Jayasankar has taken up research on environmental DNA (eDNA). He has published over 150 peer-reviewed papers and books and edited book chapters. He has also guided eight students for their master's and Ph.D. dissertation. As a research and administration manager (ex-director of ICAR-CIFA, Bhubaneswar, India), he contributed toward extension of freshwater aquaculture technology and established linkages among researchers and the industry.

Acronyms

ALPase	Alkaline phosphatase
AB	Ammonifying bacteria
AOB	Ammonia-oxidizing bacteria
EKW	East Kolkata Wetlands
LEISA	Low-external-input sustainable aquaculture
BCR	Benefit-cost ratio
BFT	Biofloc technology
BOD	Biochemical oxygen demand
BMP	Best management practices
CIFA	Central Institute of Freshwater Aquaculture
CPCB	Central Pollution Control Board
CER	Cost-effectiveness ratio
C:N:P	Carbon-nitrogen-phosphorus
COD	Chemical oxygen demand
CREAMS	Chemicals, runoff, and erosion from agricultural management systems
DNB	Denitrifying bacteria
DO	Dissolved oxygen
DPSIR	Driving forces-pressures-state-impacts-responses
DWF	Dry weather flow
EIA	Ecological impact assessment
EIA	Environmental impact assessment
ETA	Ethanolamine
FAO	Food and Agriculture Organization
FACWet	Functional assessment of Colorado Wetlands
FAME	Fatty acid methyl ester
FCR	Food conversion ratio
FQA	Floristic quality assessment
FSH	Follicle-stimulating hormone
EKWL	East Kolkata Wetlands location
GLEAMS	Groundwater loading effects of agricultural management systems
GPP	Gross primary productivity
HB	Heterotrophic bacteria
HRAPs	High-rate algal pond system

HPI	Hypothalamic-pituitary-interrenal
ICAR	Indian Council of Agricultural Research
ICER	Incremental cost-effectiveness ratio
IEE	Initial environmental examination
IMTA	Integrated multi-trophic aquaculture
IRR	Internal rate of return
IUCN	International Union for Conservation of Nature
IWMED	Institute of Wetland Management and Ecological Design
KMWSA	Kolkata Municipal Water Sanitation Authority
LIM	Landscape integrity model
LH	Luteinizing hormone
MFC	Microbial fuel cell
NF	Nanofiltration
NRCP	National River Conservation Plan
NPV	Net present value
NPP	Net primary productivity
NB	Nitrifying bacteria
NFB	Nitrogen-fixing bacteria
NPK	Nitrogen (N)-phosphorus (P)-potash (K)
NFT	Nutrient film technique
NWI	National Wetlands Inventory
OC	Opportunity cost
PCR	Polymerase chain reaction
PEG	Polyethylene glycol
PFC	Proper functioning condition
PPTA	Project preparatory technical assistance
PNCs	Polymer-clay nanocomposites
PMB	Protein-mineralizing bacteria
ROS	Reactive oxygen species
SEM	Scanning electron microscope
SDGs	Sustainable Development Goals
SGOT	Serum glutamate oxaloacetate transaminase
SGPT	Serum glutamate pyruvate transaminase
STP	Sewage treatment plant
SPC	Standard plate counts
SPCB	State Pollution Control Board
STEPS	Social, technical, environmental, political/institutional, and sustainability
EIA	Environmental impact assessment
SWOT	Strengths, weaknesses, opportunities, and threats
TFC	Thin-film composite
TFN	Thin-film nanocomposite
TMDL	Total maximum daily load
TOC	Total organic carbon

TOD	Total organic dissolved
UN	United Nations
USEPA	United States Environmental Protection Agency
VIBI	Vegetation index of biotic integrity
WQI	Water quality index
WSP	Waste stabilization pond
WHO	World Health Organization
WTP	Willingness to pay
ZWEAPS	Zero-water exchange aquaculture production system

Part I
Understanding the Fundamentals of Soil-Water Interactions and Biogeochemical Nutrient Dynamics

Chapter 1
Understanding the Soil-Water Interactions for Sustainable Ecosystem Services in Aquatic Environments

B. B. Jana, S. Lahiri, D. Ghosh, J. N. Bhakta, S. Mandal, and S. K. Bag

Abstract Healthy soils are of the utmost importance to society for the variety of ecosystem services they provide in both terrestrial and aquatic systems. Within aquatic systems, soils play an active role in carbon cycling and interactions between soils and water, and additional components of aquatic ecosystems can control the balance of carbon, whether the system becomes a net carbon source or sink. Understanding the interactions between soils and overlying water is crucial to developing adaptive strategies to mitigate climate change. An enhanced, holistic understanding of primary ecosystem drivers in mixed aquatic and soil systems is paramount for guiding their future construction and management to maximize their beneficial use while minimizing negative environmental impacts. Aeration and water circulation devices can be used to improve dissolved oxygen content of the wastewater pond system. Raking may be practiced to improve the ecological conditions of pond soils for encouraging healthy conditions and animal associations of the pond bottom particularly in wastewater-fed systems. The present chapter provides a review of different aspects of soil-water interactions and strategies to maintain ecosystem health for sustainable development.

Keywords Soil structure · Mud-water exchange · Soil composition · Biological production

Contents

B. B. Jana (✉)
International Centre for Ecological Engineering, University of Kalyani, Kalyani, West Bengal, India

Centre for Environmental Protection & Human Resource Development (Kalyani Shine India), Kalyani, West Bengal, India
e-mail: bbjana@gmail.com

S. Lahiri · D. Ghosh · J. N. Bhakta · S. Mandal · S. K. Bag
International Centre for Ecological Engineering, University of Kalyani, Kalyani, West Bengal, India

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_1

1.1 Introduction

Healthy soils are vital for maintaining robust biological production in aquatic ecosystems. The interactions between physical, chemical, and biological properties of soil help regulate aquatic ecosystem function, and soil can play a role in damping or amplifying the effects of environmental perturbations on aquatic systems. In addition to overall health, soil also plays an active role in carbon cycling in aquatic systems. In different cases, soils can act as either a carbon sink (Boyd et al. 2010) or source of carbon emission (Natchimuthu et al. 2014). Hence soils not only play an important role in the nutrient dynamics and productivity of aquatic ecosystems but also, through the carbon cycle, in climate dynamics. Understanding the functional connectivity (e.g., nutrient supply, biogeochemical cycling, etc.) between soils and aquatic ecosystems is crucial to developing a thorough, fundamental understanding of these dynamic systems, as well as being able to predict how the systems will respond to environmental perturbation and what adaptive strategies can be implemented to improve aquatic ecosystem resistance and resilience to this change. The role of soils in aquatic ecosystems is thus pertinent to developing adaptive strategies to mitigate climate change. Wetlands and large-scale aquaculture ponds provide multiple test cases for probing mechanisms of soil-water interactions and their influence on the productivity of aquatic ecosystems. An enhanced, holistic understanding of primary ecosystem drivers in mixed aquatic and soil systems is paramount for guiding their future construction and management to maximize their beneficial use while minimizing negative environmental impacts.

1.2 Ecology and Productivity of Wetlands

An aquatic environment can be conceptualized as an ecosystem containing interacting biotic and abiotic components hosted in a permanent or seasonally water-saturated zone. The biotic component of pond ecosystem consists of autotrophs and a suite of micro- and macroconsumers and saprotrophic organisms. The primary abiotic factors include water, soils, nutrients, and the local climatic regime (Fig. 1.1).

Soils can provide a source of vital nutrient inputs necessary for biological productivity. For instance, decomposable biomass in the water column may accumulate at or within the soil surface where biological activity can remineralize the nutrients to make them available to fuel additional primary productivity or heterotrophic interactions. In this role, soils regulate the biological productivity of the wetland through decomposition and degradation of organic matter through the consumptive actions of a vast array of bacteria, flagellates, fungi, and macro- and microinvertebrates that live at or near the soil-water interface. While aquaculture ponds have some fundamental distinctions from natural systems (e.g., additions of anthropogenic fertilizer to these ponds may shift traditional nutrient limitations),

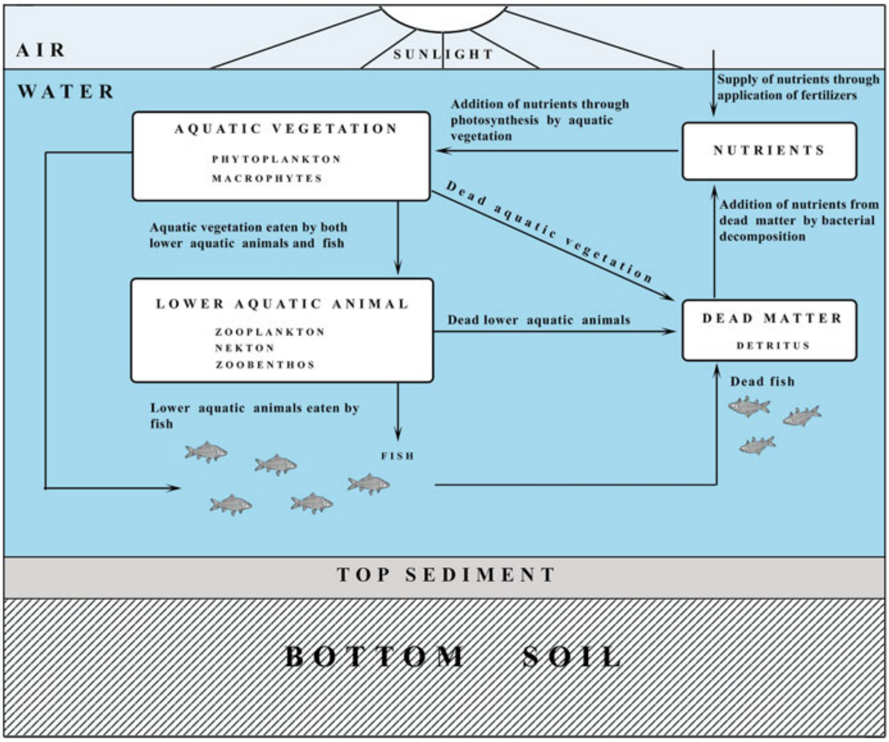


Fig. 1.1 A pond ecosystem showing the interactions of abiotic and biotic factors and food chain dynamics. Top sediment and bottom soil of aquatic system are also shown

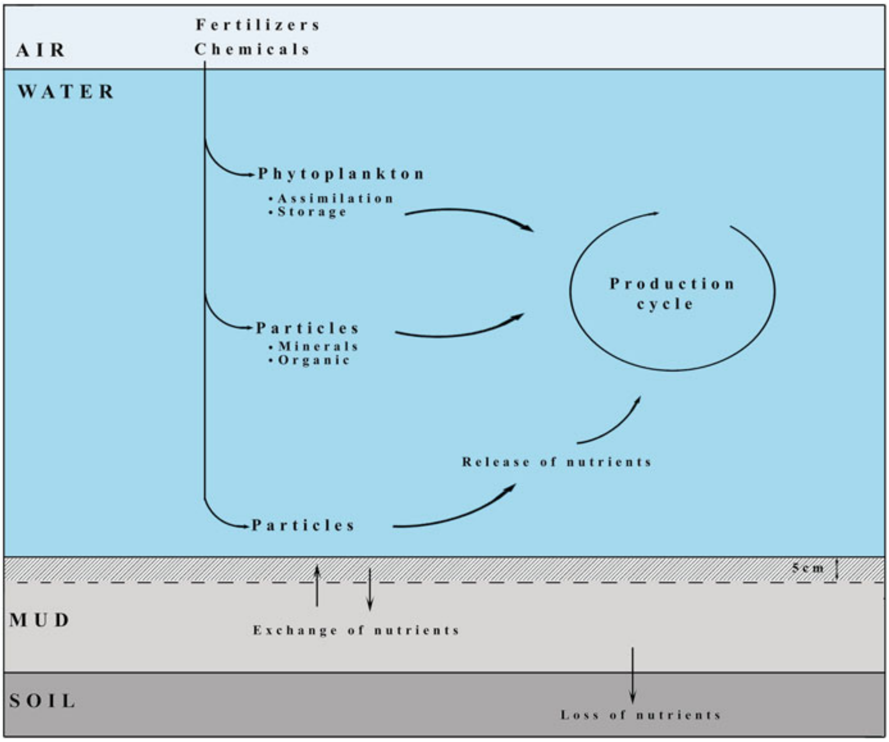


Fig. 1.2 Fate of fertilizers and manure in fish ponds: Most of the particles settle on the top of the mud layer and are released as nutrients for the production cycle in the water column

soils are nonetheless still crucial to overall nutrient cycling. For instance, in organic, manure-fed fish ponds, a large part of fish production can be linked to microbial processes that remineralize the added organics in the soil and make these nutrients available to stimulate fish productivity (Fig. 1.2). This cycling highlights a vulnerability of the aquatic system since decreased soil health can ultimately constrain overall system health and productivity. Further, if soil is unable to actively recycle the added nutrient pool (manure) contained in the municipal wastewater, this could trigger the buildup of the added material and ultimately the transition from the manure being a community resource into an effective waste component.

With a view to enhance reclamation process, more utilization of major food resources, reuse of wastewater for economic-driven activities, and promotion of climate-resilient aquafarming, selection of species of fish in wastewater-fed aquaculture is of major importance. The selected species should be hardy so as to capable of withstanding relatively adverse ecological conditions due to wide diurnal fluctuations of dissolved oxygen and pH of water. In general, cultured fishes of different feeding habits occupy different habitats and ecological niches such as herbivores, detritivores, carnivores, and omnivores. Because of the feeding preference for algae and vegetation, herbivorous fishes such as silver carp and grass carp are well known as low-carbon footprint species, and they are often selected for fish culture. Benthic-oriented species such as common carp, black carp, and tilapia are most suitable species for culture as they consume mostly the benthic invertebrates, decayed vegetation, and detritus available on the pond. Further, bottom-dwelling fishes help reclaim wastewater through physical bioturbation-driven sediment oxidation inducing microbial activities providing congenial environment for nutrient release to the overlying water.

1.3 Structure of Wetland Soils

The soil structure underlying an aquatic system can, at its most fundamental level, be divided into two major divisions: a deeper, bottom soil zone and an upper, top sediment that forms above the bottom soil. Bottom soils themselves can be subdivided to include a more shallow layer which is lighter in color, less compacted, and fairly well aerated and is compositionally a mixture of colloidal mineral and organic matter. The underlying lower layer of the bottom soil, in contrast, is generally anoxic, darker in color (e.g., gray or black) due to the resulting geochemistry (low redox potential, high abundance of ferrous iron and other minerals), and more compacted than the upper layer. The topmost flocculent layer (F) and both oxidized and reduced sediment layers (S) of soil profiles have been emphasized in aquaculture pond because of their roles in nutrient exchange with overlying water and the influence of interaction on water quality (Boyd 2012). Further, the proportions of these two layers are also important in regulating the soil properties and productivity of the ponds. Hence, the top sediment layer of pond is constantly in direct contact with overlying water and performs the exchange mechanism.

At some level, the physical, chemical, and mineralogical features of pond soils are highly similar to those of agricultural soils. Yet, there are specific distinctions between pond and agricultural soils including the following: (1) conglomeration of different soil profiles, which are completely waterlogged, devoid of air-filled spaces, and depleted of oxygen, (2) ponds may have large catchment areas with input of nutrients and soil particles from the neighboring catchment areas and runoff water, (3) sedimentation of organic matter on the pond bottom, and (4) the 10–15 cm surface layer of pond soils tends to have a lower bulk density than found in surface of agricultural soils. Pond soils are also similar to wetland soils, although high-density aquatic vegetation is generally absent in managed aquaculture ponds, despite the fact that nutrient inputs in aquaculture ponds are typically much higher than for pristine wetlands. Wastewater-fed ponds tend to have more sedimentation or accumulation of organic matter contained in the sewage effluents.

Bottom soils influence a variety of water quality conditions in aquaculture ponds including pH, alkalinity, hardness, electrical conductivity, dissolved gases, total nitrogen, organic carbon, available nitrogen, C/N ratio, available phosphorus, and exchangeable calcium. The dynamics of nutrient cycling required for maintenance of these conditions for biological production are controlled through a series of chemical and biochemical reactions that occur at the soil-water interface. These reactions result in the release of essential and beneficial nutrients into the overlying water. The transformation of fertilizers added to aquaculture ponds also influences nutrient cycling. Moreover, bottom soils act as both nutrient sources and sinks depending upon their trophic state, and because the organic matter in pond soils increases over time, the nutrient content is usually higher in older ponds than in newly constructed ponds. For these reasons, bottom soils have been rightly called the chemical laboratory or kitchen of the pond. This is particularly true for wastewater-fed ponds.

Pond soils also impact the bioavailability of heavy metals, toxic elements, and pesticide residues in the water column by adsorption and desorption processes that occur in the bottom sediments. For example, toxic metabolites entering the well-oxygenated ponds may be quickly oxidized and have less toxic effects, but if the amount of toxic elements exceed the oxidation rate of the metabolites, the equilibrium levels of metabolites in the water can have detrimental effects on biotic community (Boyd et al. 2002).

1.3.1 Soil Formation

The formation of soil in aquatic systems is a dynamic process and depends upon a number of typical soil-forming factors including weathering, erosion, leaching, sedimentation, parent material, etc. Erosional processes (e.g., alluvial, fluvial, or resulting from bioperturbation) can introduce particulates into a pond. Two main processes can then aggregate these small particulates into larger structure: (1) electrochemical bonding in which the aggregation of negatively charged colloidal clay and/or humus particles are brought together to bridge water molecules and metallic ions, particularly calcium (Fig. 1.3), and (2) cementing, which involves the action of substances adsorbed on the surface of soil particles that effectively glue them together.

1.3.2 Soil Composition

The composition of soil plays a pivotal role in the biological productivity of aquatic systems. Soil texture is one of the important physical factors, whereas chemical factors such as soil reactivity (i.e., through pH) and nutrient status determine the water holding capacity and productivity of a pond. The elemental composition of various components combined with the organic matter content influences the chemical and biological properties of the soil.

Pond soils grouped as alluvial, black, red, and laterite soils are known to have higher amount of clay, silt, cation-exchange capacity, Ca, Mg, P, N, and organic

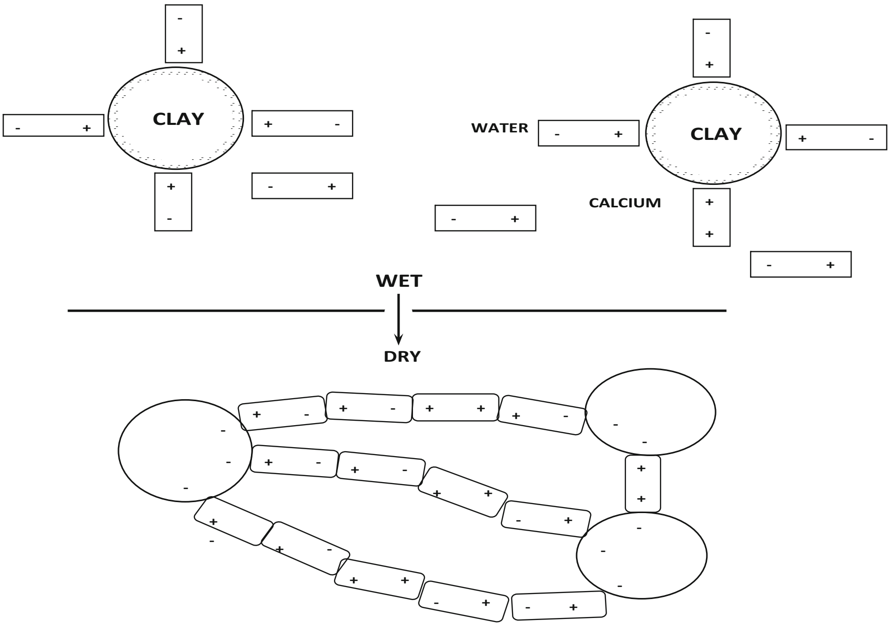


Fig. 1.3 Electrostatic bonding of clay particles in wet and dry conditions (Source: Boyd 2012)

matter with higher resulting water retention capacity than comparable terrestrial soils. Soils dominated by clay and silt tend to have high adsorptive and retention capacities for moisture, gases, and nutrients due to their large surface areas. Sand bottom and high clay bottom soils are not preferred for aquaculture because nutrients are either lost due to heavy leaching (sandy) or because high adsorption capacity removes nutrients from the overlying water (clay), resulting in poor recycling to the water column and reduced productivity. Sand and sandy loam soils are also typically low in colloidal clay and deficient in humus, whereas heavier soils contain more clay and more organic matter. Laterite soils are poor in phosphorus, potassium, calcium, and nitrogen and are usually acidic in reaction.

1.3.3 Clay Particles

Clay particles are generally considered to have a prominent role in maintaining water levels in constructed pond since layers of clay can vastly reduce water permeability, allowing water to be retained in a pond. Clay particles form layered structures typically categorized as a two-layer (e.g., kaolinite) or three-layer structure (e.g., montmorillonite). These structures are malleable and cohesive, capable of being molded into highly plastic forms. Water loss through an underlying soil horizon by seepage is a common phenomenon in pond without clay soil. For instance, Boyd (2012) has estimated that a pond made of fine sandy loam or sandy clay loam can lose over 14 inches of water a day. While a pond constructed from clay or clay loam (even if not properly packed) may lose only one inch of water in a day. Ponds constructed with clay layers which have been properly compacted may lose as little as ~0.002 inch of water in a day, illustrating the impact clay can have in physically retaining the water column of a pond (Boyd 2012).Water loss by vertical seepage through soil horizon is not a problem in wastewater-fed ponds as the pond bottoms contain large quantity of organic matter and humus as blanket.

1.3.4 The Top Sediment

The top sediment of the pond bottom is a true mud, composed of fine soil particles and deposits of finer particle organic matter, as well as high molecular weight humus materials. The topography of the pond changes over time as the topsoil matures resulting from both sedimentation of organic matters and erosion of pond embankment. This is particularly true in the shallow zones of large ponds where some areas are subject to erosion and in the deep central parts of ponds that receive high sedimentation. Pond bottoms are also subject to accumulation of plant-derived organic matter from planktonic aquatic vegetation, further enhancing sedimentation rates.

1.4 Sediment Composition

The upper layer of the pond sediment consists of (a) organic matter in various stages of decomposition and (b) particulate mineral matter, including clays, carbonates, and non-clay silicates, and inorganic component of biogenic origin. The topsoil (typically up to 3.5 cm thick) and different layers of the mud affect resident microbial populations. The superficial layer (up to 1.5 cm thick) of the topsoil is the major site for active decomposition and remineralization of organic matter due to the presence of large amounts of relatively labile heterogeneous humus (both acidic and neutral) compounds. Decomposition occurs mainly at the water-sediment interface, which is the site of nutrient exchange to the overlying water. Thus, in many respects, organic sediments in F (flocculent) layer of top sediment are similar to the uppermost A_o horizon (topsoil rich in organic load) in terrestrial soils.

1.4.1 Organic Matter

In general, a soil is classified as organic if more than 50% of the upper 80 cm layer is organic soil material. There are three basic types of soil materials: (a) fibric soil materials or peat soil materials containing mostly plant tissue excluding roots,

(b) sapric or muck soil materials containing highly decomposed organic matter, and (c) hemic soil materials that contain plant fibers filling one sixth to three fourths of their volumes. Wastewater-fed ponds belong to the second category with highly decomposed organic matter.

Decomposition of organic matter can result in formation of carbon dioxide (under oxic conditions) or methane (under anoxic conditions) (Sorokin and Kadota 1972). Decomposition can be impacted by soil pH (e.g., organics decompose more slowly in acid versus neutral or alkaline soils) and recalcitrance of the dominant organic compound (e.g., lignin decomposes more slowly than cellulose (Sahai 1999).

1.4.2 Humus

Humus refers to the organic matter, compost and complexes formed from a variety of natural organic substances. Humus materials are a complex aggregate of brown to dark color materials and formed from plant materials through the process of humification. Compositionally, humus is a recalcitrant, complex mixture of partial breakdown products of plant compounds. Typical pond humus contains mixtures of polyphenols, polyquinols, polyuronides, and polysaccharides. Humus is colloidal in nature, containing a high surface area and slow sedimentation rates. Pond soils with high colloidal content and humus have a high adsorption capacity for nutrients. Humus particles are closely associated with mineral particles in soil, which is important in accelerating soil aggregation and thereby decreasing the permeability of pond soils and enabling the pond to better retain water (Fig. 1.4). Depending upon the type of soil (e.g., peaty, fertile), the humus may be acidic, neutral, or alkaline in reaction and contain a mixture of colloidal acids, lime, and calcium salts. In wastewater systems, the deposition of humus or sludge is dominated by the input of organic matter. Similar situations may arise in aquatic systems having large numbers of trees, forests, or vegetation on the pond embankment. Pond soils can also adsorb phosphorus and potash. Such properties of humus reflect the chemical characteristics and productivity of overlying water.

1.4.3 Humic Acid

Humic acid is the principal component of soil humus, peat, and coal and is produced by biodegradation of dead organic matter. It is among the most biochemically active materials found in soil and can act both as a weak acid and a weak base. The base exchange capacity of humic acid is similar to that of inorganic colloidal clay, but it is three to seven times stronger than colloidal clay. It is made up of nearly 32% of protein-like material.

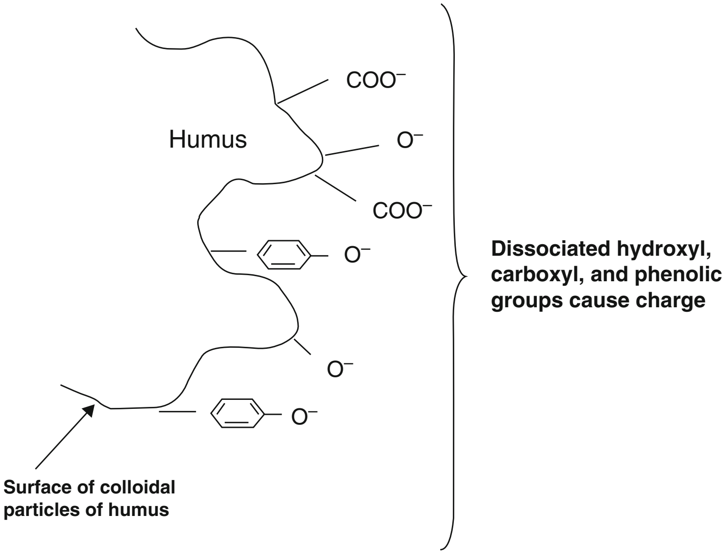


Fig. 1.4 Illustration of negative charges on humus (Source: Boyd 2012)

Humic acid has several beneficial impacts on the growth of microalgae and microbial activity in sediments and particularly in organically deficient soils. Within carbon-limiting systems, humic acid stimulates microbial activities of phosphate-solubilizing bacteria and other nutrient cycling bacteria by providing a needed source of carbon. In a similar fashion, the addition of organically rich wastewater can be used to stimulate microbial processes to enhance overall ecosystem nutritional content.

1.5 Acid Sulfate Soils

In some coastal areas, brackish water marshes contain iron pyrite (FeS_2) and become highly acidic upon exposure to air. Aquaculture ponds used mainly for shrimp farming, for example, are primarily constructed in acid sulfate soils in coastal areas. The sulfide layer of the soil refers to acidic soils caused by oxidation of iron pyrite, but pyrite is oxidized slowly in flooded soils. Since unusually high amounts of lime are required to neutralize the acid sulfate soils in shrimp farming ponds, a new approach has been developed that incorporates successive stages of drying, flooding, and flushing (Boyd 2012). However, wastewater-fed ponds located in acid sulfate soils would have interactions between acidic soils and organic loadings.

1.6 Soils in Pond Construction

Soil properties are an important consideration for construction of managed aquatic systems with properties including soil texture, organic matter content, and sulfide content often being the primary focus. Soil having at least 20% clay is necessary for construction of pond embankments and to prevent the seepage of water. However, ponds can be constructed in any site with modifications of construction, design, management, or maintenance of water. In wastewater-fed ponds, one of the serious issues of water loss through vertical seepage of water may be mitigated by gradual accumulation of organic matter that increases over the span of time.

1.7 Physical Properties of Soil

In general, redox potential decreases with increasing soil depth and vice versa. Highly anaerobic conditions induce the formation of methane (CH_4), nitrogen gas (N_2), or hydrogen sulfide (H_2S) and various organic acids that are harmful to aquaculture ponds (Natchimuthu et al. 2014). In wastewater-fed systems, high rates of organic matter decomposition at the soil-water interface can lower the redox potential and allow reduced substances to enter into the overlying water, which negatively affect aquatic life.

1.7.1 Oxidation-Reduction at Soil-Water Interface

Oxic bottom layers in ponds can provide a major sink for phosphorus and therefore control excessive phosphate levels in the water column and help prevent undesired surface eutrophication and algal blooms. Loss of the oxic surface layer (often resulting from unchecked microbial degradation of organic matter) results in the release of insoluble ferric phosphate from the sediment and its conversion to soluble ferrous phosphate in the overlying water column. Therefore, a healthy reducing state should be maintained in the pond bottom to optimize the water quality conditions for fish growth.

1.8 Chemical Properties of Soil

Pond soils act as an effective elemental buffer system, providing a source or sink for nutrients in the overlying waters and helping to maintain relatively stable nutrient concentrations in the overlying waters despite nutrient-related environmental perturbations.

The chemical nature of pond soils is largely driven by (1) the clay abundance (2 μm) that exists in a colloidal state (1–200 μm), (2) the capacity for ion adsorption (e.g., to provide binding sites for fertilizer addition to help buffer their aqueous concentrations), and (3) the origin of charges in soil and ion exchange; electric charges on soil colloids arise mainly from isomorphic substitution of one ion by another within the clay mineral structure, the ionization of OH groups, etc.

While examining the physico-chemical properties of soils at nine aquaculture ponds in Bangladesh, Siddique et al. (2012) observed a remarkable similarity between systems based on pond age (1.5 years, 6–10 years, and above 10 years). In short, there was a strong correlation between pond age and clay, silt, organic matter, and organic carbon content. In contrast, there was no correlation between age and pH.

1.9 Soil-Water Exchange

As mentioned above, pond soil can act as a buffer for aquatic nutrients. The contact layer between the soil surface and water is the major gateway connecting the nutritional buffering capacity of soil with the overlying water column. Substances stored in the pond soil are released to the overlying water through ion exchange, dissolution, and decomposition processes within this gateway. The exchange or dissolution mechanisms continue until an equilibrium is obtained between the soil and the water column. In an experimental study, the decline of phosphorus from the water column was logarithmic and within 30 days 70–90% of added phosphorus had been precipitated or bound in the soil (Boyd 2012).

The major factor impacting phosphorous availability in an aqueous system is the availability of aluminum, calcium, iron, and oxygen which drive the complexation with phosphorous. The solubility of aluminum, calcium, and iron phosphate is in turn strongly affected by the soil pH and redox potential. Under oxic conditions, both iron phosphate and aluminum phosphate behave in a similar manner, but iron phosphates show increased solubility under anoxic conditions. Therefore, the control of phosphate concentrations across the sediment-water exchange zone is sensitive to oxygen levels. This sensitivity highlights one of the connections between phosphorous and carbon cycling in pond soils where the increase in organic carbon inputs can drive decreases in soil redox potential and oxygen content resulting in increased phosphorous solubility.

In aerobic soil, much of the phosphorus is associated with amorphous ferric oxyhydroxide gels or is coprecipitated in coatings of ferric hydroxide surrounding silt or clay particles. Under reduced conditions in anoxic soils, ferric iron is reduced to soluble ferrous iron, and the associated phosphorus is solubilized with phosphorous being made more abundant in the overlying water column. Thus, in anaerobic soil, the pore water phosphorus concentration will typically be much higher than in pore waters of aerobic soil. The role of oxygen in aquatic soils was demonstrated in the experimental studies of Mortimer (1971), which revealed that as long as the oxygen concentration at the sediment surface did not fall below 1 or 2 mg/l, the

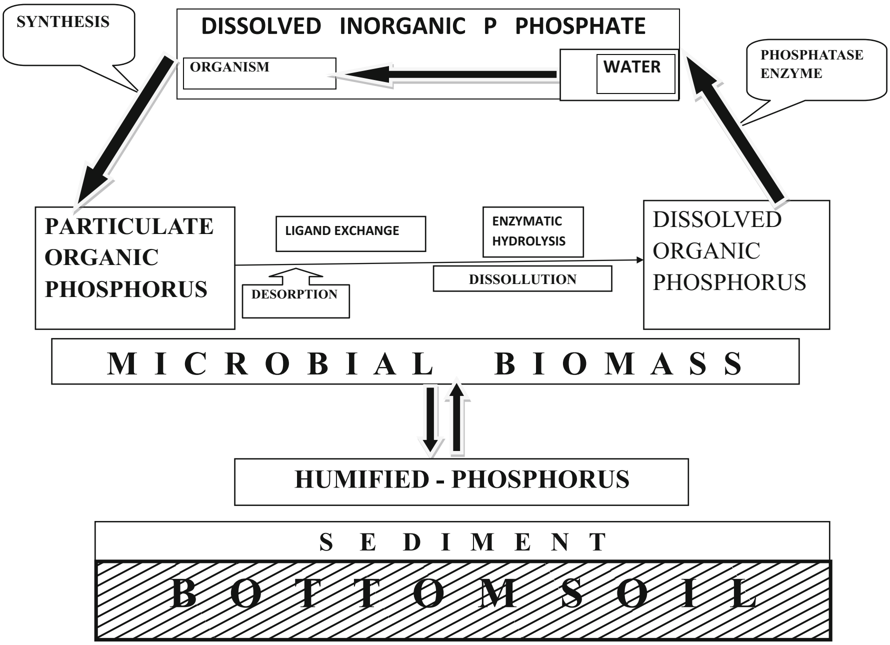


Fig. 1.5 Mud-water exchange of phosphorus in a pond system

deepwater sediments in Great Lakes appeared to exert a measurable, but quantitatively unimportant, influence on the chemistry of the overlying waters. The sequence of more conspicuous change takes place when oxygen falls below 1 mg/l at the interface. A progressive decline in oxygen concentration from 2 mg/l to analytical zero at the interface was accompanied by a fall in electrode potential in the upper few millimeters of sediment, which was correlated with mobilization and transfer into the water first of manganese and later of iron.

Except under highly acid conditions, most of the inorganic phosphorus in soil is bound up as insoluble $Ca_3(PO_4)_2$ and adsorbed phosphate on colloids. Further, the particulate organic phosphate in the sediment is transformed into dissolved organic phosphate and finally released into the water phase as dissolved inorganic phosphate (Fig. 1.5).

1.10 Microbial Activities

Microbial activities housed within pond soils help drive the soil biogeochemical cycling of nutrients and overall pond dynamics. Different groups of nutrient cycling bacteria are responsible for mineralization of carbon, nitrogen, and phosphorus, which are then released into the overlying water where they can stimulate biological productivity. Aerobic bacteria use molecular oxygen to oxidizing organic matter to carbon dioxide. Wastewater-fed ponds with accumulating organic matter can have very high biological oxygen demand which can reduce oxygen content or create anoxic zones within the soil. The anaerobic microorganisms within these oxic zones rely on a suite of fermentative and anaerobic respiration processes (e.g., methanogenesis; iron, manganese, or sulfate reduction; etc.) to continue the remineralization of organic carbon under anoxic conditions. Anaerobic metabolisms may rely on direct consumption of organic compounds or be secondarily linked to degradation of metabolites released by other microorganisms (e.g., organic acids, hydrogen gas, and/or carbon dioxide). In either case, anaerobic microorganisms use either direct generation of energy through fermentation or an anaerobic respiration utilizing suitable substrate as a terminal electron acceptor (e.g., carbon dioxide, ferric iron, sulfate, etc.). These respirations can drive more than just the carbon cycle by being linked to nitrogen, sulfur, iron, manganese, or other terminal electron acceptor. In some cases, the buildup of anaerobic metabolites can be released and harm aquatic life in the water column (e.g., the release of hydrogen sulfide generated from sulfate reduction can harm or kill fish). This mechanism is particularly true for wastewater-fed ponds where accumulation of organic matter predominates resulting in anaerobic state.

Microbiological investigations of bottom sediments in managed ponds are rather limited. However, available information suggest that the composition and nutrient status of the sediments play an important role in determining the density of different groups of biogeochemical cycling bacteria and their activities (Hoellein et al. 2013). For example, field investigations conducted in three farming systems with differences in species composition and management protocol revealed marked differences in soil characteristics among the ponds (Table 1.1).

Likewise, marked differences were also observed in the distribution of different groups of biogeochemical cycling bacteria (Table 1.2) and their activities (Table 1.3) (Barat and Jana 1987; Jana et al. 1982; Jana and Roy 1983, 1985a, b, 1986; Jana and Patel 1984a, b, 1985a, b, 1986).

The results revealed that the counts of heterotrophic bacteria (HB), nitrogen-fixing bacteria (NFB), nitrifying bacteria (NB), and denitrifying bacteria (DNB) were significantly higher in the surface sediments of all the three categories of ponds located in the site Kalyani compared to their counterparts located 20 km apart in Naihati, reflecting to the differences in soil profile. This suggests that the location of farm pond or rather composition and nutrient profile of the farm pond was more important than the composition of fish and the management protocol (culture system) used in regulating the N-cycling bacterial activities. However, the plate counts of ammonifying bacteria (AB) and protein-mineralizing bacteria (PMB) that occurred in sediments of Naihati ponds were higher compared to Kalyani correlating to enrichment with organic matter, resulting in reduced level of residual oxygen that limited nitrification processes. As a result, both the potential and actual rates of ammonification were higher in Naihati ponds than in Kalyani, implying an unfavorable state for nitrification in the former (Table 1.3). Further, both microbial population and their activities were distinctly higher in bottom sediment compared to water column regardless of farm sites suggesting that bottom sediment was potentially more productive than overlying water.

Table 1.1 Differences in soil criteria due to location and farming management

Soil parameters	Polyculture system				Monoculture system				Traditional system			
	Kalyani		Naihati		Kalyani		Naihati		Kalyani		Naihati	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
pH	7.3	6.6–7.7	7.3	6.6–7.8	7.4	7.1–7.8	7.1	6.7–7.5	6.7	6.0–7.4	7.4	7.0–7.6
$CaCO_3$ (%)	2.9	1.4–5.7	4.5	0.8–9.4	3.2	1.1–5.7	5.6	2.7–9.6	4.9	1.7–6.4	3.9	2.2–8.6
Organic carbon (%)	2.1	0.7–3.9	1.6	0.6–3.3	2.2	1.2–3.9	1.9	0.7–2.9	1.3	0.5–2.9	0.9	0.5–1.9
C/N ratio	35.8	15.9–57.3	26.9	11.5–39.3	31.1	19.7–45.4	27.6	13.8–43.1	35.5	12.3–65.8	39.7	21.9–60.0
PO_4-P (mg/g)	15.2	10.0–25.0	12.7	7.8–20.0	17.5	9.3–30.0	17.2	8.3–26.7	12.4	7.5–22.0	6.9	3.9–9.9
Available N (%)	0.027	0.009–0.061	0.028	0.009–0.057	0.037	0.015–0.066	0.033	0.014–0.055	0.015	0.004–0.028	0.011	0.004–0.022
Total N (%)	0.058	0.039–0.099	0.061	0.04–0.084	0.071	0.045–0.095	0.069	0.038–0.099	0.039	0.025–0.068	0.028	0.014–0.041
N/P ratio	1.7	0.8–2.7	2.1	1.0–3.7	2.1	0.9–3.1	2	0.9–3.1	1.3	0.2–1.9	1.6	0.7–3.5

Table 1.2 Summary of selected groups of biogeochemical cycling bacteria (grown in specific culture medium in agar plates) in three types of fish farming located in two sites

Bacterial groups in soil sediment	Polyculture system				Monoculture system				Traditional system			
	Kalyani		Naihati		Kalyani		Naihati		Kalyani		Naihati	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
HB × 10^5 cells/g						50.9						23.1
Ammonifying × 10^6/g	1.04–1.9	1.484286	1.3–2.1	1.701429	1.5–2.75	2.048214	1.8–2.9	2.314286	0.1–1.04	0.529286	0.3–1.06	0.738571
NFB × 10^3/g	6.2–10.75	8.428571	4.9–8.5	6.592857	10.0–16.0	12.9125	8.5–14	11.05714	1.8–4.5	3.107143	1.6–3.4	2.503571
Nitrifying × 10^2/g	14.8–21.2	18.11429	14–18.8	17.12857	20–24	24.03571	18–23.2	22.92143	4.8–9	8.778571	3.2–8	7.5
DNB × 10^3/g	3.05–10.8	7.080357	1.3–11.3	5.8	5–13.1	10.11071	5–13.2	8.307143	2–6.55	4.036429	0.9–8.7	3.141071
PSB × 10^3/g	7.9–15.8	10.04286	5–11.8	8.260714	10.0–19.0	13.93929	8.1–15	11.53214	2.7–10.8	5.403571	2.4–7.1	4.421429
Iron-precipitating bacteria × 10^3/g	4.25–7.5	5.928571	3.6–6.25	4.832143	8.0–13.3	10.25536	4.5–11.0	8.041071	2.6–4.7	3.555357	1.0–2.85	1.998214
Sulfate-reducing bacteria × 10^3/g	6.2–23.5	14.45357	3.8–25.0	13.175	4.2–20.2	12.56893	2.5–17.2	9.771429	4.2–11.2	7.282143	0.5–9.0	4.978571
Thiosulfate-oxidizing bacteria × 10^5 cells / g	2.0–7.7	4.710714	0.5–7.6	3.407143	0.3–6.25	3.1125	1.2–4.1	2.498214	0.8–4.72	2.234286	0.02–3.5	1.109643
PMB × 10^4/g	1.5–8.2	4.841071	1.9–9.1	5.823214	1.4–9.7	5.966071	1.8–10.9	7.255357	1.1–6.1	3.760714	1.9–7.2	4.675
CDB × 10^3cells/g				10.8				9				

Table 1.3 Summary of natural (ammonification, nitrification, and denitrification) and potential (ammonification, nitrification, and denitrification) activities of ammonifying, nitrifying, and denitrifying groups of bacteria occurring in three farming ponds located in two sites

Sediment activities	Polyculture system				Monoculture system				Traditional system			
	Kalyani		Naihati		Kalyani		Naihati		Kalyani		Naihati	
mg/l/72 h	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Natural ammonification (NH_4-N)	1.18–1.5	1.384107	1.3–1.65	1.501607	1.4–1.76	1.59	1.45–1.85	1.672321	1.09–1.32	1.234464	1.2–1.47	1.343571
Ammonification potential (NH_4-N × 10^2)	1.5–4.9	3.503571	2.8–5.6	4.319643	2.3–6.1	4.3375	3.6–7.2	5.485714	1.5–3.7	2.671429	3.05–4.2	3.133929
Natural nitrification (NO_2-N)	0.04–0.71	0.283214	0.09–0.68	0.268214	0.02–0.82	0.336786	0.06–0.82	0.329643	0.04–0.61	0.232143	0.04–0.6	0.221071
Natural nitrification (NO_3-N)	14.8–21.2	1.162857	14–18.8	1.143571	20.0–24.0	1.304286	18–23.2	1.253214	4.8–9.0	1.030357	3.2–8.0	0.985
Nitrification potential (NO_2-N)	0.76–1.65	4.3125	0.72–1.64	3.528571	0.9–1.74	5.114286	0.82–1.7	3.939286	0.66–1.6	3.4625	0.64–1.52	3.003571
Nitrification potential (NO_3-N)	2.8–5.6	2.901852	1.4–4.8	2.596429	3.3–6.9	4.248214	2.0–5.6	3.533929	2.1–4.5	1.832143	2.0–4.1	1.526786
Natural denitrification (NO_3-N)	0.84–1.84	1.34786	0.42–1.56	0.78143	1.16–3.28	2.06857	0.48–2.08	1.27286	0.72–1.28	1.01571	0.18–0.72	0.36643
Natural denitrification (NO_2-N)	0.32–0.98	0.64964	0.2–0.76	0.43679	0.52–1.84	1.095	0.2–1.88	0.78857	0.08–0.48	0.3075	0–0.5	0.16786
Natural denitrification (NH_4-N)	0.3–0.84	0.524286	0.14–0.8	0.394286	0.64–1.88	1.122857	0.44–1.56	0.772143	0.05–0.36	0.211071	0.03–0.33	0.154464
Potential denitrification (NO_3-N)	45.0–145.0	96.67857	40.0–111.0	77.21429	30.0–78.0	58.67857	22.0–62.0	42	15.0–47.0	27.69643	2.0–35.0	17.78571
Denitrification potential (NO_2-N)	5.4–18.6	12.2	7.8–9.0	10.0286	3.2–8.0	5.38571	1.7–5.5	3.6375	1.25–5.0	2.79643	0.2–3.75	1.69286
Denitrification potential (NH_4-N)	6.4–16.0	10.7143	6.0–14.0	9.11429	4.0–9.8	7.01786	3.2–7.6	5.44286	2.4–5.8	4.01429	1.5–4.2	2.99286

Micro- and macroinvertebrates, fungi, and algae that live in and on the bottom soil are often used as source of food for some aquaculture species. Their roles in the soil-water exchange of gases by way of burrowing, swimming, and bioturbation or physical disturbance (Chakraborty et al. 2004) are well documented. Benthic animals also enhance the rate of decomposition by breaking down the organic matter and increasing the surface area for microbial degradation (Jana and Sahu 1993). High rates of sedimentation, however, can suppress the productivity of benthic invertebrates and destroy fish habitats. Suboptimal soil texture and pH may also limit benthic production and thus food availability of benthivorous fishes.

1.11 Soil and Biological Production

Soils play a crucial role in determining the productivity of aquatic systems. The seasonal or perennial nature of wetlands is also determined by the water holding capacity of the wetland soils. Soil quality of fish ponds performs an important role in determining the biological productivity of fish ponds both in direct and indirect ways (Vaas et al. 2015). The residues of the feed that accumulate in the managed pond soils play an important role in increasing the soil fertility and overall biological productivity of the fish ponds. The total weight of benthic animal biomass in fertilized ponds was about 10–12 g/m^2 compared to 3–9 g/m^2 in unfertilized ponds (Boyd 2012). However, information about the role of soil quality on biological productivity of tropical ponds, particularly in wastewater-fed system, are extremely meager.

Pond soils affect the nutrient level of the overlying water which is responsible for the fish production through grazing and detritus food chains of ponds. A pond with fertile soils will have higher fish yield than that of ponds with infertile soils due largely to the nutrient buffering capacity and intrinsic microbial processes housed within the soil. Again, fertilized ponds with acidic soils have lower fish production than the fertilized ponds with near-neutral or slightly alkaline soils. It has also been found that pH and concentrations of carbon, nitrogen, and phosphate as well as their ratios in soil affect fish growth. Ponds with high organic matter content develop anaerobic zones in the pond bottom and produce toxic elements that retard fish growth. Acidic soils, anaerobic conditions at the soil-water interface, high amount of soil organic matter, high rates of sedimentation, erosion of pond soils, and algal bloom and infestations of aquatic weeds are all adverse factors that negatively affect aquaculture production.

On the basis of the results of soil qualities and nutrient conditions of a large number of fish ponds under different agroclimatic conditions in the country, Banerjea (1967) classified these ponds into low, medium, and high productivity (Table 1.4).

Soil pH is known to have significant influence on inorganic transformation of soluble phosphate and exchange of essential nutrients at the soil-water interface. Examination of 90 fish ponds located in different states of India revealed that both

Table 1.4 Soil qualities and nutrient conditions of fish ponds under different agroclimatic conditions classified as low, medium, and high productivity

Available N mg/100 gm	Available P_2O_5 mg/100 gm	Organic carbon (%)
Low < 25	< 3	< 0.5
Medium 25–50	3–6	0.5–1.5
High > 50	> 6.0	> 1.5

Source: Banerjea (1967)

high acid (pH < 5.5) and high alkaline (pH > 8.5) conditions in the pond soils were unsuitable for fish ponds. The optimal soil reaction is a near-neutral condition (pH 6.5–7.5), while average production was obtained from moderately acid (pH 5.5–6.5) and moderately alkaline (pH 7.5–8.5) soil (Banerjea 1967).

The total alkalinity and total hardness of surface waters are regulated by the kind of soil. Ponds with low total alkalinity and low total hardness are found on acid surface soils, peat soils, sandy soils, or sands with high degree of base unsaturation on cation-exchange sites. Pond water with total alkalinity and total hardness values below 20 mg/l are usually less productive in phytoplankton following fertilization than ponds with higher total alkalinity and total hardness concentrations.

The importance of soil phosphorus for increasing the aquatic productivity is also well recognized. The available phosphate content of bottom soil is known to have a direct correlation with pond productivity. In fact, it is phosphorus availability that correlates most closely with the biological productivity of fish ponds. On the basis of the concentration of available phosphate expressed as mg of P_2O_5/100 g of soil, aquaculture ponds have been grouped into four ranges: (1) <3.0, (2) 3.0–6.0, (3) 6.0–12, and (4) > 12. It is observed that 28 ponds with available phosphate less than 3 are unproductive. In the range of 3–6 mg of P_2O_5/100 g of soil, 26 ponds are average and 1 unproductive, while ponds with >12 mg of P_2O_5/100 g of soil all are productive. It is suggested that soil phosphorus levels below 3 mg of P_2O_5/100 g of soil are considered unproductive and that between 3 and 6 of mg of P_2O_5/100 g of soil average production and above 6 mg of P_2O_5/100 g of soil are productive (Banerjea 1967). Considering this criterion, wastewater-fed ponds are highly productive.

Likewise, the study revealed that the production was poor in ponds with available N below 25 mg of N/100 g of soil and those between 25–50 and 50–75 mg of N/100 g of soil or above 75 mg of N/100 g of soil had average productivity. Though no definite conclusion was drawn, the range 50–75 mg of N/100 g of soil may be taken as relatively more favorable. Exchangeable calcium in soil did not show any correlation with production of fish in ponds suggesting it has little influence on biological production.

Decomposition of organic matter as well as microbial activity is strongly influenced by different factors including the C/N and C/P ratios. Bacterial growth efficiency decreases about 100-fold with increasing C/N and C/P ratios in the substrate (Goldman et al. 1987). Thus, dissolved organic matter (DOM) loading can play a crucial role in linking terrestrial and aquatic systems. This physical connection of soils and surface waters demonstrates the importance of understanding fundamental processes such as nutrient cycling, pedogenesis, and microbial metabolism at a whole-landscape scale (Jansen et al. 2014).

Studies have shown that microbial activity is low when the C/N ratio falls below 10:1 and high for C/N above 20:1. Most of the ponds examined by Banerjea (1967) showed the organic carbon content to be less than 2.5%, while the range of 0.5–1.5% was considered average and the range of 1.5–2.5% appeared to be optimal. Ponds with very high organic carbon content may not be desirable for fish production.

Examination of C:N:P ratio in soils of different water bodies showed that the carbon concentration averaged 3.758, 1.912, and 5.575 mg/g; the nitrogen concentration 0.390, 0.302, and 0.552 mg/g; and the phosphorus concentration 0.095, 0.032, and 0.096 mg/g (Jana et al. 2001). In terms of fish production, ponds with C/N ratio of <5 are usually indicative of poor production, those in the range of 5–10 show average production, while the range of 10–15 appeared to be optimal. A ratio of C/N above 1 appears to be unfavorable. The data of wastewater-fed ponds are, however, not available for comparison, but the C/N value would be on the higher side due to nutrient enrichment caused by sewage discharge.

The available phosphate and organic carbon contents of bottom sediment in three shrimp farming ponds located in coastal areas of Diu (UT) were found to be positively correlated with primary productivity of phytoplankton of overlying water (Kumar et al. 2012). The studies by Jana and Das (1980) used correlation of N content in pond soils and fish yields from five different agroclimatic zones of West Bengal to identify an inverse relationship between fish productivity and available N.

1.12 Effects of Aquatic Animals on the Soil

It is well known that the production of aquatic animals is largely influenced by the soil conditions of ponds. Aquatic animals, on the other hand, also contribute to the development of pond soils, mediated through the alteration of soil properties of fish ponds. While performing swimming, burrowing, and grazing activities on the bottom water and soils, benthivorous fishes, benthos, and other bottom-dwelling organisms modify the soil texture through bioturbation activities. Organisms such as annelids, molluscs, chironomid larvae, etc. are known to loosen the soil by burrowing and mixing the sediment (Biswas et al. 2009). Stirring or physical disturbance of the pond bottom can resuspend the sediment (Chakraborty et al. 2004).

Burrowing activities enhance the aeration of the upper layers of the soil by facilitating the exchange of pore water with pond water. This activity is particularly useful for oxygenation of soil and keeping the bottom soil healthy by the removal of accumulated noxious gases from the pond bottom. It is evident that the water of ponds stocked with common carp, goldfish, and other bottom feeding fish are turbid due to soil particles suspended by the feeding activities of fish (Boyd and Tucker 1998). The concentrations of total carbon, total nitrogen, and calcium increase gradually over time in ponds stocked with shrimp *L. vannamei* in almost all ponds of Tamil Nadu (Gunalan et al. 2012). In wastewater-fed ponds, culture of hardy benthivorous fishes is encouraged for maintaining the healthy soil and aquatic ecosystem for sustainable development.

1.13 Soil Management

Given the wide variety of bottom soil quality associated with different agroclimatic zones (Koerschens et al. 2013), a soil system-based nutrient management approach has been developed (Banerjee et al. 2010) to provide target nutrient status levels for maintaining high rates of overall productivity. While working with primary productivity in a large number of fish ponds located in red and laterite soil zones, Banerjee et al. (2010) observed that pH, phosphorus, and nitrogen of soil contributed 41%, 26%, and 9%, respectively, of the gross primary production of phytoplankton. Estimates of gross primary productivity, net primary productivity, and fish yield obtained in the soil-based pond fertilization systems were, respectively, 29%, 37%, and 22% higher than that of traditional fertilization systems. Experimental studies further revealed the critical levels of major nutrients to be 200, 13, and 18 mg/g soil for nitrogen, phosphorus, and potash, respectively, in red and laterite soil zones, indicating target levels for optimizing fish productivity in an engineered system.

Because fish pond soils exhibit higher amount of organic matter than upland agricultural soils and as the pH of bottom soil and water remains alkaline, the availability of potassium in the sediment is high. Hence, potash is not often a limiting element in ponds except in those located in potash-deficient laterite soil zones (Das and Jana 1996). On the other side, carbon plays a critical role in these ponds. Thus, in most cases, the concept of pond fertilization should be based on NPC rather than NPK as practiced in agricultural soil (Das and Jana 1996).

Turbidity of wastewater-fed ponds may arise from a combination of both biological and non-biological factors. In either case, this turbidity may have negative impacts on primary productivity by preventing light transmission through water column, which limits phytoplankton production and can result in anaerobic conditions at depth. In the first case, eutrophication-induced massive algal bloom was responsible for anaerobic state in pond bottom by promoting autolysis of algal bloom. The impact of clay particle is considered to be less in wastewater-fed system. However, turbidity caused by clay particles is largely attributed to the negatively charged clay particles that repel each other and remain in suspension. The addition of positively charged particles such as limestone, alum, and gypsum can help remediate the problem by inducing coagulation and precipitation of clay particles (Fig. 1.6).

Aeration and water circulation devices can be used to improve dissolved oxygen content of the wastewater pond system. Raking may be practiced to improve the ecological conditions of pond soils for encouraging healthy conditions and animal

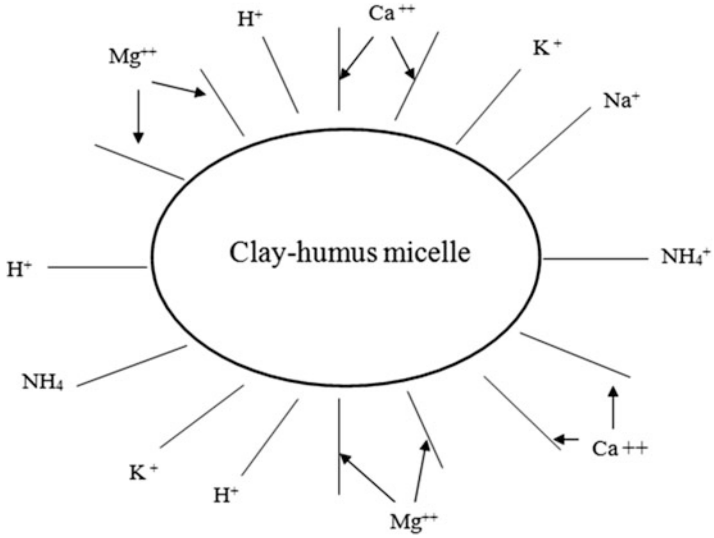


Fig. 1.6 Clay-humus micelle showing absorbed ions held by attraction of cation to anion charges

associations of the pond bottom. Raking has been found to be a useful tool for increasing fish yields by removing toxic gases accumulated in the pond soil (Chakraborty et al. 2004). Sedimentation tanks can be used to remove suspended soil particles from water before it enters into the fish ponds and help retain overall water clarity.

1.14 Role of Pond Sediments in Carbon Cycle

Many processes in small aquatic ecosystems play a major role in global carbon cycles (Downing 2010), but they are completely ignored with respect to global cycling of carbon. Wastewater-fed wetland system, due to nutrient enrichment syndrome, has been an ideal set of condition for massive growth of diverse microalgae that capture CO_2 from high-CO_2 streams (Hsueh et al. 2007) apart from its resilience to structural and functional integration of the waste stabilization pond system and may be regarded as carbon cycling hot spots (Koerschens et al. 2013). The role of pond sediments in climate change through carbon sequestration has been well recognized. The soil carbon sequestration is a truly win-win strategy. Downing et al. (2008) suggested that small eutrophic impoundments bury carbon at an average rate of 2122 g m^{-2} $year^{-1}$ which is 5 times higher than in large river impoundments and 30 times higher than in small, natural lakes (Boyd et al. 2010). Global CO_2 evasion rates of 1.8 petagrams of carbon (Pg C) per year have been reported from streams and rivers and 0.32 Pg C $year^{-1}$ from lakes and reservoirs (Raymond et al. 2013). Under Indian conditions, the carbon sequestration capacity of pond sediments ranged from 0.442 to 1.882 mg C/ha (1 mg = 10 (6) g) with an average value of 1.018 ± 0.447 mg C/ha (Anikuttan et al. 2016).

The role of soils in carbon sequestration of wastewater ponds has hardly been examined. The studies of Lahiri et al. (2015) and Sarkar et al. (2016) have revealed distinctly higher values of Shannon diversity index for Myxophyceae, Euglenophyceae, and Chrysophyceae in facultative pond compared to maturation ponds, whereas those of Chlorophyceae and Bacillariophyceae were predominant in later ponds. The sum of total scores for different optimal conditions for fish growth also increased spatially exhibiting two clear-cut zones: the facultative pond with dominance of blue-green algae with greater carbon sequestration potential and the maturation ponds which developed the benign environment for fish culture mediated through microalgae-zooplankton grazing and microbial detritus food chain. Though the carbon sequestration potentials of wastewater-fed ponds have not been studied, the spatial differences of organic matter in the pond bottom were clearly indicated.

Based on a combined area and average carbon burial rate, aquaculture ponds sequester an estimated 16.6 MT/year of carbon globally, most of which occurs in Asia, particularly China, which has 94% of the global aquaculture pond area. It is estimated that aquaculture ponds bury 0.21% of current annual global carbon emissions of about 8000 MT/year and represent a small but previously non-quantified sink of carbon emissions (Boyd et al. 2010). It claimed that ponds represent a net source of carbon dioxide emission to the atmosphere. Based on the life cycle analysis, of all aquaculture commodities, shrimp farming consumes a lot of energy and emits more greenhouse gases such as methane, nitrous oxide, and carbon dioxide which escape to the atmosphere through diffusion mainly by methanogenesis, nitrification, and denitrification processes in the pond bottom sediments. A recent experimental study (Jana et al. 2016) observed contrasting responses of buffering mechanisms between open and simulated greenhouse conditions. It was further revealed that the carbon sink in the bottom soil was primarily due to the allochthonous origin of the former and from autochthonous source in the latter.

1.15 Conclusions

Wastewater resources are of great importance for economic development as well as for water conservation. Though wastewater-fed systems are generally discarded due to excessive nutrient input and eutrophication potential in some economically developed countries, effective management through biological process-dependent nutrient recovery and reclamation is a wise strategy for harnessing the water resources for production of value-added cash crops, especially for fish protein in the tropical countries. Maintenance of healthy soils through understanding of its functional role, sink of carbon, and interactions with overlying water is most vital for enhancing the degree of performance in wastewater-fed system and providing profitable ecosystem services to the society.

Acknowledgement We are extremely thankful to Dr. T. Linley and Dr. J. Moran, Ecology Division, Pacific Northwest National Laboratory, Richland, Wasington, USA for critically going through the draft manuscript and suggesting improvements in the paper in the present form.

References

Anikuttan KK, Adhikari S, Kavitha M, Jayasankar P (2016) Carbon sequestration capacity of sediments, algae, and zooplankton from fresh water aquaculture ponds. Environ Monit Assess 188:422

Banerjea SM (1967) Water quality and soil condition of fish ponds in some states of India in relation to fish production. Indian J Fish 14:115–144

Banerjee A, Chattopadhyay GN, Boyd CE (2010) Soil system based approach: a tool for fish pond fertilization. Better Crops 94:22–24

Barat S, Jana BB (1987) Distribution pattern of protein mineralizing and ammonifying bacterial populations and ammonification rate in experimental tanks differing in husbandry systems. Bamidgeh 39:120–132

Biswas JK, Rana S, Bhakta JN, Jana BB (2009) Bioturbation potential of chironomid larvae for the sediment–water phosphorus exchange in simulated pond systems of varied nutrient enrichment. Ecol Eng 35:1444–1453

Boyd CE (2012) Bottom soils, sediments and pond aquaculture. Chapman & Hall, New York, p 347

Boyd CE, Tucker CS (1998) Pond aquaculture water quality management. Kluwer, Boston

Boyd CE, Wood CW, Thunjai T (2002) Aquaculture, pond bottom soil quality management. Report: pond dynamics/aquaculture collaborative research support program, Oregon State University, Corvallis, USA

Boyd CE, Wood CE, Chaney PL, Queiroz JF (2010) Role of aquaculture pond sediments in sequestration of annual global carbon emissions. Environ Pollut 158:2537–2540

Chakraborty P, Biswas JK, Jana BB (2004) Sediment raking as a tool for enhancement of phosphate and productivity of water in tropical pond system. Hydrobiologia 524:157–165

Das SK, Jana BB (1996) Pond fertilization through inorganic sources: an overview. Indian J Fish 43:137–155

Downing JA (2010) Emerging global role of small lakes and ponds: little things mean a lot. Limnetica 29:9–24

Downing JA, Cole JJ, Middelburg J, Striegl RG, Duarte CM, kortelainen P, Prairie YT, Laube KA (2008) Sediment carbon burial in agriculturally eutrophic impoundments over the last century. Glob Biogeochem Cycles 22:10

Goldman JC, Caron DA, Dennett MR (1987) Regulation of gross growth efficiency and ammonium regeneration in bacteria by substrate C:N ratio. Limnol Oceanogr 32:1239–1252

Gunalan B, Nina Tabitha S, Soundarapandian P, Anand T, Kotiya AS (2012) Estimation of soil nutrients in *L. vannamei* culture ponds. Basic Res J Agric Sci Rev 15:124–131

Hoellein TJ, Bruesewitz DA, Richardson DC (2013) Revisiting Odum (1956): a synthesis of aquatic ecosystem metabolism. Limnol Oceanogr 58:2089–2100

Hsueh HT, Chu H, Yu ST (2007) A batch study on the bio-fixation of carbon dioxide in the absorbed solution from a chemical wet scrubber by hot spring and marine algae. Chemosphere 66:878–886

Jana BB, Das RN (1980) Relationships between environmental factors and fish yield in a pond with air-breathing fish, *Clarias batrachus*. Aquac Hung 1:139–145

Jana BB, Patel GN (1984a) Measurement of some groups of microbial population with special reference to denitrification in water and sediments of fish farming ponds under mono- and polyculture systems. Int Rev Gesamten Hydrobiol 69:231–240

Jana BB, Patel GN (1984b) Spatial and seasonal variations of phosphate solubilizing bacteria in fish ponds of varying fish farming managements. Arch Hydrobiol 101:555–568
Jana BB, Patel GN (1985a) Distribution pattern denitrifying bacteria in fish ponds of differing farming managements. Arch Hydrobiol 103:291–303
Jana BB, Patel GN (1985b) Distribution pattern of sulphate reducing and thiosulphate oxidising bacterial populations in fish ponds of differing farming managements. Hydrobiologia 127:171–186
Jana BB, Patel GN (1986) Seasonal and spatial distribution of iron precipitating heterotrophs in water and sediments of fish ponds differing in farming managements. Int Rev Gesamten Hydrobiol 71:259–270
Jana BB, Roy SK (1983) Estimates of microbial populations involved in N-cycle and their activity in water and sediments of fish ponds under mono-and polyculture systems in India. Int Rev Gesmten Hydrobiol 68:581–590
Jana BB, Roy SK (1985a) Distribution patterns of protein mineralizing and ammonifying bacterial populations in fish farming ponds under different management systems. Aquaculture 44:57–65
Jana BB, Roy SK (1985b) Spatial and temporal changes of nitrifying bacterial populations in fish ponds of different management practices. J Appl Bacteriol 59:195–204
Jana BB, Roy SK (1986) Seasonal and spatial distribution pattern of nitrogen fixing bacteria in fish ponds under different management systems. Hydrobiologia 137:45–54
Jana BB, Sahu SN (1993) Relative performance of three bottom grazing fishes (*Cyprinus carpio, Cirrhinus mrigala, Heteropneustes fossilis*) in increasing the fertilizer value of phosphate rock. Aquaculture 115:19–29
Jana BB, Patel GN, Roy SK, De UK (1982) Heterotrophic bacteria, physico-chemical regime and stocking of fish in the tanks under three trophic conditions. Limnologica (Berlin) 14:363–375
Jana BB, Chakraborty P, Biswas JK, Ganguly S (2001) Biogeochemical cycling bacteria as indices of pond fertilization: importance of CNP ratios of input fertilizers. J Appl Microbiol 90:733–740
Jana BB, Kundu D, Datta D, Lahiri S, Bag S, Sarkar D, Bhakta JN (2016) Evidences of manure driven and C:N regulated enhanced carbon status and microalgal productivity in managed aquatic system under simulated green house conditions. J Earth Sci Clim Chan 7:336–347. https://doi.org/10.4172/2157-7617
Jansen B, Kalbitz K, McDowell WH (2014) Dissolved organic matter: linking soils and aquatic systems. Vadose Zone J 13. https://doi.org/10.2136/vzj2014.02.0015
Koerschens M, Albert E, Armbruster M, Barkusky D, Baumecker M, Behle-Schalk L, Bischoff R, Cergan Z, Ellmer F, Herbst F et al (2013) Effect of mineral and organic fertilization on crop yield, nitrogen uptake, carbon and nitrogen balances, as well as soil organic carbon content and dynamics: results from 20 European long-term field experiments of the twenty-first century. Arch Agron Soil Sci 59:1017–1040
Kumar P, Jetani KL, Yusuzai SI, Sayani AN, Ahamd Dar A, Rather MA (2012) Effect of sediment and water quality parameters on the productivity of coastal shrimp farm. Adv Appl Sci Res 3:2033–2041
Lahiri GS, Sarkar PD, Jana BB (2015) Evaluating the ecological resilient driven performance of a tropical waste stabilization pond system using ecological signature of biological integrity. J Ecol Eng 16:97–107
Mortimer CH (1971) Chemical exchanges between sediments and water in the Great lakes-speculations on probable regulatory mechanisms. Limnol Oceanogr 16:387–404
Natchimuthu S, Panneer-Selvam B, Bastviken D (2014) Influence of weather variables on methane and carbon dioxide flux from a shallow pond. Biogeochemistry 119:403–413
Raymond PA, Hartmann J, Lauerwald R, Sobek S, McDonald C, Hoover M, Butman D, Striegl R, Mayorga E, Humborg C et al (2013) Global carbon dioxide emissions from inland waters. Nature 503:355–359
Sahai VN (1999) Fundamentals of soil. Kalyani Publishers, Ludhiana, pp 106–137

Sarkar PD, Lahiri GS, Jana BB (2016) Evaluating the ecological integrity and microalgal carbon sequestration potential across the sewage effluent gradient of tropical waste stabilization pond system. Hydrobiol J (Kiev) (in Press)

Siddique MAM, Barua P, Ghani MH (2012) Comparative study of physico-chemical properties of soil according to the age of aquaculture pond of Bangladesh. Mesopot J Mar Sci 27:29–38

Sorokin YI, Kadota H (eds) (1972) Techniques for the assessment of microbial production and decomposition in fresh waters, IBP handbook 23. Blackwell Scientific Publications, Oxford/London. Xvi + 112 p

Vaas KK, Chattopadhyay GN, Jana BB (2015) Soil, fishery and aquaculture. In: Pathak H, Sanyal SK, Takkar PN (eds) State of Indian agriculture – soil. National Academy of Agricultural Sciences, New Delhi, pp 165–182. xiii +392

Chapter 2
Biogeochemical Cycling Bacteria and Nutrient Dynamics in Waste Stabilization Pond System

Susmita Lahiri, Debarati Ghosh, and Dipanwita Sarkar (Paria)

Abstract Wastewater generated from different sources creates environmental problems after entering the aquatic ecosystem due to its heavy organic load and other undesirable toxicants. As a consequence, biological and chemical oxygen demand increases with depletion of oxygen level of water; all the biotic organisms suffer from stress-related symptoms often reaching to lethal limits. However, wastewater may become a useful resource for various economic-driven activities. Wastewater reuse is primarily dependent on the microbial degradation of different nutrients present in sewage. Thus, biogeochemical cycling bacteria have profound role on the decomposition, degradation and regeneration of nutrients from organic sewage water. Thus, the metabolism and turnover of the whole sewage-fed ponds are regulated by nutrient cycling and energy flow in the trophic level. Waste stabilization pond has been recognized as effective treatment system with removal of as high as 90–95% dissolved organic matter and reducing pathogens through microbial activities under aerobic and anaerobic conditions in trickling filter, activated sludge processes, etc. Interactions within and between carbon, nitrogen and phosphorus pools in nutrient cycles of wastewater-fed ponds ultimately result in nutrient removal from wastewater. A series of waste stabilization ponds (anaerobic, facultative and maturation) in which the detritus food chain is dominant over the grazing food chain is popular. It is evident that microbial activities play a crucial role in nutrient recovery from wastewater through microbial degradation of organic load leading to increased biological production while accelerating the enhancement of water quality through microbial-driven ecological processes.

Keywords Wastewater · Nutrient cycle · Biogeochemical cycling bacteria · Waste stabilization pond

S. Lahiri (✉) · D. Ghosh
International Centre for Ecological Engineering, University of Kalyani, Kalyani, West Bengal, India
e-mail: minku_lahiri@yahoo.co.in

D. Sarkar (Paria)
Department of Zoology, Chandernagore College, Hooghly, West Bengal, India

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_2

Contents

2.1 Introduction

A major environmental crisis that made a noticeable impact between pre- and post-rapid industrialization and urbanization is the sharp rise in generation of various kinds of anthropogenic wastes such as liquid wastes, agricultural pesticides, detergents, trace metals, pharmaceutical drugs, hormones and other toxic materials. This is due to discharge of industrial effluents and untreated sewage of most of the cities and towns. This is particularly true for the developing countries where the facilities for sewage treatment plants are inadequate due to economic reasons. Following drainage patterns or sewers, liquid wastes enter neighbouring aquatic ecosystem on a scale that overwhelms the homeostasis of aquatic ecosystem causing undesirable deterioration of water quality (Welch and Lindell 2004) either by severe contaminations or eutrophication. The discarded materials of the society may become a resource or wastes depending upon the management (USEPA 2001; Okun 2002). Due to its immense nutrient potentials, municipal wastewater has been extensively used for irrigation in agriculture, in horticulture and directly in aquaculture in most of the countries in Asia (Edwards 1996, 2000). Adequate technologies have been developed at present to use wastewater as a source of energy by producing hydrogen gas.

Though there are several methods for wastewater treatment, the waste stabilization pond system consisting of anaerobic, facultative and maturation ponds has been proven to be low cost and highly effective as it relies on functioning of natural ecosystem and self-purification processes. The sustainable waste management strategy is based on well-known 4-R concept of ecological engineering (Jana 1998; FNQLSDI 2008). This primary strategy has been aimed to reduce high organic load coupled with reduction of biological oxygen demand and bacterial loads. Ecosystem service provided by waste stabilization pond system would be more focussed towards environmental protection especially with respect to wastewater reclamation utilizing the micro-algal biomass in the aquatic food chain as well as for mitigation of greenhouse gases from the atmosphere through carbon sequestration.

The waste management strategy of the waste stabilization pond system is primarily dependent on the microbial degradation of organic matter through decomposition, degradation, mineralization and stabilization (Bobeck 2010; Monga et al. 2014; Lahiri et al. 2015). The self-purification processes of the ecosystem resulted in reduction of biological oxygen demand by 90–95% (Brassington 1995) leading to augmentation of nutrient-dependent biological productive functions.

Microorganisms play a key role in the decomposition and degradation of organic matter of wastewater and, hence, in the nutrient dynamics and biological productivity of the system. The cellulose, lignin and hydrocarbons contained as carbon compounds in the organic waste are degraded by the microbial community (Atlas and Bartha 1998) and release carbon for growth. The microbial transformation of ammonia to nitrite and then to nitrate is performed by chemoautotrophic nitrifying bacteria along with subsequent denitrification process (Nicklin et al. 2001). Microorganisms present in the wastewater are responsible for the transformations of organic to inorganic phosphates or by converting insoluble immobilized forms to soluble or mobile compounds by production of organic acids (Atlas and Bartha 1998).The basic understanding of biogeochemical cycling bacteria involved in the nutrient cycle of wastewater pond system has hardly been investigated. The present chapter attempts to review the subject with respect to reclamation efficiency of waste stabilization pond citing relevant examples. This will reveal the extent and nature of nutrient reclamation of the wastewater-fed systems for its proper utilization in various anthropogenic activities.

2.2 Characteristics of Wastewater

Wastewater is defined as spent water origination from a combination of domestic, industrial, commercial or agricultural activities, surface run-off or storm water, sewer inflow or infiltration having negative impact on water quality of anthropogenic activities.

Sewage is the term used for wastewater that contains faeces, urine and laundry wastes. Crude sewage contains 100–700% higher concentrations of biological oxygen demand, chemical oxygen demand, total organic carbon, suspended solids, ammonia-N and nitrate-N than in the final effluent after treatment (Tebbutt 1998). It contains a vast array of microorganisms such as bacteria, viruses, protozoan cysts, yeasts and other moulds, algae, eggs of helminths, etc. A number of unwanted elements such as Zn, Cd, Cu, Pb, Cr, Hg, Ag and Ni, pesticides and insecticides are also present in sewage (Leenheer et al. 2001). Unless source separation facilities are provided, agricultural wastes and industrial wastes are mixed with domestic sewage and cause more harmful effects on aquatic environment.

Table 2.1 Characteristics of domestic and industrial wastes

Domestic sewage	Industrial sewage
Total organic carbon: 80–290 mg/l	Iron and other minerals like copper, zinc, etc.
Nitrogen: 20–85 mg/l	Toxic chemicals like polychlorinated biphenyls, polybrominated biphenyls, chlorinated hydrocarbon insecticides and dioxins
Biological oxygen demand: 110–400 mg/l	High biological oxygen demand, for example, 30,000 mg/l in sulphite plants
Total solid particles: 350–1200 mg/l	Obnoxious gases like H_2S, NH_3, etc.
C/N ratio: 3:1	Higher C/N ratio

Source: Raizada et al. (2002), Aluko et al. (2003), and Rawat et al. (2011)

Comparison of chemical characteristics between domestic and industrial sewage (Table 2.1) shows higher values of biological oxygen demand and carbon-nitrogen ratio and the presence of toxic chemicals and obnoxious gases in industrial effluents (Raizada et al. 2002; Aluko et al. 2003; Rawat et al. 2011).

2.3 Degradation of Sewage in Wastewater System

As defined by Odum (1983), the chemical elements of the protoplasm tend to circulate in the biosphere from the environment to organisms and back to the environment in a more or less cyclical manner which is known as biogeochemical cycles. This cycle is crucial in maintaining the productive cycle of the ecosystem through food chain and food web mechanism. Thus, the biogeochemical cycles within an ecosystem reflect the total metabolism of the system, including autotrophic and heterotrophic processes and anabolic (assimilation) and catabolic (dissimilation) pathways (Jorgensen and Vollenweider 1989). A steady input of energy is required to drive the cycles because all changes in the oxidation states of the elements require energy for transformation so that the elements are available in proper form for any given group of organisms (Refsgaard et al. 2005).

In a wastewater-fed ecosystem, the autotrophs in the form of algal bloom maintain the oxygen balance of pond ecosystem functioning through the solar energy-driven photosynthesis, whereas the heterotrophs affect the turnover and cycling of matter within an ecosystem; predation by protozoa would interfere in the food chain transfer mechanism (Rittmann and McCarty 2001).

The decomposition and degradation processes of organic wastes in the sewage were carried out by a large number of microorganisms leading to a chain of events that drastically alter the ecology of the environment (Campbell et al. 1991). The bacteria responsible for reducing the concentration of pollutants and carbonaceous BOD_5 by the coagulation of colloidal solids and the stabilization of organic matter are *Bacillus*, *Nitrobacter*, *Pseudomonas* (two strains), *Aerobacter*, *Cellulomonas*, *Rhodopseudomonas* (Campbell et al. 1991; Bitton 1999), *Flavobacterium* sp. or *Achromobacter* sp. and *Alkaligens* sp. (Zinebi et al. 1994). Isolated designed consortia comprising *Bacillus pumilus*, *Brevibacterium* sp. and *Pseudomonas aeruginosa* in the ratio of 1: 2 (effluent:biomass) at 200 rpm, 35 °C, were reported to be a specific strain capable of maximum biodegradation of wastewater (Dhall et al. 2012) and, hence, responsible for wastewater reclamation.

2.4 Nutrient Dynamics in Wastewater

In a wastewater-fed system, the typical nutrient dynamics in waterbodies involve different major nutrient cycles such as nitrogen, phosphorus, carbon and other minor nutrients functioning through respective groups of biogeochemical cycling bacteria. Since there is heavy input of organic matters in the sewage-fed system, cyclings of nitrogen, carbon and phosphorus are predominant than others and often cause nutrient enrichment called eutrophication. Understanding of such cycles is necessary to explain how the system is functioning for a better management of eutrophication and ecosystem service mediated through wastewater reclamation.

2.4.1 Role of Heterotrophic Bacteria in Degradation of Sewage Water

In wastewater-fed system, heterotrophic bacteria, the predominant component of microbial community, play an important role in the decomposition as well as mineralization of organic matter (Costa-Pierce and Laws 1985; Fry 1987). They are the only biological entity capable of significantly altering both dissolved and particulate organic matter. Because of short generation time and highest metabolic rate per unit biomass (Barik et al. 2000), their high performances are well recognized. Chemoautotrophic and photoautotrophic microorganisms as well as many heterotrophs use CO_2 as their sole carbonaceous nutrient (Alexander 1991). Out of two types of heterotrophs, chemoheterotrophs use organic compounds as sources of energy, hydrogen, electrons and carbons for biosynthesis, and photoorganoheterotrophs use light energy in addition to other sources of energy. The photoorganoheterotrophs such as purple non-sulphur bacteria and green non-sulphur bacteria are common in a wide range of polluted habitats (Prescott et al. 1999). The physico-chemical milieu as well as ratios for carbon, nitrogen and phosphorus (Tezuka 1990) and interactions between substrates and bacteria-fungi-actinomycetes complex strongly affect the microbial activity that finally influence the nutrient dynamics of wastewater.

In a study with sewage-fed ponds of the waste stabilization pond systems, the microbial nutrient uptake was responsible for substantial reduction of organic load from 55 mg/l in anaerobic pond to 30 mg l^{-1} in the final effluent (Lahiri et al. 2015) which was strongly correlated with the gradual decline in the counts of heterotrophic bacteria (Fig. 2.1).

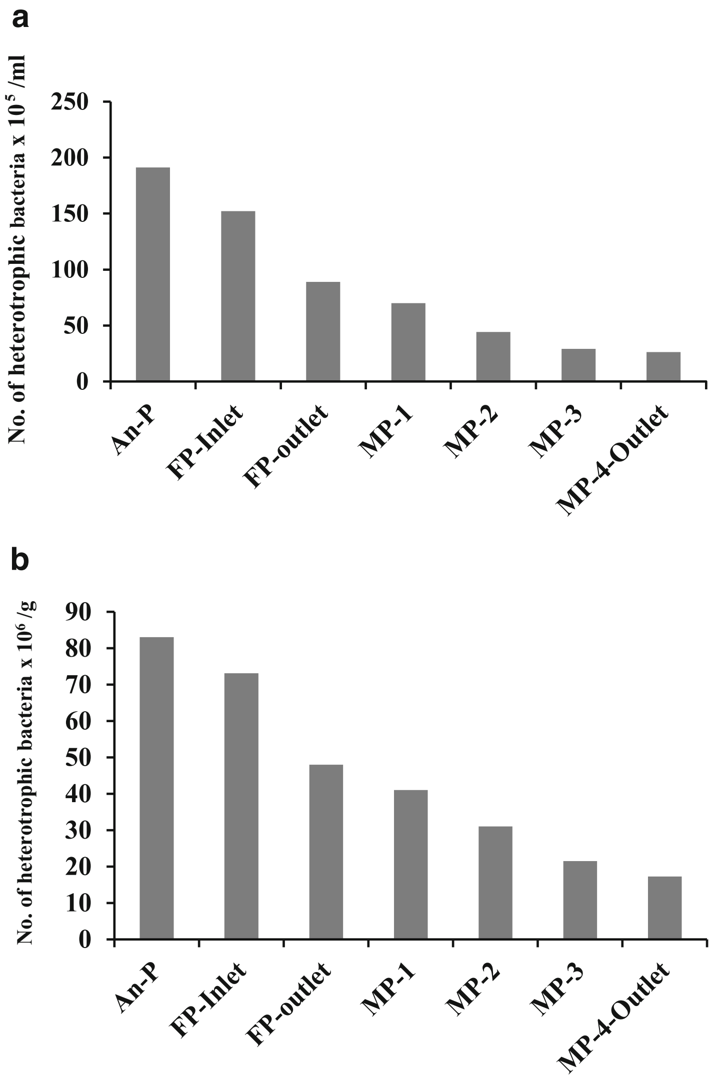


Fig. 2.1 Spatial distribution of the mean counts of heterotrophic bacteria occurring in water (**a**) and in sediment (**b**) of different sites of ponds in a WSPs in Kalyani, West Bengal, India

2.4.2 *Nitrogen Cycle in Wastewater*

The biogeochemical cycle of nitrogen includes nitrogen fixation, ammonification, nitrification and denitrification (Fig. 2.2). Currently, the global nitrogen cycle has dramatically altered the aquatic ecosystem due to anthropogenic input of nitrogenous materials. This is particularly true for sewage-fed system where most of the nitrogen is bound with living and decaying organic matters, and the N-dynamics start with the anaerobic decomposition of organic-N in pond bottom sludge releasing ammoniacal-N with subsequent nitrification to NO_3^- and ammonia volatilization. This is followed by assimilation of inorganic-N (NH_4-N and NO_3) into algal and bacterial cells. The process of denitrification of NO_3^- to dinitrogen (N_2) and nitrous oxide (N_2O) gases takes place (Figs. 2.1 and 2.2). This nitrification-denitrification process is a responsible mechanism for nitrogen removal from wastewater (Camargo-Valero et al. 2010). It is estimated that nearly about 66–67% removal of nitrogen occurs from wastewater anaerobic ponds (Silva et al. 1995).

2.4.2.1 Nitrogen Fixation

The major source of elemental nitrogen is atmosphere. In aquatic environment, N-fixation is done by some nitrogen-fixing bacteria; cyanobacteria; aerobic, anaerobic and facultative bacteria; etc. The elemental N is transformed into an

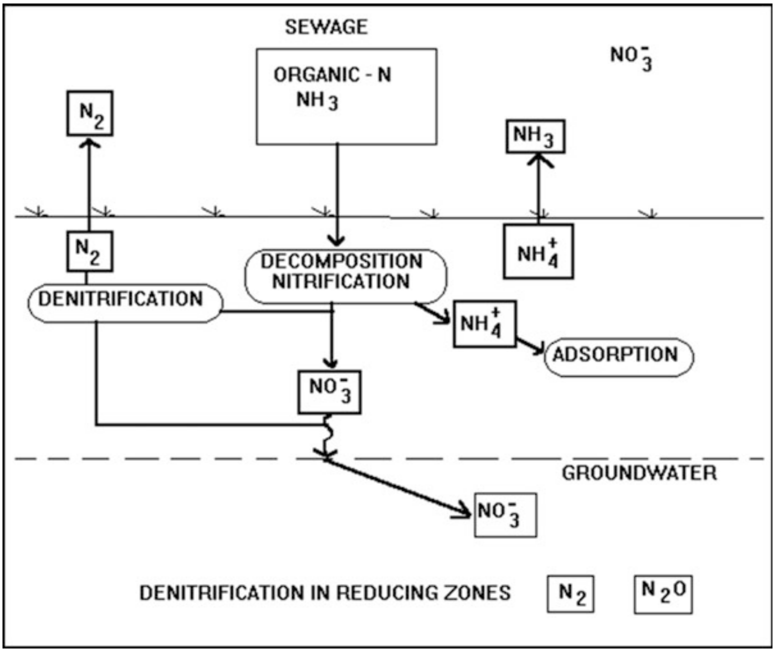


Fig. 2.2 A generalized nitrogen cycle in wastewater (Source: Nguyen and Davies-Colley 1998)

inorganic form, largely nitrate and ammonia before it can be trapped into biological process. Although fixation can occur by electrochemical, physico-chemical and biological means, the latter is by far the most significant phenomenon in nature. In this process atmospheric nitrogen is reduced to NH^{4+} which is subsequently incorporated in biomass.

The studies on N_2 fixation and new N production to toxic cyanobacteria in freshwater ecosystems are limited. In N-limited, shallow polymictic lakes, N inputs can come from regenerated benthic N and heavy precipitation events (Xu et al. 2010). New N can enter the system as ammonium ions (NH_4^+) and dissolved organic nitrogen (e.g. glutamate and glutamine) that leak out of cells during the fixation process (Capone et al. 1994) or after cell lysis and remineralization. This input of new N can often support the growth of contemporary phytoplankton communities and has been suggested in a variety of settings to stimulate subsequent blooms of benthic algae, non-N_2-fixing cyanobacteria and the toxic dinoflagellate, *Karenia brevis* (Gondwe et al. 2008; Lenes and Heil 2010). In model simulations, Agawin et al. (2007) calculated that *Synechococcus* abundance was four times greater in competition experiments with the N_2-fixing *Cyanothece* than it would have been in monoculture. Zuberer (1982) and Duong and Tiedje (1985) demonstrated nitrogen fixation associated with duckweed covers.

N_2 fixation is important in polluted aquatic ecosystems because it often leads to the production of "new" N. Nitrogen fixation is basically an adaptation to compensate nitrogen deficiency in aquatic environment as nitrogen fixation usually does not occur if ammonia is present in the environment. In the presence of ammonia, nitrogenase synthesis is suppressed by a phenomenon called the "ammonia switch-off" effect (Brock et al. 1991). This is very true for sewage-fed ponds where the concentration of ammoniacal-N is very high due to the decomposition effect of organic nitrogenous materials. On the contrary, a massive bloom of nitrogen-fixing cyanobacteria does occur in the sewage-fed ponds in response to eutrophication syndrome. Hence, further input of new N in the wastewater-fed system occurs through cyanobacterial bloom following some ammonia switch-off mechanism. It is suggested that the amount of new N could potentially support *Microcystis* growth and the production of toxins in several eutrophic lakes. Duong and Tiedje (1985) reported a N-input in naturally occurring duckweed-cyanobacterial associations of 1–2 mg-N m^{-2} d^{-1}. This value is low compared to the total amount of nitrogen fed to the treatment ponds via the wastewater (possibly 1–2 g-N m^{-2} d^{-1}). N-fixation therefore is not likely to affect the overall nitrogen balance in wastewater treatment ponds.

Though the information about nitrogen fixation in wastewater pond system is hardly available, the sum total of nitrogen-fixing bacterial population in water and sediment of three kinds of fish farming ponds in Naihati farm was 384.2×10^3 cells/ mL and 562.6×10^3 cells/ g, respectively, while the count in the Kalyani farm was 380.3×10^3 cells/mL and 683.8×10^3 cells/ g, respectively. The mean bacterial density of water obtained in traditional system remained significantly lower than the monoculture and polyculture systems (Jana and Roy 1983).

2.4.2.2 Ammonification

Ammonification is a process of the breaking down or conversion of organic nitrogen, i.e. compounds containing the amine group ($-NH_2$), to ammonia. This is fairly done by heterotrophic bacteria. Hydrolysis of urinary urea by urease enzymes also contributes ammoniacal-N to wastewater (Silva et al. 1995). A number of microorganisms such as *Escherichia coli*, *Proteus vulgaris*, *Bacillus subtilis*, *Aeriobacter cloacai*, *Pseudomonas* sp., *Flavobacterium* sp., *Achromobacter* sp. and *Micrococcus* sp. are capable of hydrolysing proteins into simpler compounds such as peptides, urea, amino acids, etc. which, in turn, are metabolized by ammonifying bacteria to liberate ammonia or ammonium sulphate (Alexander 1991; Kruger 1978). After the incorporation of inorganic (NO_3) into an organic form via protein and nucleic acid synthesis, it is metabolized and returned to the major part of the cycle as waste products of that metabolism (e.g. urea or uric acid) or as organized protoplasm in dead organisms which further used as organic nitrogen-rich substrate by many heterotrophic bacteria, actinomycetes and fungi in wastewater. The subject of ammonification in aquatic environment has been extensively reviewed by Jana (1994).

Evidences suggest that natural ammonification and ammonifying bacteria are strongly correlated with each other (Barat and Jana 1987, 1991). In a waste stabilization pond system, the rate of natural and potential ammonification tended to decrease by 87–88% and 75–76%, respectively, from inlet to the outlet of sewage effluents. The rates occurring in bottom water was 30–94% higher than that occurred in surface water. In sediments, maximum rates of natural (0.901–0.135 mg/l/4 days) and potential ammonification (285.6–523.4 mg/l/4 days) were registered at inlet of wastewater-fed pond (Fig. 2.3).

2.4.2.3 Nitrification

Biological nitrification is the microbe-mediated process of oxidizing ammonia to remove nitrogenous compounds (Fig. 2.4) from wastewaters. The NH_4-N can be transformed to NO_2-N and NO_3-N through the nitrification process by nitrifying bacteria (*Nitrosomonas* sp. and *Nitrobacter* sp.) in the presence of oxygen. A large number of heterotrophic nitrifying organisms, such as *Pseudomonas* sp., *Corynebacterium simplex*, *Nocardia* sp., *Aspergillus* sp. and *Vibrio* sp. were also responsible for production of nitrite from ammonium (Alexander 1991). In the presence of oxygen, bacteria will break ammonia down to nitrate. The process of nitrification is summarized in the following equations:

$$NH_4 + 3/2O_2 \rightarrow NO_2^- + 2H^+ + H_2O$$
$$NO_2^- + 1/2O \rightarrow NO_3^-$$

Nitrification plays an important role in the purification of sewage water as majority of nitrogen in water is transformed with nitrification in sewage oxidation ponds and

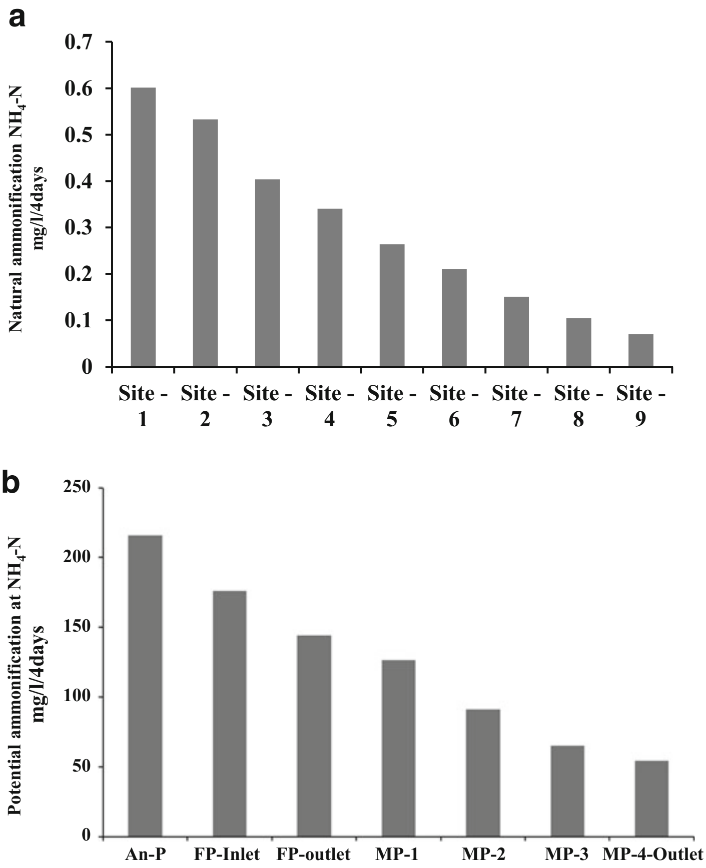


Fig. 2.3 Natural (**a**) and potential (**b**) ammonification measured in different sites of ponds in waste stabilization ponds in Kalyani, West Bengal, India

eliminated through denitrification (Painter and Loveless 1983; Wagner et al. 1996). In wastewater-fed system, the paradigm for ammonium removal from wastewater has been shifted from removal based on conventional two-step nitrification/denitrification to a one-step anaerobic ammonium oxidation system (anammox) in which aerobic ammonium-oxidizing bacteria (AOB) oxidize part of the influent ammonium to nitrite (Speth et al. 2016).

Information about the nitrogen transformation process in sewage-fed ponds is very limited. However, some data are available for waste stabilization pond system consisting of anaerobic, facultative and maturation ponds in the township of Kalyani, West Bengal, India. It becomes evident that the rates of natural and potential nitrification at NO_2-N and at NO_3-N tended to have sharp rise from the inlet to the outlet of the facultative pond and then followed a downward trend in the rest of the ponds tested (Fig. 2.5). The interactions of nutrient concentrations and

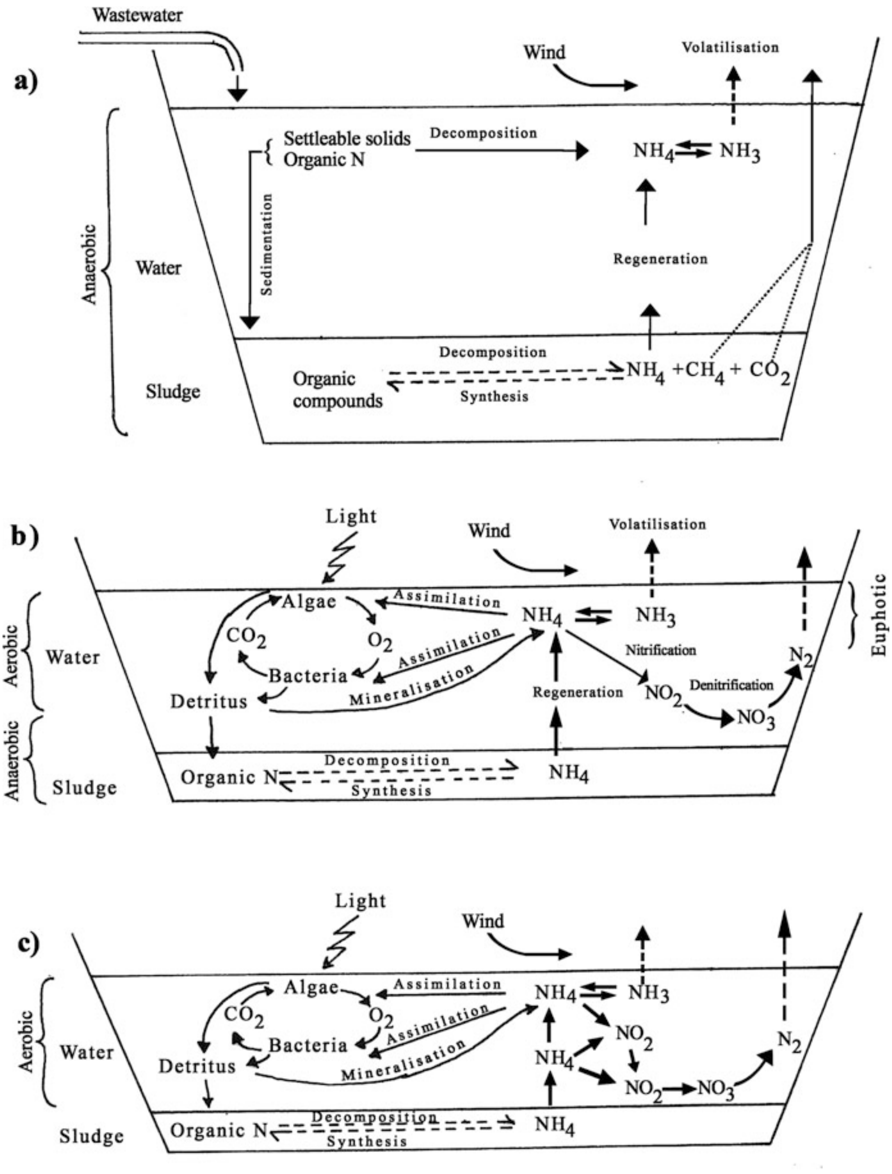


Fig. 2.4 Nitrogen transformation in waste stabilization pond (Source: Nguyen and Davies-Colley 1998)

dissolved oxygen were responsible for the increased abundance of ammonia-oxidizing bacteria in facultative pond inlet as well as in fish ponds. Evidences suggest that dissolved oxygen affected the density of ammonia-oxidizing bacteria both in adverse and in a positive manner (Jana and Roy 1985). Significant correlation between the seasonal changes of ammonia-oxidizing bacterial populations and organic carbon and ammonia-N suggests that nutrients were used by ammonia oxidizers causing nutrient depletion along the sewage effluent gradient.

2.4.2.4 Denitrification

The microbial reduction of nitrate and nitrite with the liberation of nitrogen and nitrous oxide is known as denitrification. Denitrification (dissimilatory process) is the major pathway to remove nitrate from wastewater in wetland systems

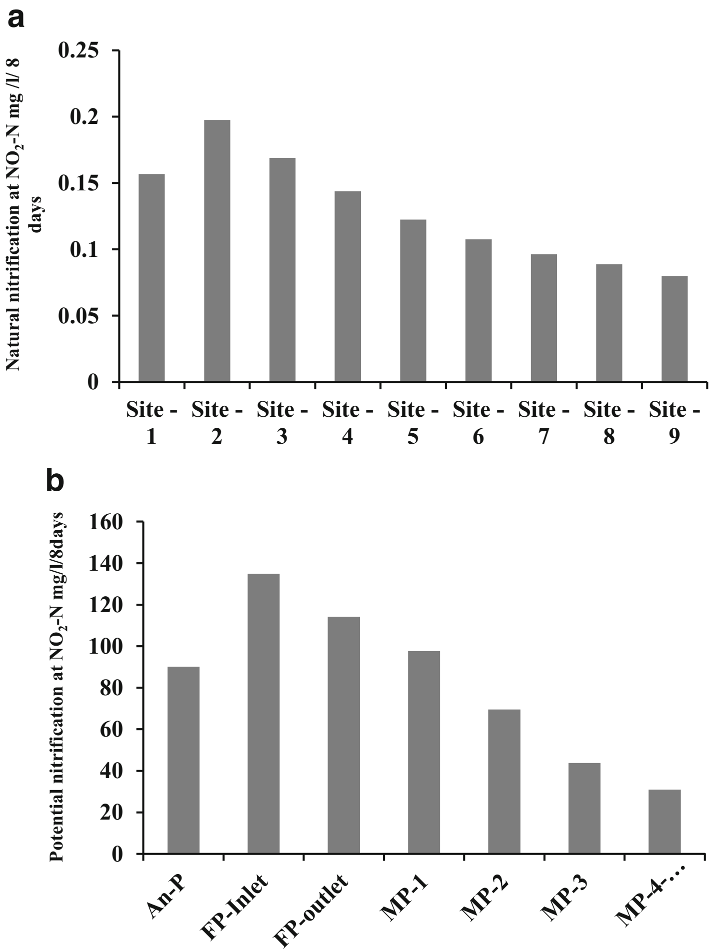


Fig. 2.5 Natural and potential nitrification at NO_2-N (**a** and **b**) and at NO_3-N (**c** and **d**) measured in different sites of ponds in waste stabilization ponds in Kalyani, West Bengal, India

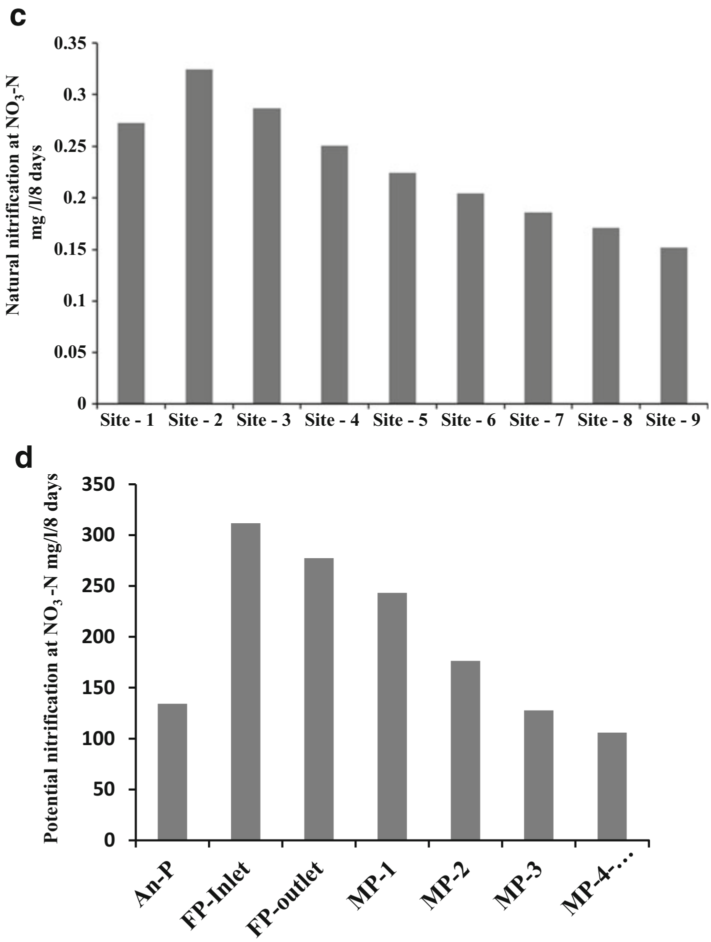


Fig. 2.5 (continued)

(Johnstons 1993; Rittmann and McCarty 2001). It is the microbiologically facilitated process where nitrate is reduced and ultimately produces molecular nitrogen through a series of intermediate gaseous nitrogen oxide products. Basically, denitrifiers utilize NO_3-N, NO_2-N or both as electron acceptor for their multiplication, reducing each to N_2 (Geise 1988; Hoarseley 1979; Hoarseley et al. 1982).

Abundant denitrifying bacterial population occurring in the facultative pond (Fig. 2.6) with adequate substrate and dissolved oxygen while its decrease in the remaining sites with less substrate and adequate dissolved oxygen implied that the interactions between substrate and dissolved oxygen were important in determining the density of denitrifying bacteria. This suggests that denitrifying bacterial populations were oxygen dependent at reduced level of oxygen in the presence of

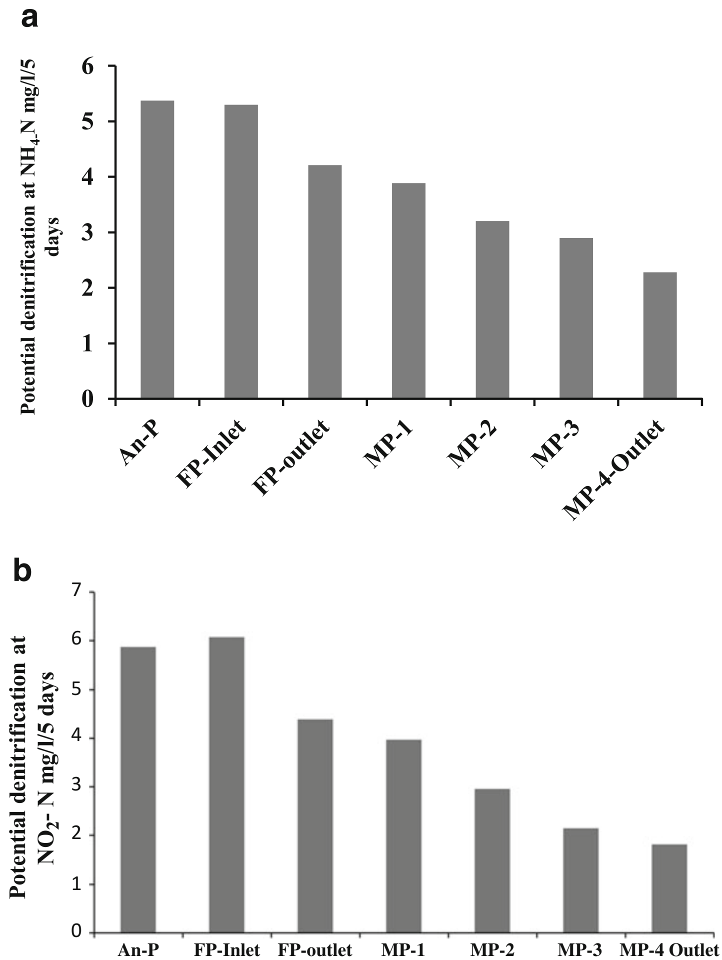


Fig. 2.6 Denitrification potential at NH_4-N (**a**) and NO_2-N (**b**) measured in different sites of ponds in waste stabilization ponds in Kalyani, West Bengal, India

unlimited nutrients, but became oxygen independent at higher values of oxygen and reduced amount of nutrients.

2.4.3 Phosphorus Cycle

Phosphorus is an important element for the nucleotides and ATP of living being. Plants assimilate phosphorous from the environment and then convert it from inorganic phosphorous to organic phosphorous. Phosphorous can be transferred to other organisms when they consume the plants and algae. Animals either release

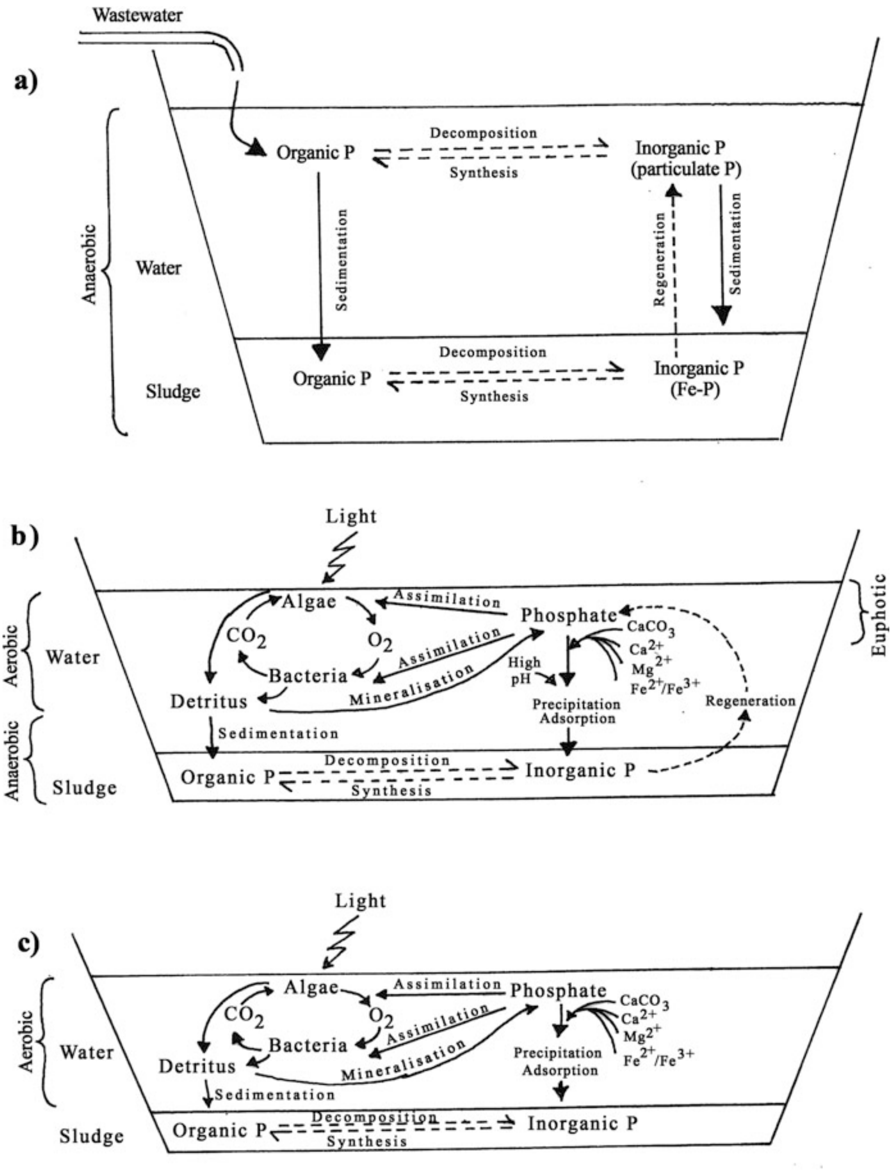


Fig. 2.7 Phosphorus pools and transformation processes in anaerobic (**a**), facultative (**b**) and maturation ponds (**c**) (Source: Nguyen and Davies-Colley 1998)

phosphorous through urination or defecation; dead plants and animals are broken down by bacteria (Fig. 2.7). It is estimated that about 10% of the fertilizer applied caused increase in soluble phosphate in the water phase, which is absorbed by the phytoplankton within few minutes of fertilizer application, whereas the rest is rapidly precipitated and settled at the bottom and converted into insoluble compounds. Thus, the pond bottom acts as a sink of phosphorus in fertilized ponds whereas a source of P in unfertilized ponds. Sewage-fed ponds have very high amount of organic phosphorus settled at the bottom as sludge.

Phosphorus dynamics in wastewater depend on the processes of sedimentation of particulate-bound P including algal and bacterial biomass along with P release as dissolved inorganic-P from sludge to pond waters by mineralization. Inorganic-P is then taken up by algae and bacteria in pond waters (Nguyen and Davis-Colley 1998). Phosphorus may be precipitated in bottom sludges of maturation ponds as hydroxyapatite [$Ca_5(PO_4)_3OH$], tricalcium phosphate $Ca_3(PO_4)_2$ and other insoluble complexes (e.g. magnesium phosphate) because of the high daytime pH resulting from algal metabolism in maturation ponds (Nurdogan and Oswald 1995) (Fig. 2.3).

$$3HPO_4^{2-} + 5Ca^{2-} + 4OH^- = Ca_5(PO_4)_3OH + 3H_2O$$

Solubilization of insoluble phosphate by bacteria is of considerable importance in the sewage-fed ponds. A large number of phosphate-solubilizing microorganisms such as bacteria, fungi and cyanobacteria occurring in water and sediments are capable of assimilating insoluble inorganic phosphate like hydroxyapatite and tricalcium phosphate and make a large portion soluble by the production of organic and inorganic acids. Some chemolithotrophic microorganisms such as *Nitrosomonas* and *Thiobacillus* mobilize inorganic phosphates by producing nitrous and sulphuric acids, respectively (Tiessen and Stewart 1985). Species of *Pseudomonas*, *Mycobacterium*, *Micrococcus*, *Bacillus*, *Flavobacterium*, *Penicillium*, *Sclerotium*, *Fusarium*, *Aspergillus* and others are active in the conversion (Alexander 1991). It is reported that amongst the microbes, *Bacillus* is the most effective one in respect of phosphate solubilization and phosphate production. Invertebrates can contribute to the mineralization of dissolved and particulate compounds in the sediment, and their burrowing activity can affect several exchange processes by increasing the mixing of the sediment surface. Exogenous introduction of phosphate-solubilizing bacteria with compost resulted in the highest concentrations of different species of phosphate in water or sediments amongst all treatments. This was attributable to the combined effects of the phosphate-solubilizing bacteria population of both exogenous and compost origin with short generation time (Jana 2006).

A major share of phosphorus removal (35%) takes place in anaerobic ponds by the process of sedimentation, while removal in facultative and maturation is as low as 4% (Mason 1996). Most important P removal process accounting for 62–90% removal is P precipitation besides biological P uptake. The immobilization of P in aerobic sludges is attributable to the sorption of P by ferric oxyhydroxide (Richardson and Craft 1993). Changes in the chemical environment that affect the chemical mobilization of phosphorus are largely caused by microbial activity by oxygen and nitrate consumption, sulphide and methane formation, etc., thus affecting redox potential that is crucial for phosphate exchange between sediment and water phase (Bostrom et al. 1982).

In a study of wastewater pond system, spatial and seasonal variability of phosphate-solubilizing bacterial population were highly correlated with the concentrations of organic carbon, ammonium-N, nitrate-N and orthophosphate suggesting nutrient uptake by bacteria. The spatial distribution of phosphate-solubilizing bacterial populations was represented by the exponential decay model from facultative to the last maturation pond. In a domestic sewage-fed pond in Orissa, Patri (2000) observed the mean counts of inorganic phosphorus-solubilizing bacteria as 0.16–2.45 CFUs $\times$ 10^3/ml and 0–0.24 CFUs $\times$ 10^3/ml of water at the inlet and outlet of an aquaculture pond.

2.4.4 Carbon Cycle

Carbon metabolism constitutes an important function of nutrient dynamicity of wastewater. Although maximum carbon transformations occur under aerobic conditions, biodegradations of hydrocarbons and lignins, methanogenesis occurs exclusively under anaerobic conditions leading to biogeochemical zonation of habitats (Atlas and Bartha 1998).

Sewage is characterized by the occurrence of carbon cycling bacteria such as aerobic and anaerobic mesophilic bacteria, filamentous fungi, thermophilic bacteria and actinomycetes. Cellulolytic bacteria have been distributed widely in compost (Srinivasan 1987), decomposed reed leaves in a saline lake (Tanaka 1993) as well as in municipal sewage plant.

The important part of microbial carbon cycling is the biodegradation of plant polymers such as cellulose, hemicellulose and chitin which are abundant in domestic sewage. Cellulose, the most abundant biopolymer is a carbohydrate consisting of a linear chain of β-1,4 linked glucose units (Atlas and Bartha 1998). It is known that both aerobic and anaerobic bacteria, filamentous fungi and actinomycetes are capable of utilizing cellulose and converting it to simple sugars with the help of enzyme cellulase. Species capable of decomposing cellulose have been identified as *Clostridium*, *Pseudomonas* and *Alkaligenes* like Pseudomonads (Alexander 1991), aerobic gram-negative bacteria such as *Cytophaga*, *Sporocytophaga*, *Cellvibrio*, *Chromobacterium* and *Pseudobacterium* in aquatic habitats (Kuznetsov 1970; Rodina 1972). It is reported that degradation of organic materials by fermentation or respiration under anaerobic or aerobic conditions releases methane CH_4 and CO_2, respectively (Sorokin and Kadota 1972; Campbell et al. 1991; Bitton 1999).

The spatial variability of cellulose-decomposing bacterial population (Fig. 2.8) from inlet to outlet of a series of WSPs revealed the maximum abundance in the inlet of the facultative pond in the presence of sharp rise in dissolved oxygen of water and nutrient favouring the growth but 45–68%; reduced nutrient at the outlet of facultative pond resulted in decreased CDB population. Because of accumulation of cellulolytic substances in the bottom sediment, occurrence of considerable abundance of cellulose-decomposing bacteria in aquatic system is very common. Nutrient depletion by 45–66% but substantial increase in dissolved oxygen level at the

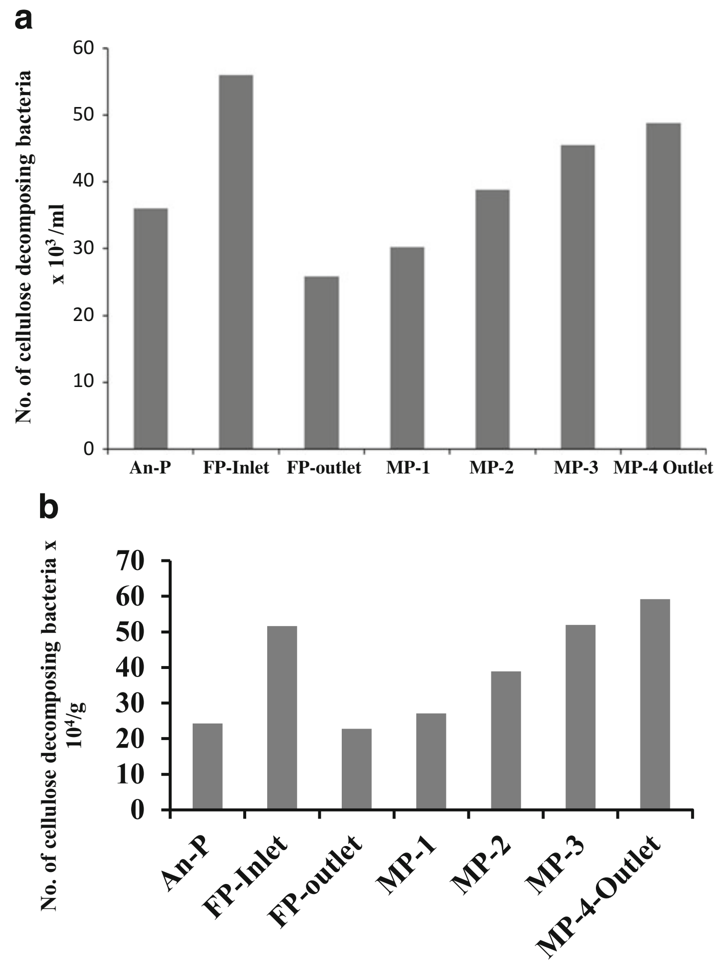


Fig. 2.8 Spatial distribution of the mean counts of cellulose-decomposing bacteria occurring in water (**a**) and sediment (**b**) of different sites of ponds in a WSPs in Kalyani, West Bengal, India

outlet of the facultative pond caused substantial reduction in the counts of cellulose-decomposing bacterial populations. Cellulose degradation is known to occur at a faster rate under aerated habitats than in the anaerobic ones (Alexander 1991).

2.5 Facultative Pond Dynamicity

A theory of facultative pond dynamicity has been proposed (Lahiri et al. 2015) to explain the maximum reclamation capacity of the facultative pond system. A special design of facultative ponds with an island at the centre for waste stabilization and maximum sedimentation of organic load through maximum retention of water caused reduction of as high as 30–35% of organic load from inflowing sewage. Energetically, the facultative pond system has become biologically energy intensive and can mitigate the use of energy-generating mechanical treatment required in the conventional sewage treatment plant. This was due to increased level of photosynthetic oxygen production (6.76–9.71 mg l^{-1}) in surface water by the dense algal bloom caused by nutrient enrichment (phosphate- 0.16–0.37 mg l^{-1}; nitrate- 0.19–0.27 mg l^{-1} and organic carbon- 32–39.5 mg l^{-1}). As a result, primary productivity has been increased by 243–251% at the outlet of the facultative pond when compared to that of the outlet of the anaerobic pond. High concentrations of nutrient-dependent dense algal bloom caused not only substantial reduction of nutrients but were also responsible for die-off of most of the pathogenic bacteria including that of obligatory anaerobic forms. The highly aerobic condition, in turn, induced the decomposition rate of sewage effluents through biogeochemical cycling microbial activities. The responses of biogeochemical cycling bacteria along the effluent gradient further served as functional indicators of reclamation of the system.

2.6 System Reclamation

It is evident that microbial activities play an important role in nutrient recovery from wastewater leading to increased biological production. The process of reclamation through microbial degradation of organic load was responsible for gradual improvement in water quality exhibited in terms of increase in dissolved oxygen (232–256%) coupled with decline in the values of COD (82–86%) and major nutrient parameters such as organic carbon (75–77%), phosphate (87%), ammonia (78–88%) and nitrate (61–62%) of water from the source to the final discharge point of the sewage effluent (Lahiri et al. 2015).

All these factors were responsible for maximal reclamation of about 22–69% of the total that occurred in the facultative waste stabilization pond system. Removal of organic matter in the facultative waste stabilization ponds normally follows a first-order kinetics represented by the equation $ds/dt = K_pS$, where S = substrate mass and K_p = overall substrate removal rate constant per unit time (Arceivala et al. 1970).

It is evident from the study that reclamation of sewage effluents through microbial degradation resulted in improvement in water quality exhibited in significant rise in dissolved oxygen (232–256%) and marked decline in chemical oxygen demand (82–86%), ammonium-N (78–88%), nitrate-N (61–62%) and phosphate (87%) level of water. The effluents at the final discharge points have achieved permissible limits set by ISI standards (Table 2.2). It is evident that the present system has achieved required reclamation for fish culture. The responses of biogeochemical cycling bacteria along the effluent gradient further served as functional indicators of reclamation of the system.

Table 2.2 Reclamation efficiency of the sewage-fed pond system

Physico-chemical parameters	Concentration at source	Concentration at the final outlet point	Increase/ decrease (%)	Concentration at the inlet of the first stocking pond	Increase/ decrease (%)	Increase/decrease through fish ponds (%)	Standard concentration
pH	6.94–7.08	7.78–8.06	12–13	7.32–7.55	5–6.5	6.5–7	5.5–9.0
DO (mg/l)	2.16–2.5	7.7–8.38	235–256	9.06–9.24	270–319	9.3–15	–
COD (mg/l)	430–560	60–102	81–86	202–226	53–60	26–28	250
Organic carbon (mg/l)	43–47	10–11	76–77	27–28.5	37–39	38–39	–
Ammonium-N (mg/l)	2.5–2.7	0.48–0.56	79–81	1.32–1.4	47–48	32–33	5.0
Nitrate-N (mg/l)	0.212–0.222	0.08–0.089	60–61.5	0.166–0.17	22–23	38–38.5	10.0
Orthophosphate (mg/l)	0.287–0.433	0.038–0.055	86–87	0.125–0.238	42–43	42–44	5.0
Soluble reactive phosphorus (mg/l)	0.278–0.34	0.017–0.03	92–94	0.086–0.132	61–69	25–31	–

2.7 Conclusions

In the last decades, sewage water treatment plants have focused on removal of the nutrients nitrogen and phosphorus from wastewater, and this strategy has been very successful in preventing eutrophication of surface waters. Based on the conceptual attributes of the wastewater biosystem, it was hypothesized that reclamation of wastewater is a function of degradation of organic load attributed to the activities of certain biogeochemical cycling bacterial population. It becomes, therefore, pertinent to consider biogeochemical cycling bacteria as indicators of wastewater reclamation. However, the challenges ahead require us to rethink these technologies so that they not only become more energy efficient but also make it possible to recycle valuable nutrients. This can provide new opportunities to create value from wastewater, thus creating new business models for the treatment of sewage.

Acknowledgements SL gratefully acknowledges the valuable guidance of Professor B. B. Jana, International Centre for Ecological Engineering, Kalyani University, in suggesting the topic of research and supervising the work done under his guidance.

References

Agawin NSR, Rabouille S, Veldhuis MJW, Servatius L, Hol S (2007) Competition and facilitation between unicellular nitrogen-fixing cyanobacteria and non-nitrogen-fixing phytoplankton species. Limnol Oceanogr 52:2233–2248

Alexander ML (1991) Introduction to soil microbiology, 2nd edn. Kreiger, Malabar

Aluko OO, Sridha MKC, Oluwande PA (2003) Characterization of leachates from a municipal solid waste landfill site in Ibadan, Nigeria. J Environ Health Res 2(1):32–37

Arceivala SJ, Lakshminarayan JSS, Algaraswamy SR, Sastry CA (1970) Waste stabilization pond, design, construction and operation in India. Central Public Health Engineering Research Institute, Nagpur, p 100

Atlas RM, Bartha R (1998) Microbial ecology: fundamentals and applications. Benjamin/Cummings Science Publishing, Menlo Park, p 694

Barat S, Jana BB (1987) Distribution pattern of protein mineralizing and ammonifying bacterial populations and ammonification rate in experimental tanks differing in husbandry systems. Bamidgeh 39:120–132

Barat S, Jana BB (1991) Distribution of nitrifying bacteria in fish culture tanks: influence of management factors. Acta Microbiol Hung 38:7–16

Barik SK, Sahu M, Sudha M, Puroshothaman CS, Ayyappan S (2000) Phosphatase producing microbes and phosphorus in aquatic ecosystems. Indian J Microbiol 40:83–102

Bitton G (1999) Wastewater microbiology, 2nd edn. Wiley-Liss/Wiley/INC. Publication, New York, p 578

Bobeck M (2010) Organic household waste in developing countries. Environmental Science BA C, Individual Assignment, 15 higher education credits Department of Engineering and Sustainable Development

Bostrom B, Jansson M, Forsberg C (1982) Phosphorus release from lake sediments. Arch Hydrobiol Beih Ergebn Limnol 18:5–59

Brassington R (1995) Finding waters- a guide to the construction and maintenance of private water supplies, 2nd edn. Wiley, Abingdon, p 282

Brock TD, Madigan MT, Martinko JM, Barker J (1991) Biology of microorganisms, 17th edn. Prentice Hall Inc, London

Camargo-Valero MA, Read LF, Mara DD, Newton RJ, Curtis TP, Davenport RJ (2010) Nitrification-denitrification in waste stabilisation ponds: a mechanism for permanent nitrogen removal in maturation ponds. Water Sci Technol 61(5):1137–1146

Campbell R, Berkeley RC, Linton AH, Madelin MF (1991) Microbiology of soil, air and water. In: Hawker LE, Linton AH (eds) Microorganism function, form and environment, 2nd edn. Edward Arnold Ltd, London, pp 243–274

Capone DG, Ferrier MD, Carpenter EJ (1994) Amino acid cycling in colonies of the planktonic marine cyanobacterium Trichodesmium thiebautii. Appl Environ Microbiol 60:3989–3995

Costa-Pierce BA, Laws EA (1985) Effects of denitrification on autotrophic and heterotrophic microplankton productivity in eutrophic aquaculture ponds. Aquaculture 50(1–2):141–151

Dhall P, Kumar R, Kumar A (2012) Biodegradation of sewage wastewater using autochthonous bacteria. Sci World J 2012:1–8

Duong TP, Tiedje JM (1985) Nitrogen fixation by naturally occurring duckweed cyanobacterial associations. Can J Microbiol 31:327–330

Edwards P (1996) A note on wastewater-fed aquaculture system: status and prospects. NAGA, ICLARM 19(1):33–35

Edwards P (2000) Wastewater fed aquaculture: State –of-the-art. In: Jana BB, Banerjee RD, Guterstam B, Heeb J (eds) Water recycling and resource management in the developing world. University of Kalyani/IEES, Kalyani/Wolhusen, pp 37–49

First Nations of Quebec and Labrador Sustainable Development Institute (FNQLSDI) (2008) Reduce, reuse, recycle and recover waste: a 4R's. Guide Wendake, Quebec, p 231

Fry JC (1987) Functional roles of the major groups of bacteria associated with detritus. In: Moriarty dJW, Pullin RSV (eds) Detritus and microbial ecology in aquaculture. ICLARM, Manila, pp 83–122

Geise F (1988) Study on nitrogen metabolism of ten bacterial strain taken from the sediment of brackish water. Zentralbl Mikrobiol 143(3):239–243

Gondwe MJ, Guildford SJ, Hecky RE (2008) Planktonic nitrogen fixation in Lake Malawi/Nyasa. Hydrobiologia 596:251–267

Hoarseley RW (1979) The heterotrophic, nitrate-reducing bacterial flora of Grasmere, English Lake District. J Appl Bacteriol 46:507–520

Hoarseley RW, Roscoe JV, Talling IB (1982) Nitrate reduction by *Pseudomonas* sp. antagonism by fermentative bacteria. J Appl Bacteriol 52:57–66

Jana BB (1994) Ammonification in aquatic environment : a brief review. Limnologica 24:389–413

Jana BB (1998) Sewage-fed aquaculture: the Calcutta model. Ecol Eng 11:73–85

Jana BB (2006) Distribution pattern and role of phosphate solubilizing bacteria in the enhancement of fertilizer value of rock phosphate in aquaculture ponds: state of the art. Plant Soil 258:1–10

Jana BB, Roy SK (1983) Estimates of microbial populations involved in N-cycle and their activity in water and sediments of fish ponds under mono-and polyculture systems in India. Int Re Gesmten Hydrobiol 68:581–590

Jana BB, Roy SK (1985) Distribution patterns of protein mineralizing and ammonifying bacterial populations in fish farming ponds under different management systems. Aquaculture 44:57–65

Johnstons CA (1993) Mechanisms of wetland-water quality interaction. In: Mosheri GA (ed) Constructed wetlands for water quality improvement. Lewis Publishers, Boca Raton, pp 293–299

Jorgensen SE, Vollenweider RA (1989) Guidelines of lake management, Principles of lake management, vol 1. International lake Environment Committee Federation, Otsu, p 199

Kruger D (1978) The influence of the silver carp (*Hypophthalmichthys molitrix*) on eutrophication of the environment of carp ponds: 2. Active microflora changes in nitrogen conversion. Rocz Nauk Roln Ser H Rybactwo 99:33–54

Kuznetsov SI (1970) The microflora of lakes and its geochemical activity, Oppenheimer CH (ed). University of Texas Press, Austin, p 503
Lahiri S, Sarkar (Paria) D, Jana BB (2015) Evaluating the ecological resilient driven performance of a tropical waste stabilization pond system using ecological signature of biological integrity. J Ecol Eng 16:97–107
Leenheer JA, Hsu J, Barber LB (2001) Transport and fate of organic wastes in groundwater at the String fellow hazardous waste disposal site, southern California. J Contam Hydrol 51 (3–4):163–178
Lenes JM, Heil CA (2010) A historical analysis of the potential nutrient supply from the N_2 fixing marine cyanobacterium Trichodesmium spp. to Karenia brevis blooms in the eastern Gulf of Mexico. J Plankton Res 32:1421–1431
Mason IG (1996) Performance of a facultative waste stabilisation pond treating airy shed wastewater. Trans Am soc Agric Eng 40:211–218
Monga O, Garnier P, Pot V, Coucheney E, Nunan N, Otten W, Chenu C (2014) Simulating microbial degradation of organic matter in a simple porous system using the 3-D diffusion-based model MOSAIC. Biogeosciences 11:2201–2209
Nguyen ML, Davies-Colley RJ (1998) Nitrogen and phosphorus cycling in waste stabilization ponds and their influence on the quality of discharge effluents: a review. NIWA Technical Report, vol 43, p 32
Nicklin J, Graeme-Cook K, Paget T, Killington R (2001) Instant notes in microbiology. Bios Scientific Publishers, Oxford
Nurdogan Y, Oswald WJ (1995) Enhanced nutrient removal in high-rate ponds. Water Sci Technol 31(12):33–43
Odum EP (1983) Basic ecology. Saunders College Publication, Philadelphia
Okun DA (2002) Water reuse introduces the need to integrate both water supply and wastewater management at local and regulatory levels. Water Sci Technol 46(6–7):273–280
Painter HA, Loveless JE (1983) Effect of temperature and pH value on the growth rate constants of nitrifying bacteria in the activated sludge process. Water Res 17:237–248
Prescott LM, Harley JP, Klein DA (1999) Microbiology, 4th edn. WCB McGraw-Hill, Upper Saddle River
Raizada N, Sonakya V, Anand V, Kalia VC (2002) Waste management and production of future fuels. J Sci Ind Res 61:184–207
Rawat I, Ranjith KR, Mutanda T, Bux F (2011) Dual role of microalgae: phycoremediation of domestic wastewater and biomass production for sustainable biofuels production. Appl Energy 88:3411–3424
Refsgaard JC, Henriksen HJ, Harrar WG, Scholten H, Kassahun A (2005) Quality assurance in model based water management – review of existing practice and outline of new approaches. Environ Model Softw 20(10):1201–1215
Richardson CJ, Craft CB (1993) Effective phosphorus retention in wetlands: fact or fiction? In: Moshiri GA (ed) Constructed wetlands for water quality improvement. Lewis Publication, Boca Raton
Rittmann BE, McCarty PL (2001) Environmental biotechnology: principles and applications. McGraw-Hill, New York
Rodina AG (1972) Methods in aquatic microbiology, Colwell RR, Zambruski MS (eds). University Park Press/Butterworths, Baltimore/London, p 461
Silva SA, de-Oliveira R, Soares J, Mara DD, Pearson HW (1995) Nitrogen removal in pond systems with different configurations and geometries. Water Sci Technol 31(12):321–330
Sorokin YI, Kadota H (1972) Techniques for the assessment of microbial production and decomposition in freshwaters. International biological programme. Blackwell Scientific Publications, London, p 112
Speth DR, Zandt MH, Guerrero-Cruz S, Dutilh BE, Jetten MSM (2016) Genome-based microbial ecology of anammox granules in a full-scale wastewater treatment system. Nat Commun 7:11172. https://doi.org/10.1038/ncomms11172

Srinivasan VR (1987) Conversion of cellulosic and other organic wastes into microbial proteins. In: Moriarty, DJW, Pullin, RSV (eds) Detritus and microbial ecology in aquaculture. ICLARM conference proceedings, Manila, Philippines, pp 123–147

Tanaka Y (1993) Aerobic cellulolytic bacterial flora associated with decomposing phragmites leaf litter in a seawater lake. Hydrobiologia 36(3):920–922

Tebbutt THY (1998) Principles of water quality control, 5th edn. Butterworth Heinemann, Oxford

Tezuka Y (1990) Bacterial regeneration of ammonium and phosphate as affected by the carbon: nitrogen: phosphorus ratio of organic substrate. Microb Ecol 19(3):227–238

Tiessen H, Stewart JWB (1985) The biogeochemistry of soil phosphorus. In: Caldwell DC, Brierley JA, Brierley CL (eds) Planetary ecology. Nostrand Reinhold, New York, pp 463–472

US Environmental Protection Agency (USEPA) (2001) Water recycling and reuse: the environmental benefits, Region 9, San Francisco, p 11

Wagner M, Rath G, Koops HP, Flood J, Amann R (1996) In situ analysis of nitrifying bacteria in sewage treatment plants. Water Sci Tech 34:237–244

Welch EB, Lindell T (2004) Ecological effects of wastewater. Applied limnology and pollutant effects, 2nd edn. Taylor and Francis, Boca Raton, p 436

Xu H, Paerl HW, Qin B, Zhu G, Gao G (2010) Nitrogen and phosphorus inputs control phytoplankton growth in eutrophic Lake Taihu, China. Limnol Oceanogr 55:420–432

Zinebi S, Henriette C, Petitdemange E, Joret JC (1994) Identification and characterization of bacterial activities involved in wastewater treatment by aerobic fixed bed reactor. Water Res 28 (12):2575–2582

Zuberer DA (1982) Nitrogen fixation (acetylene reduction) associated with duckweed (Lemnaceae) mats. Appl Environ Microbiol 43:823–828

Part II
Culture Practices of Wastewater Fed Aquaculture

Chapter 3
Global Prospects for Safe Wastewater Reuse Through Aquaculture

Stuart W. Bunting and Peter Edwards

Abstract Given the parlous provision of basic sanitation and wastewater treatment globally, the rationale for safe wastewater reuse through aquaculture is presented. Wastewater-fed aquaculture-related responses to counteract negative driving forces, pressures and impacts associated with inadequate sanitation and wastewater treatment and to enhance the state of systems are systematically reviewed with the DPSIR framework. Prospects for a rational design-based approach to safe wastewater reuse using treatment lagoons are discussed. A SWOT (Strengths, Weaknesses, Opportunities and Threats) assessment is presented concerning the future development of safe wastewater reuse through aquaculture. Specific opportunities for value addition to products through cutting-edge biorefinery approaches are reviewed, and the need for appropriate hazard barriers is highlighted. Conditions required to support and promote safe wastewater-fed aquaculture are assessed using the STEPS (Social, Technical, Environmental, Political/Institutional and Sustainability) framework. It is concluded that reuse using intermediaries and biorefinery approaches holds great promise. Widespread adoption of wastewater reuse through aquaculture could contribute to achieving targets specified for sanitation and safe wastewater reuse by 2030 in accordance with the United Nations' Sustainable Development Goals.

Keywords Aquaculture · DPSIR · Safe reuse · STEPS · SWOT · UN · SDGs

Contents

S. W. Bunting (✉)
Bunting Aquaculture, Agriculture and Aquatic Resources Conservation Services, Suffolk, UK
e-mail: stuartwbunting@gmail.com

P. Edwards
Asian Institute of Technology, Bangkok, Thailand
e-mail: pedwards1943@gmail.com

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_3

3.1 Introduction

Globally 2.4 billion people do not have basic sanitation (toilets or latrines), and 'up to 90% of wastewater in developing countries is discharged partially treated or untreated directly into rivers, lakes or the ocean' (WHO 2015). Safe reuse to reduce the proportion of wastewater discharged untreated is a global priority highlighted in the Sustainable Development Goals (SDGs) adopted under the United Nations' 2030 Agenda for Sustainable Development (UN 2016). In support of Goal 6 'Ensure availability and sustainable management of water and sanitation for all', Target 6.3 specifies that 'By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally' (UN 2015).

The practice of wastewater reuse through aquaculture was widespread in the first half of the twentieth century, with notable examples from China, India, Indonesia and Vietnam in Asia and Germany and the Soviet Union in Europe (Edwards and Pullin 1990; Edwards 1992; Prein 1996; Little and Bunting 2015). Towards the end of the last century, traditional systems of reuse through aquaculture, often devised by local entrepreneurs, were in decline or lost with rapid urbanisation in many developing countries (Edwards 2005a, b). Conversion of large peri-urban wetland areas used for wastewater-fed aquaculture to more valuable housing and industrial development was common. Other reuse systems were abandoned owing to pollution or were outlawed based on perceived public health risks and the desire to portray a more 'developed' image on the world stage (Rigg and Salamanca 2005). Furthermore, unreliable wastewater flows attributed to either the deliberate neglect or poor maintenance of delivery channels and infrastructure, and prioritising direct discharges to natural waterways to avoid urban flooding, contributed to the demise of wastewater-fed aquaculture. Adopting conventional wastewater treatment plant designs, with fixed packages of technology, effectively eliminated any chance of wastewater reuse.

Provision of new wastewater treatment has been wholly inadequate to meet the needs of burgeoning urban populations, and this has caused widespread environmental degradation and exacerbated public health problems (WHO 2015). The pressing need to address these issues was again highlighted in the SDGs (UN 2015). Under Goal 3 'Ensure healthy lives and promote well-being for all at all ages', Target 3.1 specifies that 'By 2030, substantially reduce the number of deaths and illness from hazardous chemicals and air, water and soil pollution and contamination'. Under Goal 6, Target 6.2 specifies that 'By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations'. Against this backdrop, it is reasonable to ask whether wastewater reuse through aquaculture has a role to play in meeting the UN SDGs by 2030.

An assessment of wastewater-fed aquaculture-related responses needed to counter negative driving forces, pressures and impacts and enhance the state of the system using the DPSIR framework is presented in Fig. 3.1. This analysis builds on the DPSIR-based reviews of threats to wastewater reuse through aquaculture in the East Kolkata Wetlands (EKW) in Kolkata, West Bengal, India (Bunting et al. 2010), and future potential of urban aquaculture to contribute to resilient food

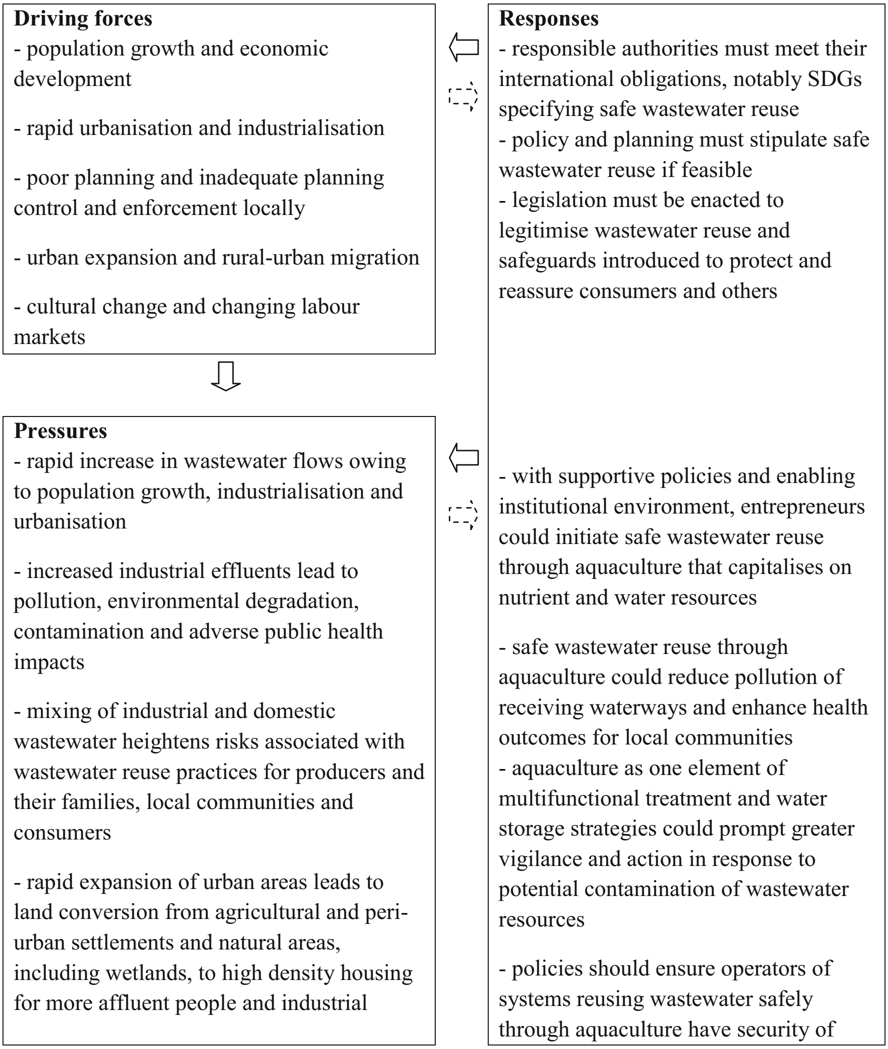


Fig. 3.1 DPSIR framework assessment for wastewater-fed aquaculture globally. Following the convention established by Bunting et al. (2016) 'Solid arrows indicate the typical cause-and-effect interpretation of the DPSIR framework and scope for responses across this continuum; broken arrows indicate that responses must be moderated in light of prevailing conditions'

developments

- low-lying areas, including lakes and ponds, are in-filled so that the land could be sold for development at a much greater price

tenure and that there is a strategy for 'managed retreat' in anticipation of urban expansion

State
- share of global population living in urban areas exceeded 50% in 2007 and this trend continues with many hundreds of millions of poor people suffering as they lack access to basic services, such as sanitation, and have to live in insecure and polluted environments

- surface water quality in many urban settings and downstream environments is below acceptable international standards (and adversley affects human health)

- vast amounts of nutrients are discharged to receiving waters (causing eutrophication and the loss of a valuable resource)

- extent of low-lying areas that could previously accommodate runoff and flood water has declined significantly (leading to substantial financial costs associated with need to build drainage infrastructure and heightened risk of flooding in established and newly urbanised areas)

- wastewater reuse could aid cost recovery to subsidise appropriate collection and treatment and provide income opportunities for poor and marginal groups
- appropriate reuse systems could avoid capital and O&M costs for conventional sewage treatment systems
- wastewater reuse could achieve better environmental protection and biodiversity conservation and restoration of ecosystem services that sustain economic and socio-cultural activities
- wastewater reuse could facilitate nutrient recycling and added value from water appropriated for human use
- production of affordable aquatic plants and animals could enhance nutrition and food security amongst poor communities
- water-bodies established for wastewater reuse could provide additional capacity to store urban runoff and floodwater

Fig. 3.1 (continued)

Impacts

- poor and marginal groups suffer owing to limited employment and income, insecure living conditions and food supplies, absence of health care and sanitation, air and water pollution, and flooding

- population pressure leads to informal settlements on accessible areas that are not served by sewers and consequently discharge wastewater indiscriminately and lead to open defecation and overhung latrines along canals and over ponds

- discharge of untreated wastewater negatively impacts biodiversity, undermines stocks and flows of ecosystem services, and increases animal and public health risks associated with direct and unintentional wastewater reuse through aquaculture

- conflicts between land use activities, with poor communities and agriculture and aquaculture generating modest financial returns displaced or further marginalised

- financial costs associated with living in urban settings force younger generation to avoid farm work and seek urban employment

Fig. 3.1 (continued)

systems (Bunting and Little 2015). The assessment benefitted further from the addition of cultural and administrative factors identified by Rigg and Salamanca (2005) concerning the 'drivers of peri-urban change' affecting peri-urban aquatic food production systems in Southeast Asia.

Considering the situation in India, wastewater reuse through aquaculture is still practised, notably in the EKW (East Kolkata Wetlands). Globally, the practice of irrigation with wastewater for food production is more common in terrestrial farming (Strauss 2003), and 'at least 10% of the world's population is thought to consume food irrigated by wastewater' (WHO 2015). Large volumes of processed sludge from sewage treatment plants are currently applied to agricultural land in Europe. The practice is not generally challenged as it is not very visible, occurring sporadically in rural areas, and no adverse effects have been reported. Furthermore, the separation of waste inputs to the soil earlier in the growing season, and the harvest of grains that undergo processing, may psychologically allay any concerns. There is a degree of trust in the regulatory authorities, whom the public expect would prevent any unhygienic or unsafe practices.

3.2 Prospects for Rational Design and Participatory and Integrated Planning

Prominent practitioners and scientists advocated an ecological engineering approach to wastewater treatment using lagoons and fishponds recalling the example set by indigenous reuse practices developed and refined by producers, as with the EKW, and Mudialy Fishermen's Cooperative Society also in West Bengal, India (Ghosh 1999; Jana 1998, Jana et al. 2000; Mara 1997; Pye-Smith et al. 1994). Lagoon-based wastewater treatment and reuse systems were established at Bally (North Howrah), Nabadwip, Panihati and Titagarh (Mara 1997) in West Bengal, under the Ganga Action Plan (GAP) initiative. Fish were grown in batch culture in maturation ponds established as part of a waste stabilisation pond system at the Kalyani Sewage Treatment Plant (STP) (Jana 1998; Ganguly et al. 2015). A demonstration system was commissioned to reuse sewage from treatment ponds in San Juan, Lima, Peru, to test and promote the technology in South America (Moscoso 2006). A lagoon-based treatment system was established to treat polluted water extracted from the Kam Tin River, Hong Kong, and trials were conducted to growing fish in the water following sedimentation and aeration (Liang et al. 1999).

Treatment lagoons are routinely designed to produce water that meets international standards for safe reuse. This level of treatment, however, removes significant quantities of nutrients, thus limiting the productivity of the receiving fishponds. Cognisant of this limitation, a rational design approach was formulated that capitalises on the rapid die-off of bacteria in aerobic and alkaline fishponds to compensate for a more moderate treatment phase (Mara et al. 1993). Anaerobic ponds with a depth of 2 m and retention time of 1 day are followed by facultative ponds, 1.5 m deep and with a retention time of 5 days. To validate the design, the volumetric and areal BOD_5 loading should not exceed 300 g/m^3/day or 350 kg/ha/day for the anaerobic and facultative ponds, respectively. Fishponds are then designed based on the optimal nitrogen loading of 4 kg/ha/day (Edwards 1992); this necessitates calculating the removal of nitrogen in the facultative ponds, but no loss of nitrogen is expected from the anaerobic ponds.

Faecal coliform (FC) concentrations in the fishponds are estimated using the relationship established for a continuous stirred reactor (CSTR) defined by Mara et al. (1993) and based on the earlier work of Marais (1974); thus, $N_p = N_i/(1 + k_T O_a)(1 + k_T O_f)(1 + k_T O_p)$, where N_p is the number of FCs in 100 ml of fishpond water, N_i is the number of FCs in 100 ml of untreated wastewater, k_T is the rate constant for FC removal per day ($2.6(1.19)^{T-20}$) and O_a, O_f and O_p are the retention times (days) in the anaerobic pond, facultative pond and fishponds, respectively. Subsequent evaluation deemed the CSTR model safer as compared to the alternative dispersed flow (DF) model proposed by Oakley (1997) as the DF model tends to overestimate faecal coliform removal rates in ponds with plug-flow conditions and higher retention times (Buchauer 2007).

Assuming that the rational design approach was adopted to enhance the reuse of 550,000 m^3/day of wastewater in the EKW, it was indicated that fish production could be increased to 45,000 t annually (Bunting 2007). This would, however, require extensive and costly reconfiguration of the existing pond system and the creation of 27.5 ha of anaerobic ponds and 182 ha of facultative ponds. Water entering the fishponds in this case would contain 2.2×10^5 FC/100 ml, thus exceeding WHO (2006c) guideline targets for wastewater for aquaculture reuse. If the fishponds were reconfigured so that they were small (1 ha), infrequently loaded with wastewater and well mixed, then rapid pathogen die-off in the ponds would ensure the safety of producers, local communities and consumers (Mara et al. 1993).

Hybrid waste stabilisation pond and storage and treatment reservoirs have been proposed to store treated water for unrestricted irrigation whilst simultaneously producing water for restricted irrigation (Mara and Pearson 1999). The authors calculated that to treat 10,000 m^3 of wastewater daily and store water for 5 months of unrestricted irrigation would require a storage reservoir of 15.75 ha. Following a 1-month rest phase, the faecal coliform count would be below 1000/100 ml of water. At this concentration, the reservoir water meets the microbial quality target for wastewater-fed aquaculture to safeguard 'aquacultural workers and local communities' (WHO 2006c), and within 4 months a crop of 200 g tilapia could be produced (Mara et al. 1993). Cages could be used to culture fish in wastewater treatment ponds to facilitate harvesting and to avoid predation of farmed stock by larger wild carnivorous fish (Gaigher and Krause 1983).

Opportunistic fish culture in wastewater treatment lagoons has been reported from several countries including Bangladesh and India in Asia and Ghana, Kenya and South Africa in Africa (Ampofo and Clerk 2003; Bunting 1998; Kumar et al. 2015; Letema 2012; Prinsloo and Schoonbee 1992). Fishponds were constructed downstream of the Keshopur wastewater treatment plant, Delhi, to make use of treated wastewater (Spatial Decisions and Winrock International India 2006), whilst these authors also noted that untreated wastewater was used for aquaculture in large slums, such as Yamuna Pushta, Delhi, to produce food and income for the local community. An urgent need for 'policy-makers and authorities as well as donors and the private sector' to confront 'the realities of wastewater use in agriculture [and aquaculture]' was highlighted by the signatories to 'The Hyderabad Declaration on Wastewater Use in Agriculture' (IWMI 2002). The declaration specified the need to adopt appropriate policies and commit financial resources for implementation and apply 'cost-effective and appropriate treatment suited to the end use of wastewater, supplemented by guidelines and their application'. As with formal wastewater-fed aquaculture, the international guidelines for safe reuse published by the WHO (2006c) present a sound starting point for responsible authorities to devise appropriate risk management strategies and implement hazard barriers that safeguard the health of consumers, as well as producers, their families and local communities.

3.3 Alternative Reuses Paradigms to Mitigate Health Risks and Concerns

Ten years on from the publication of revised guidelines by the World Health Organization for the 'Safe Use of Wastewater, Excreta and Greywater' (WHO 2006a, b, c, d), the impact of this major policy development on public health still demands assessment. A central tenet of the guidelines for 'wastewater and excreta use in aquaculture' (WHO 2006c) was 'to ensure that waste-fed aquacultural activities are made as safe as possible so that the nutritional and household food security benefits can be shared widely in affected communities' (pxiii). The urgent need to tackle untreated wastewater discharges to protect the Ganges River and the communities it sustains was highlighted by the recent call for innovative solutions (NMCG 2016). The call identified 144 drains across four states (Uttar Pradesh, Uttarakhand, Bihar and West Bengal) discharging 6614 million litres/day of untreated wastewater to the Ganges (Annexure VI). A further 853 million litres/day is discharged to two of the rivers' major tributaries, and the situation is made worse by non-point source pollution and open defecation along the river banks.

Wastewater interception and treatment schemes established over 20 years under the auspices of the Ganga Action Plan (GAP) cost many hundreds of millions of dollars but did not result in the ecological restoration of the Ganges owing to 'bad planning, poor execution, extensive corruption, absence of coordination ... delay ... cost escalation ... inadequate treatment of effluents, especially in tackling ... bacterial load ... deficient public awareness and participation' (Dayal 2016). A comprehensive review of 152 wastewater treatment plants established under the National River Conservation Plan (NRCP) in India noted that the cumulative design capacity was 4716 million litres/day but that only 3126 million litres/day (66%) was operational (CPCB 2013). Of the 152 plants surveyed, 31 were WSP systems, and it was noted that associated average capital costs of Rs. 2.3 million per million litres/day of capacity to achieve secondary treatment were significantly lower than conventional treatment technologies.

Nationally the flow of wastewater from class I cities (population above 100,000 in 2001) was estimated at 35,558 million litres/day, but the treatment capacity was only 11,554 million litres/day or 32.5% of the total. For class II cities (population 50,000–99,999 in 2001), a flow of 2697 million litres/day was estimated, but the treatment capacity was only 234 million litres/day or 8.7% of the total. It was noted that inadequate wastewater collection meant the limited treatment capacity that was available was not fully utilised. Focusing on West Bengal, 34 treatment plants with a design capacity of 457 million litres/day were surveyed, but the actual treatment level was 214 million litres/day (46.8% of the total). It was observed that 13 plants were not operational. One facility operating at its design capacity of 6 million litres/day and effectively treating wastewater was the Baidyabati plant (CPCB 2013). This WSP-based system consists of an anaerobic pond, a facultative pond, an aerobic pond and five fishponds. Revenue generated from fish culture could provide an incentive to ensure the correct functioning of the plant.

Key to meeting the SDG to ensure sanitation for all by 2030 will be the adoption of appropriate technologies given the prevailing environmental, social and economic setting (Mara 2009). Supporting policies and institutional arrangements are required to legitimise wastewater reuse through aquaculture. Considering Vietnam, with its history of wastewater-fed aquaculture in and around Hanoi, it was noted that 'although policies, strategies, laws and guidelines support the use of wastewater in agriculture and aquaculture', there is a lack of implementation and enforcement (Evans et al. 2014). The need for reciprocal arrangements within agriculture, aquaculture and irrigation policies and regulation concerning health impacts was highlighted. Consequently, it was noted that 'small changes could lead to safe, cost effective planned reuse which would protect the environment and provide Hanoi with a much needed water supply in the future'.

Cost-effective and easy-to-operate strategies are required as opposed to conventional energy intensive technological packages. Fundamental to the WHO guidelines for safe use of wastewater and excreta in aquaculture is that 'minimum good practices or health-based targets should be based on local social, cultural, environmental and economic conditions and be progressively implemented over time depending on the existing reality and resources of each individual country or region, leading to steady public health improvements' (WHO 2008). Innovative financing and management arrangements should be devised that are efficient, effective and accountable. Waste Enterprisers Ltd. signed a public-private partnership agreement with Kumasi Metropolitan Assembly, Ghana, to operate and maintain the waste stabilisation ponds at Ahensan Estate and Chirapatre Estate in return for access to the maturation ponds to culture catfish (Murray and Yeboah-Agyepong 2012). Water conditions in the maturation ponds were suboptimal for fish growth and survival. Poor design, short-circuiting and siltation led to poor treatment performance; in response stocking advanced fingerlings that had been acclimatised to wastewater was recommended.

The crux of the matter is finding a balance between wastewater treatment to make it safe and acceptable to use and optimising the reuse strategy to maximise the benefits. A distinction is made between safe and acceptable, as practices that conform to international standards for safe reuse may still be regarded as unacceptable by consumers and authorities from a psychological or sociocultural perspective. Fish raised using wastewater in Egypt were deemed safe for human consumption based on international guidelines, but were not accepted by consumers owing to cultural barriers (Mancy et al. 2000). To allay concerns over the reuse of sewage sludge in terrestrial agriculture in the UK, a consortium of wastewater operators and major food retailers produced the 'Safe Sludge Matrix' (ADAS 2001). The matrix summarises what level of sludge processing is appropriate for different crop categories and what harvest interval post sludge application is required. A safe wastewater reuse matrix for aquaculture within the local context could be developed jointly by authorities, producers and consumer representatives adopting these principles. Prospects for wastewater-fed aquaculture are critically reviewed here using the SWOT (Strengths, Weaknesses, Opportunities, Threats) framework to structure the assessment (Table 3.1).

When an additional degree of separation, whether temporally, spatially or psychologically, is deemed necessary to allay the concerns of potential consumers and others, an intermediate production phase could be included. Aquatic plants could be grown on wastewater-fed lagoons and harvested and processed to feed to livestock or herbivorous fish in ponds not receiving wastewater (Alaerts et al. 1996; Edwards et al. 1992). Comprehensive trials growing duckweed on wastewater have been undertaken, and the optimal conditions to maximise the yield and composition

Table 3.1 SWOT assessment of wastewater-fed aquaculture

Strengths: *existing or potential resources or capability*	**Weaknesses**: *existing or potential internal force that could be a barrier to achieving objectives/results*
Demand for aquaculture products amongst burgeoning urban populations and more affluent middle-class consumers is strong and increasing	Responsible authorities do not widely recognise wastewater reuse through aquaculture as a legitimate urban/peri-urban activity or effective and efficient option for wastewater treatment and management
Wastewater reuse through aquaculture is recognised in national and international policy and supported by aid agencies and development banks	Widespread discharges of partially and untreated wastewater from rapidly expanding urban populations are not safe for reuse through aquaculture, contaminate surface waters and cause environmental degradation
Optimal production strategies have been devised through local innovation by farmers and extensive programmes of scientific research	Lack of supportive and coherent policies and legislation across different sectors, combined with weak enforcement and insecurity of tenure dissuade entrepreneurs from investing in aquaculture businesses that could reuse wastewater
Productive wastewater-fed aquaculture systems can act as a bioindicator for good environmental health, conserve biodiversity, restore ecosystem services, and notably open spaces for flood retention and infiltration	Poor urban planning and inertia that perpetuates the selection of inappropriate wastewater treatment options means that wastewater reuse through aquaculture is not given equal consideration with regard to cost-benefit analysis (CBA) or comparative health impact assessments
Wastewater reuse through aquaculture can provide income and employment opportunities for poor and marginal groups and produce aquatic plants and fish that are affordable and contribute to the nutrition and food security of poor communities	
Opportunities: *existing or potential factors in the external environment that, if exploited, could provide a competitive advantage*	**Threats**: *existing or potential force in the external environment that could inhibit maintenance or attainment of unique advantage*
Perfect storm of population growth, urbanisation, untreated wastewater flows, water scarcity, food insecurity and rising energy costs make the rationale for safe reuse through aquaculture undeniable	Wastewater reuse through aquaculture requires more extensive use of land than conventional wastewater treatment systems, a major constraint in peri-urban areas of rapidly expanding cities where available land at reasonable cost may be limited
International agreements stipulating the need for far greater wastewater reuse and supporting policies and guidelines should legitimise and encourage adoption of reuse through aquaculture	Concerns amongst consumers regarding wastewater reuse practices may be exacerbated or made insurmountable through adverse media coverage of practices and adverse public health outcomes

(continued)

Table 3.1 (continued)

Growing awareness of environmental and public health impacts of discharging untreated wastewater and the reality of unintended and unsafe use for aquatic food production should shift public opinion favourably towards appropriate treatment and safe reuse through aquaculture	Advocates for conventional treatment practices, notably engineers and those with commercial interests, may promote inappropriate technological packages given prevailing environmental, social and economic conditions
Abstraction of water from waterways receiving wastewater for use in aquaculture (with appropriate precautions) could promote ecological restoration whilst mitigating cultural and psychological aversions to direct wastewater reuse	Contamination with industrial effluents and chemical pollutants and the occurrence of pathogens, notably trematodes, within the general population, may make risks associated with wastewater reuse through aquaculture unacceptable
Innovative community members and entrepreneurs exploit opportunities to appropriate wastewater (raw and partially treated) flows and access treatment lagoons to culture aquatic plants and fish to meet demand from expanding urban populations	Products cultured using wastewater (directly or indirectly) must compete with products from elsewhere, and costs of treating and conditioning wastewater and elevated land and labour costs in urban and peri-urban areas may mean reuse strategies are not financially viable
	Limited information on extent and nature of wastewater reuse (intentional and unintentional) in aquaculture means that authorities do not appreciate the contribution to livelihoods, nutrition and food security and economic development, and health risks are not assessed and managed

Adapted from Bunting and Little (2015)

of the biomass produced are well defined (Iqbal 1999). Tilapia and small carp species could be cultured in wastewater-fed ponds for processing to make feed for other aquatic animals (Edwards 1990). Wastewater could be used to cultivate aquatic animals, plants and phytoplankton for use as feedstock for industrial processes and bioenergy production.

The non-use or intrinsic values of ecologically based treatment systems may justify their establishment when productive reuse of wastewater is not possible. Treatment wetlands could sustain a broad range of ecosystem services, in addition to regulating waste discharges, and could provide a valuable habitat for aquatic species. Reuse through aquaculture of waste not originating from humans, such as manure from animals, waste streams from agro-industrial processes and food and drink production, is well established (Little and Edwards 2003). Promotion of such practices to reuse wastewater, capture nutrients and safeguard the environment should be less controversial. Ecologically based wastewater treatment should be integrated with other uses as part of multifunctional floodplains or landscapes to maximise synergistic effects, but associated public health risks would demand assessment and appropriate safeguards.

3.4 Value Addition Through Cutting-Edge Biorefinery Approaches

Biorefinery approaches have the potential to add substantial value to plants and animals cultured in wastewater reuse systems. Plants such as microalgae and seaweeds and animals such as crustaceans and molluscs could be transformed through extraction and purification processes to higher-value products. Microalgae are cultured to produce a range of chemicals, fatty acids and bioactive compounds. Harvesting microalgae represents a major constraint to commercialisation of pond-based culture. Culturing fish on algae derived from high-rate algae ponds may be a viable alternative that could add value to microalgae production using wastewater (Edwards and Sinchumpasak 1981; de la Noue et al. 1992). Seaweed biomass can be degraded by bacteria (*Alteromonas espejiana*) to produce single cell detritus that can be fed to suspension feeding animals in hatcheries or to *Artemia* nauplii for use as fish feed.

By-products from seafood processing, notably crustacean shell material, have been highlighted as a potential source of nitrogen-rich chemicals, and the development of appropriate biorefinery practices could help protect the environment and generate substantial economic benefits (Yan and Chen 2015). Calcium carbonate derived from shells can be used in agriculture, construction, paper manufacture and pharmaceuticals. Protein from shrimp shell could be processed to produce livestock feed as it contains essential amino acids and is nutritionally comparable to soya bean meal. Chitin from shells can be used in biomedicine, cosmetics, textile manufacture and water treatment. Composed of a linear polymer containing nitrogen, chitin could be a significant new feedstock for ethanolamine (ETA). Two million tonnes of ETA, with a value of $3.5 billion, are used annually for carbon sequestration, household cleaning products, soap and surfactants (Yan and Chen 2015). According to these authors, the refinery of shell-derived industrial feedstock materials is constrained as extraction methods that are 'destructive, wasteful and expensive'. Innovative methods using ionic liquids are being developed to extract long-chain and high-molecular-weight chitin polymers that can be spun into fibres and used to produce films, both with excellent potential for commercialisation.

Prospects for reusing wastewater to culture zooplankton (*Daphnia magna*) in aerated waste stabilisation ponds were assessed in the Grand Duchy of Luxembourg (Cauchie et al. 2002). The chitin content of the zooplankton biomass was between 3% and 7% on a dry weight basis. Depending on the processing mechanism, the average molecular weight ranged from 600,000 to 2,600,000 and had a low nitrogen content 'indicating a high degree of acetylation'. Wastewater from the Iztacalco treatment plant in Mexico City, Mexico, was used to culture four cladoceran species, and population growth rates comparable to those achieved with green algae were obtained (Nandini et al. 2004). Comparing different organic wastes to produce zooplankton (*Moina micrura*), it was found that diluted human urine was the best media (Golder et al. 2007). Feeding by zooplankton species can reduce the bacterial load in wastewater. But prior to using cladocerans grown using wastewater to feed fish larvae, it was noted that the risks from transferring bacterial diseases and the bioaccumulation of toxins must be evaluated. Zooplankton (*Daphnia carinata*) from wastewater treatment lagoons at Werribee, Melbourne, Australia, had a protein content of 54.8% and when fed to silver perch (*Bidyanus bidyanus*) resulted in better growth and feed conversion ratios than a control diet (Kibria et al. 1999). The authors also noted that heavy metal concentrations in fish fed zooplankton were very low.

Biorefinery approaches are being devised to add value to small mussels cultured in suboptimal conditions and low-trophic level species biomass produced from integrated multi-trophic aquaculture (IMTA) systems. Opportunities to produce biomass as an industrial feedstock from wastewater reuse through aquaculture could avoid problems with reuse to produce food for people. Considerable investment in research and development is required, however, to devise processing pipelines that are efficient and suitably refined to produce high-quality and high-value products. Appropriate hazard barriers to safeguard the health of operators, their families, local communities and those working in biorefinery pipelines will still be needed.

3.5 Enhancing Prospects for Wastewater-Fed Aquaculture

Problems encountered by operators of wastewater-fed aquaculture systems have been widely reported, and media coverage has borne witness to the demise of iconic systems such as Boeng Tompun Lake in Phnom Penh, Cambodia (The Cambodia Daily 2014), and the EKW, West Bengal, India (The Times of India 2015). Critical reflection on such experiences can, however, help clarify the conditions required to successfully implement and sustain the safe reuse of wastewater through aquaculture (Bunting et al. 2010). The STEPS (Social, Technical, Environmental, Political, Sustainability) framework that cuts across disciplines and sectors is used to structure such an assessment (Table 3.2).

3.6 Conclusions

Prospects for wastewater-fed aquaculture have been critically reviewed from a global perspective. Technologies and processes to enable the safe reuse of wastewater through aquaculture have been established although they require more extensive use of land than conventional wastewater treatment systems, a major constraint in peri-urban areas of rapidly expanding cities where available land at reasonable cost may be limited. Problems concerning the acceptance of food products from wastewater reuse systems may constitute a fundamental barrier to future development. Reuse through intermediaries and for biorefinery feedstocks appears to hold the greatest promise. Research and development must focus on such

Table 3.2 STEPS assessment of conditions needed to support and promote wastewater-fed aquaculture

STEPS element	Conditions
Social	Acceptance and support for safe wastewater reuse through aquaculture as a legitimate and worthwhile activity
	Demand exists for animals and plants grown safely using wastewater or appropriate intermediaries, and refined materials could be produced
	Aquaculture reusing wastewater generates sufficient revenue to provide attractive employment and income-generating opportunities
Technical	Wastewater treatment and conditioning facilities, whether conventional or ecologically based systems, produce water that is safe and of sufficient quality to stimulate natural productivity in culture ponds and promote good aquatic animal or plant growth
	Practices in which indirect or unintentional wastewater reuse through aquaculture is occurring identified using appropriate tests and safeguards implemented to manage health risks
	Monitoring programmes implemented to ensure that systems function correctly and within permissible limits
	Quality inputs, e.g. healthy fish and nutritious supplementary feed, are available, and employees are sufficiently trained to effectively operate and maintain the system (including wastewater treatment facilities where necessary)
	Arrangements across product value chains are implemented to safeguard the health of workers, the general public and consumers
Environmental	Wastewater reuse through aquaculture recognised as an effective and legitimate element in managing wastewater to protect receiving waterways and facilitate recycling of resources
	Wastewater treatment system components and aquaculture facilities are designed appropriately given prevailing climatic conditions and safeguards included to mitigate against extreme weather events, flooding and climate change
	Authorities enforce laws to prevent pollution to safeguard wastewater reuse through aquaculture practices and products
	City planning includes provision for green infrastructure, including space for appropriate wastewater treatment and reuse through aquaculture, as this will help dissipate adverse impacts of urbanisation such as the urban heat island effect and flooding (within urban areas and downstream) and provide habitat for biodiversity
Political (institutional)	National and international polices explicitly support wastewater reuse through aquaculture for increased sanitation coverage, public health and environmental protection, ecosystem services enhancement, resource recovery and food security
	Signatories to the UN 2030 Agenda for Sustainable Development adhere to their commitments, notably improve water quality and reduced pollution through safe reuse of wastewater for aquaculture
	Municipal authorities and engineers recognise and encourage wastewater reuse through aquaculture as a legitimate and desirable activity

(continued)

Table 3.2 (continued)

STEPS element	Conditions
	Land-use planning policy and tenure arrangements provide security for operators and enable them to access credit and justify investment in ongoing operation and maintenance
	Government agencies and extension services and private sector support providers cover aquaculture using wastewater (intentionally and unintentionally)
	Operators of systems reusing wastewater for aquaculture cooperate, share knowledge and pool resources to lobby for greater support and recognition within wastewater management and urban planning processes
Sustainable (long-term viability)	Policies supporting appropriate wastewater treatment strategies and wastewater reuse through aquaculture continue and remain consistent with developments in other sectors
	Management plans and the design and location of treatment and reuse systems are adaptable to changing circumstances
	Investment in wastewater collection and treatment infrastructure continues so that wastewater flows are maintained and the quality of aquaculture products is safeguarded
	Minimum good practices and health protection targets should be appropriate to local conditions and progressively implemented given the reality of the situation and availability of resources

Adapted from Bunting and Little (2015)

strategies to ensure that they are cost-effective and appropriate. Responsible authorities have a key role to play in ensuring that safe reuse through wastewater-fed aquaculture is regarded not only as a legitimate practice but is championed as a practical means towards protecting the environment, safeguarding public health and contributing to food security. Awareness must be raised regarding the risks of practising aquaculture (either intentionally or inadvertently) in faecally polluted surface waters and appropriate safeguards implemented to protect the health of producers, local communities and consumers (WHO 2006c). Widespread adoption of wastewater reuse through aquaculture is an appropriate strategy for small- and medium-sized settlements in low- and middle-income countries with tropical climates and could make a significant contribution to achieving the United Nations' SDGs by 2030.

References

ADAS (2001) The safe sludge matrix. British Retail Consortium/Water UK/ADAS, Cambridge

Alaerts GJ, Mahbubar R, Kelderman P (1996) Performance analysis of a full-scale duckweed-covered sewage lagoon. Water Res 30:843–852

Ampofo JA, Clerk GC (2003) Diversity of bacteria in sewage treatment plant used as fish culture pond in southern Ghana. Aquacult Res 34(8):667–675

Buchauer K (2007) Comparison of model approaches for predicting coliform removal in waste stabilization ponds. Water Environ J 21:108–113
Bunting SW (1998) Constraints and opportunities in wastewater aquaculture. Back-to-office report. Institute of Aquaculture, University of Stirling, Stirling
Bunting SW (2007) Confronting the realities of wastewater aquaculture in peri-urban Kolkata with bioeconomic modelling. Water Res 41:499–505
Bunting SW, Little DC (2015) Urban aquaculture for resilient food systems. In: de Zeeuw H, Drechsel P (eds) Cities, food and agriculture: towards resilient urban food systems. Earthscan, Oxon, pp 312–335
Bunting SW, Pretty J, Edwards P (2010) Wastewater-fed aquaculture in the East Kolkata wetlands: anachronism or archetype for resilient ecocultures? Rev Aquac 2:138–153
Bunting SW, Luo S, Cai K, Kundu N, Lund S, Mishra R, Ray D, Smith KG, Sugden F (2016) Integrated action planning for biodiversity conservation and sustainable use of highland aquatic resources: evaluating outcomes for the Beijiang River, China. J Environ Plan Manage 59:1580–1609
Cauchie HM, Jasper-Versali MF, Hoffmann L, Thome JP (2002) Potential of using *Daphnia magna* (crustacea) developing in an aerated waste stabilisation pond as a commercial source of chitin. Aquaculture 205:103–117
CPCB (2013) Performance evaluation of sewage treatment plants under NRCD. Central Pollution Control Board, New Delhi
Dayal R (2016) Dirty flows the Ganga: why plans to clean the river have come a cropper. Econ Polit Wkly 25:55–64
de la Noue J, Laliberte G, Proulx D (1992) Algae and wastewater. J Appl Phycol 4:247–254
Edwards P (1990) An alternative excreta-reuse strategy for aquaculture: the production of high-protein animal feed. In: Edwards P, Pullin RSV (eds) Wastewater-fed aquaculture. Proceedings of the international seminar on wastewater reclamation and reuse for aquaculture, Calcutta, India, 6–9 December 1988. Environmental Sanitation Information Center, Asian Institute of Technology, Bangkok, Thailand, pp 209–221
Edwards P (1992) Reuse of human wastes in aquaculture: a technical review. Water and sanitation report 2, UNDP-World Bank Water and Sanitation Program. The World Bank, Washington, DC
Edwards P (2005a) Demise of periurban wastewater-fed aquaculture? Urban Agric Mag 14:27–29
Edwards P (2005b) Development status of, and prospects for, wastewater-fed aquaculture in urban environments. In: Costa-Pierce B, Desbonnet A, Edwards P (eds) Urban aquaculture. CAB International, Wallingford, pp 45–59
Edwards P, Pullin RSV (eds) (1990) Wastewater-fed aquaculture. In: Proceedings of the international seminar on wastewater reclamation and reuse for aquaculture. Calcutta, India, 6–9 December 1988. Environmental Sanitation Information Center, Asian Institute of Technology, Bangkok
Edwards P, Sinchumpasak OA (1981) The harvest of microalgae from the effluent of a sewage fed high rate stabilisation pond by *Tilapia nilotica*. Part 1: Description of the system and the study of the high rate pond. Aquaculture 23:83–105
Edwards P, Hassan MS, Chao CH, Pacharaprakiti C (1992) Cultivation of duckweeds in septage-loaded earthen ponds. Bioresour Technol 40:109–117
Evans AEV, Nguyen DL, Nguyen TT (2014) Policy support for wastewater use in Hanoi. In: Proceedings of the 37th WEDC international conference, Hanoi, Vietnam
Gaigher IG, Krause JB (1983) Growth rates of Mozambique tilapia (*Oreochromis mossambicus*) and silver carp (*Hypophthalmichthys molitrix*) without artificial feeding in floating cages in plankton-rich wastewater. Aquaculture 31(2–4):361–367
Ganguly SL, Paria DS, Jana BB (2015) Evaluating the ecological resilient driven performance of a tropical waste stabilization pond system using ecological signature of biological integrity. J Ecol Eng 16(3):97–107
Ghosh D (1999) Turning around for a community based technology. Calcutta Metropolitan Water & Sanitation Authority, Calcutta

Golder D, Rana S, Sarkar (Paria) D, Jana BB (2007) Human urine is an excellent liquid waste for the culture of fish food organism, *Moina micrura*. Ecol Eng 30:326–332

Iqbal S (1999) Duckweed aquaculture: potentials, possibilities and limitations for combined wastewater treatment and animal feed production in developing countries. SANDEC, Swiss Federal Institute for Environmental Science and Technology, Duebendorf

IWMI (2002) The Hyderabad declaration on wastewater use in agriculture. http://www.iwmi.cgiar.org/research/impact-assessment/outcome-stories/outcome-stories-2004/the-hyderabad-declaration-on-wastewater-use-in-agriculture/. Accessed 16 July 2016

Jana BB (1998) Sewage-fed aquaculture: the Calcutta model. Ecol Eng 11:73–85

Jana BB, Banerjee RD, Guterstam B, Heeb J (eds) (2000) Waste recycling and resource management in the developing world: ecological engineering approach. University of Kalyani/International Ecological Engineering Society, Kalyani/Wolhusen

Kibria G, Nugegoda D, Fairclough R, Lam P, Bradley A (1999) Utilization of wastewater-grown zooplankton: nutritional quality of zooplankton and performance of silver perch *Bidyanus bidyanus* (Mitchell 1838) (Teraponidae) fed on wastewater-grown zooplankton. Aquac Nutrition 5:221–227

Kumar D, Chaturvedi KMM, Sharma SK, Asolekar SR (2015) Sewage-fed aquaculture: a sustainable approach for wastewater treatment and reuse. Environ Monit Assess 187:656

Letema SC (2012) Assessing sanitary mixtures in east African cities. Wageningen Academic Publications, Wageningen

Liang Y, Cheung RYH, Everitt S, Wong MH (1999) Reclamation of wastewater for polyculture of freshwater fish: fish culture in ponds. Water Res 33:2099–2109

Little DC, Bunting SW (2015) Aquaculture technologies for food security. In: Madramootoo C (ed) Emerging technologies for promoting food security. Woodhead Publishing, Cambridge, pp 93–113

Little DC, Edwards P (2003) Integrated livestock-fish farming systems: the Asian experience and its relevance for other regions. Inland Water Resources and Aquaculture Service and Animal Production Service. Food and Agriculture Organization, Rome

Mancy KH, Fattal B, Kelada S (2000) Cultural implications of wastewater reuse in fish farming in the Middle East. Water Sci Tech 42(1–2):235–239

Mara DD (1997) Design manual for waste stabilization ponds in India. Lagoon Technology International, Leeds

Mara DD (2009) Waste stabilization ponds: past, present and future. Desalin Water Treat 4:85–88

Mara DD, Pearson HW (1999) A hybrid waste stabilization pond and wastewater storage and treatment reservoir system for wastewater reuse for both restricted and unrestricted crop irrigation. Water Res 33(2):591–564

Mara DD, Edwards P, Clark D, Mills SW (1993) A rational approach to the design of wastewater-fed fishponds. Water Res 27:1797–1799

Marais GVR (1974) Faecal bacterial kinetics in waste stabilization ponds. J Environ Eng 100 (1):119–139

Moscoso J (2006) The use of treated sewage water from the settlement ponds in San Juan, Lima. In: van Veenhuizen R (ed) Cities farming for the future – urban agriculture for green and productive cities. RUAF Foundation, IDRC and IIRR, pp 405–407

Murray A, Yeboah-Agyepong M (2012) Waste enterprisers' wastewater-fed aquaculture business. WASTE Enterprisers, Accra

Nandini S, Aguilera-Lara D, Sarma SSS, Ramirez-Garcia P (2004) The ability of selected cladoceran species to utilize domestic wastewaters in Mexico City. J Environ Manag 71:59–65

NMCG (National Mission for Clean Ganga) (2016) Notice inviting applications for expressions of interest (EOI) from organisations/firms for treatment of the drains joining river Ganga through innovative technology. Ministry of Water Resources, River Development & Ganga Rejuvenation, Government of India. India, New Delhi

Oakley SM (1997) Manual de diseno, operacion y mantenimiento para Lagunas de estabilizacion en Hoduras. Fondo Hondureno de Inversion Social (FHIS) and Cooperacion de la Agencia de

los Estados Unidos el Desarrollo Internacional (USAID). Universidad Estatel de California, California, USA
Prein M (1996) Wastewater-fed aquaculture in Germany: a summary. Environ Res Forum 5–6:155–160
Prinsloo JF, Schoonbee HJ (1992) Evaluation of the poly- and monoculture production of the common carp *Cyprinus carpio* L. and the sharptooth catfish *Clarias gariepinus* (Burchell) in final effluent oxidation pond water of a sewage purification system. Water SA 18:7–12
Pye-Smith C, Feyerabend GB, Sandbrook R (1994) Calcutta: the Mudialy fishermen's cooperative society. In: Pye-Smith C, Feyerabend GB, Sandbrook R (eds) The wealth of communities. Kumarian Press, Bloomfield
Rigg J, Salamanca AM (2005) The future of periurban aquatic food production systems in southeast Asia. Urban Agric Mag 14:20–23
Spatial Decisions and Winrock International India (2006) Urban wastewater: livelihoods, health and environmental impacts – the case of Delhi. In: Proceedings of the national workshop on urban wastewater: livelihoods, health and environmental impacts in India. United Services Institution, 31 January, New Delhi. Winrock International India, New Delhi
Strauss M (2003) Reuse of urban wastewater and human excreta. In: RUAF (ed) Annotated bibliography on urban agriculture. ETC, Leusden
The Cambodia Daily (2014) Drying up – as Boeng Tompun lake is filled in, Phnom Penh faces a development dilemma. June. The Cambodia Daily, Phnom Penh, pp 28–29
The Times of India (2015) Wetland woes move Ramsar official. Feb 22, The Times of India, New Delhi. http://timesofindia.indiatimes.com/city/kolkata/Wetland-woes-move-Ramsar-official/articleshow/46327397.cms. Accessed 7 July 2016
UN (2015) Transforming our world: the 2030 agenda for sustainable development. A/RES/70/1. United Nations, New York
UN (2016) Sustainable development goals. http://www.un.org/sustainabledevelopment/sustainable-development-goals/. Accessed 1 July 2016
WHO (2006a) Guidelines for the safe use of wastewater, excreta and greywater, vol 1 – Policy and regulatory aspects. World Health Organization, Geneva
WHO (2006b) Guidelines for the safe use of wastewater, excreta and greywater, vol 2 – Wastewater use in agriculture. World Health Organization, Geneva
WHO (2006c) Guidelines for the safe use of wastewater, excreta and greywater, vol 3 – Wastewater and excreta use in aquaculture. World Health Organization, Geneva
WHO (2006d) Guidelines for the safe use of wastewater, excreta and greywater, vol 4 – Excreta and greywater use in agriculture. World Health Organization, Geneva
WHO (2008) Key issues in the safe use of wastewater and excreta in aquaculture. World Health Organization, Geneva
WHO (2015) Sanitation. Fact sheet no. 392. World Health Organization, Geneva
Yan N, Chen X (2015) Don't waste seafood waste. Nature 524:155–157

Chapter 4
Waste System: Its Utility and Analyses in Aquaculture

S. K. Das and A. Mandal

Abstract Importance of nutrient harvesting from liquid wastes through aquaculture production in vertically integrated systems is well established. Though wastewater reuse systems in aquaculture widely differ with respect to degree of pretreatment and its methods which have a direct bearing upon the economic conditions of the end users, the ecological and socio-economic impact analyses exhibited overall positivity. Supremacy of heterotrophic microbial pathway coupled with high fish yield at downstream of the wastewater-fed system testifies the ecological efficiency of wastewater in the conversion of wastes to wealth through aquaculture. Urbanization pressure, improved economic condition and betterment in the health quality standards warranted imposition of different safety standards in wastewater aquaculture and quality of the produce with respect to pathogenic load and contaminants. The present paper discussed the waste systems in aquaculture and their analyses in general.

Keywords Wastewater systems · Aquaculture · Impact analyses · Safety issues

Contents

S. K. Das (✉)
Department of Aquaculture, Faculty of Fishery Sciences, West Bengal University of Animal and Fishery Sciences, Kolkata, Panchasayar, West Bengal, India
e-mail: skdaswbuafs@gmail.com; skdas012@yahoo.co.in

A. Mandal
Department of Aquaculture, College of Fisheries, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab, India

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_4

4.1 Introduction

Wastewater is the used water generated from domestic, industrial or agricultural sources. Wastewater is composed of 99.9% water and 0.1% as suspended, colloidal and dissolved solids. Reuse of wastewater in aquaculture has a long history in the oriental countries particularly in East, South and Southeast Asia where the aquaculture production of the world is the maximum. Though in the traditional method of sewage-fed fish culture, wastewater generated from different sources was used without pretreatment, recent advances of engineered wastewater treatment systems incorporated an aquaculture component in the form of maturation ponds in the waste stabilization pond system for fish raising. Wastewater has been in use as a source of crop nutrients over many decades (AATSE 2004; Jiménez and Asano 2008; Keraita et al. 2008) in Mexico, Peru, Egypt, Lebanon, Morocco and other countries. However, it is relatively less common in developed countries due to apprehension of environmental and health risk associated with fish culture practice. The methods of wastewater treatment have been largely improved to maintain the hygienic conditions of wastewater-fed aquaculture in many developing countries. Sludge management has only recently become an issue, even for developed countries as such management is complex and there is a lack of social support (UNHSP 2008), be it in developed or developing countries (Snyman 2008).

4.2 Rationale of Wastewater Reuse

Wastewater from domestic and urban sources is inherent with invaluable resources to waste. It contains the metabolized nutrients of the recently consumed food. The waste disposal practice is based on the philosophy that *the solution to pollution is dilution*. The principal objective of wastewater reuse in aquaculture is to recycle the inherent nutrients such as nitrogen, phosphorus, potash, etc. through sequential biological processing leading to fish biomass. It is established that integrated resource recovery and institutionalization of urban solid and liquid waste management can reduce their cost to municipalities by 30–90% (Gunnerson 1984). Edwards (1992) pointed out that millions of people in Asia depend on reuse for treatment of excreta and for food security through agriculture and aquaculture. Such reuse and recycle approach mitigates environmental degradation and might be a powerful tool for poverty alleviation through social and economical benefits including employment generation (Edwards 2000) for the people of tropical and sub-tropical areas. WHO (1989) advocated that where possible, reuse of wastewater should be preferred to minimize costs and obtain maximum agricultural and aquacultural benefits from the nutrients contained in wastewater. In arid and semiarid areas, water resources are scarce major conflict between urban and agricultural demands for water can be resolved only by the agricultural use of pretreated wastewater. One of the most lucrative income-generating activities is the sale of wastewater and renting of pumps for lifting in Gujarat, which lack alternative sources of water (Bhamoriya 2004). Moreover, nearly 73,000 ha of peri-urban agriculture lands in India have been the subject to wastewater irrigation (Strauss and Blumenthal 1990). Therefore, recycle and reuse of wastewater could be an effective strategy for water conservation as well.

4.3 Nutrients and Contaminants in Wastewater

The suspended, colloidal and dissolved solids present in wastewater contain major nutrients (nitrogen, phosphorus and potassium) and trace nutrients (copper, iron and zinc) as well. Total nitrogen and phosphorus concentrations in raw wastewater are usually in the ranges of 10–100 mg/l and 5–25 mg/l, respectively, and potassium is in the range of 10–40 mg/l. Treated wastewater contains less nitrogen and phosphorus but approximately the same amount of potassium, depending on the treatment process used. In addition to beneficial nutrients, wastewater also contains some contaminants and toxins. In developing and underdeveloped countries, regular use of cheaper detergents loaded with phosphates and polyphosphates results in excessive phosphorus in domestic wastewater which may result in eutrophication in confined wastewater-fed aquaculture practice. Even in many European countries, residues of detergents and pharmaceutical drug residues have been the causes of negative effects on aquatic organisms (Pettersson et al. 2000). Excreted pathogens as bio-contaminants in wastewater are highly variable and primarily of four categories: viruses, bacteria, protozoa and helminth eggs (Strauss 1996). Domestic wastewater contains some pathogens, but it is much higher in concentrations and in diversity in developing countries. Further, it may also contain heavy metals and other toxic elements if the wastewater includes a significant proportion of industrial effluent and storm water. On the other side, it can be safely reused for crop irrigation provided the quality of the wastewater conforms to the recommendations of Food and Agriculture Organization of the United Nations (Ayers and Westcot 1985).

4.4 Wastewater Systems in Aquaculture

Wastewater-fed aquaculture is most common in Asia. There is a great diversity of systems currently in use (Table 4.1). The differences in the systems are mainly due to type of waste, degree of pretreatment, system design of the culture units, species of culture and integration with crop cultivation. Wastewater is also used for production of fingerlings or table fish and aquatic plants (e.g. duckweed) that are fed to livestock or herbivorous fish. Fish may be cultured in pen and cage enclosures and aquatic plants secured by stakes in ponds. A nongovernment organization (PRISM) in Bangladesh operates duckweed wastewater treatment systems at Mirzapur using wastewater from a hospital, and at Khulna with municipal wastewater, the harvested duckweed was used to feed fish and poultry and to improve overall sanitation.

However, there is a risk of using untreated sewage and human excreta in crop production. It has been estimated that at least 20 million ha in 50 countries is irrigated with raw or partially treated wastewater (Van der Hoek 2004; Hussain et al. 2001). WHO and UNICEF (2000) estimated the median percentage of wastewater treated by effective treatment plants to be 35% in Asia, 14% in Latin America and the Caribbean, 90% in North America and 66% in Europe. However, Homsi (2000) estimated that only around 10% of all wastewater are treated in developing countries where there is a need for scaling up the system for removing the risks of contamination.

Table 4.1 Types of waste-fed aquaculture system (after UNEP 2002)

Waste type and delivery system	Aquaculture system	Cultured organism	Practicing country
Human excreta	Pond	Fish	China, Indonesia, Viet Nam
Human excreta	Pond	Duckweed	Bangladesh
Contaminated surface water (waterborne)	Pond	Fish	Bangladesh, Indonesia, Vietnam
Contaminated surface water (waterborne)	Pond	Duckweed	China
Contaminated surface water (waterborne)	Cage	Fish	Indonesia
Contaminated surface water (waterborne)	Stakes in rivers, shallow in ponds	Aquatic vegetables	Wide spread in Asia
Sewage (waterborne)	Pond	Fish	China, Germany, India, Vietnam
Sewage (waterborne)	Pond	Duckweed	Bangladesh

4.4.1 Use of Untreated Waste and Wastewater

Sewage-fed aquaculture developed rapidly since its introduction in Wuhan in China in 1951. Though human excreta was used directly in aquaculture ponds in rural areas of China, there has been a major decline of such practice at present due to rapid economic growth and loss of rapid urbanization-driven land. Eutrophication and industrial pollution caused by rapid urbanization and industrialization had negative impact on wastewater-fed pond fish culture (Li 1996). Eutrophication causes mass fish kill in wastewater-fed Donghu Lake in Wuhan during 1998, and industrial pollution leads to fish with undesirable odour and taste from contamination with petroleum and phenolic compounds. This is because in China most domestic wastewater is mixed with industrial wastewater; 75% of the total wastewater in China is industrial, and only 24% is treated (Ou and Sun 1996). As a result, it is becoming increasingly difficult to market the produce because of lack of food safety standards. This warrants the necessity to upscale the involved practices for the safety of human consumption.

With improvement of economic development and public awareness, there has been official ban of overhanging latrines on fish ponds in Vietnam, Indonesia, Java, etc. Urbanization pressure and improved sanitary measures negatively impacted the traditional practice of wastewater reuse in aquaculture elsewhere in Vietnam. In Hanoi city alone, the wastewater-fed pond and rice field area have declined by 35% caused by the breakdown of the communal wastewater distribution system in the transition to a free-market economy as many farming households are now unable to obtain a supply of wastewater. In Bangladesh, wastewater-fed aquaculture is not a traditional activity though practiced in low-lying water bodies in Dhaka that contains faecal-contaminated water (Rahman 1992). This system is now constrained by excessively high organic loadings and rapid urbanization.

4.4.2 Treated Wastewater in Aquaculture

Though wastewater-fed aquaculture began in Germany as early as 1887, almost all have been closed except the system in Munich (Prein 1996). The pond system at Munich was formerly used for secondary biological treatment but currently used for tertiary treatment of activated sludge effluent. It served also a bird sanctuary and recreation area (Prein 1996). Acute shortage of freshwater warranted research on recycling and reuse of wastewater in aquaculture in Egypt where tilapia was cultured in secondary treated effluent. Based on microbial and chemical analysis for heavy metals, fish muscle was found acceptable for human consumption (Khalil and Hussein 1997). In Suez, tilapia and grey mullet were cultured in a demonstration treatment/reuse system, and again with secondary treated effluent, fish were acceptable for human consumption based on bacterial, heavy metal and organochlorine pesticide standards (Shereif et al. 1995; Easa et al. 1995; and Shereif and

Mancey 1995). In Europe, a sewage-fed system was introduced in Hungary, and that eventually transformed into commercial practice. Tertiary treated effluents were tested for tilapia culture in specially constructed research and demonstration ponds at the San Juan wastewater stabilization pond complex in Lima, Peru (Cavallini 1996). In this case, fish were also acceptable for human consumption with respect to standards for viruses, bacteria, parasites as well as heavy metals, pesticides and PCBs.

4.4.3 Constructed Wetlands in Waste Wastewater Reuse

Constructed wetlands are engineered systems designed to utilize the natural processes involving wetland vegetation, soils and their associated microbial assemblages to assist in treating wastewater (Vymazal 2010). Waste stabilization ponds are somewhat modified surface flow-constructed wetlands based on the principle of applying green technology to partially reclaim wastewater acceptable for fish culture practices. The wastewater-fed ponds involved a series of 2–3 ponds and located serially and make use of the inherent capacity of absorbing nutrients and pollutants by selective macrophytes in primarily treated wastewater having considerably long hydraulic retention time. It is reported that significant reduction of the load of coliform, faecal coliform, *Salmonella* sp. and faecal streptococci that remained within the acceptable levels (Ghermandi et al. 2007).

4.4.4 Macrophyte-Based Reclamation

Macrophytes are known to have high capacity of biological purification of organic wastewater (Gersberg et al. 1986; Mann and Bavor 1993). Abbasi and Abbasi (2010) observed that large-bodied floating water hyacinth promoted 50% reductions in nitrogen and phosphorus from municipal wastewater. Oron et al. (1988) suggested recycling systems using duckweeds to be a comprehensive solution for treatment of municipal wastewater. Duckweeds (small free-floating macrophytes) are promising for use in sustainable wastewater treatment due to their rapid growth to high biomass, high levels of nutrient removal (Alaerts et al. 1996), ease of handling, harvesting and processing, tolerance to high nutrient levels of wastewater and low fibre content (Abdalla et al. 1987; Rodrigues and Oliveira 1987; Santos et al. 1987). Direct conversion of ammonia into plant proteins in duckweed ponds is a relatively energy-efficient process compared to other alternate methods (Oron et al. 1988; Zirschky and Reed 1988). Moreover, macrophytes are often described as scavengers of contaminants in surface waters as they have the capacity to accumulate toxic metals and heavy metals like Zn, Pb, Cu, Mg, Mn, Ag, As, Cd, Co, Cr, Ni, Sn, etc. They are also equally effective in removing pollutants like pesticides, insecticides, petroleum hydrocarbons, fluoride, hydrogen sulphide and volatile fatty acids (Low et al. 1994). Further, the macrophyte-based wastewater treatment system caused significant reduction in faecal coliforms and other pathogens. It is reported that floating macrophytes are capable of removing nutrients from water phase, whereas emergent macrophytes met up their P requirements exclusively from sediments (Saha-Das and Jana 2002a, b, c). Rooted submersed macrophytes absorb most of the P from the interstitial water of the sediments and also from the surrounding water. Therefore, integration of floating, rooted and emergent macrophytes is of more use for reclamation of wastewater to be used in aquaculture (Saha-Das and Jana 2002c). This is almost similar to the performance of constructed wetlands used for nutrient removal practiced in several countries including the USA (Poole 1996). Moreover, consumption of aquatic plants is important towards food security in a number of Southeast Asian countries. However, edible plants are grown in such aquatic environments; any pathogen present in the water is likely also to be present on the plants as surface contaminants particularly on roots and other plant parts.

4.4.5 Indian Wastewater Aquaculture Systems

4.4.5.1 East Calcutta Wetlands Model

There are more than 132 wastewater-fed fish ponds in India, covering an area of 12, 000 ha, of which almost 80% are located in West Bengal. The largest of these is the Calcutta wastewater fisheries in East Calcutta Wetlands (22°25′ to 22°40′N; 88°20′ to 88°35′E), an ecologically important Ramsar site, and this system is also the classic example of wastewater-fed aquaculture in the world (Edwards 1985) which is known to be the oldest in the country as it started during 1929–1930 (Ghosh and Sen 1987). Sewage-fed fisheries in Munich, Germany, and in the bheries of West Bengal, India, are models of such biological treatment systems, where raw or partially treated sewage is directly fed into the fish ponds (Edwards 1992; Jana and Datta 1996; Jana 1998). The hydraulic regime of the wastewater-fed fish ponds has unique properties; it is neither lentic nor lotic. Wastewater is introduced into the fish ponds in batches and is released accordingly. When these ponds are large, more than 40 ha, the wastewater inflow is almost continuous, and the water regime becomes lotic. The inlet arrangement in wastewater-fed fish ponds uses an edge feeding system in which sewage is released in small doses into one side of the pond during the fish culture cycle. The depth of the ponds varies between 50 and 150 cm. with fairly flat bottom. The photosynthetic activity of microalgae within these ponds is the basis of natural biological purification (Ghosh 1990) through oxygenation.

In the culture practice, before stocking, bheries (large culture units) are dried up and sewage is allowed to enter. After stabilization of effluents and examining the plankton density, the bheries are stocked with advanced fingerlings at 7000–10,000/ha. Normally, multiple stocking and multiple harvesting are adopted, and the fish are reared for 3–5 months, depending on the growth of the fish to reach a marketable size of 250–400 g. In addition, there is running water fish culture, wherein the water from hill-streams/rivers is made to flow through a series of dugout embankment ponds constructed along the course of the stream/river using diversion canals/pipes. This helps maintain a mild water flow through the culture ponds. Screens of fine-meshed nets are erected at the inlet and outlet of the ponds to prevent the entry and escape of organisms to and from the ponds (FAO 2005). Environmental benefits of this practice include low-cost wastewater treatment, storm water drainage and a green area as a lung for the city; social benefits include employment for about 17,000 poor people and about 20 tonnes of fish/day for the urban poor (Morrice et al. 1998).

4.4.5.2 Modified East Calcutta Wetlands Models

The lessons learned from East Calcutta Wetlands (EKW) over the past few decades have been replicated in other places in West Bengal (Ghosh 1995) though in comparatively smaller scale and with some improvisation. The design used to establish new wastewater-fed fish pond systems incorporates anaerobic ponds. Mudiali Fishermen's Cooperative Society, a small wastewater-fed fish pond system in Greater Kolkata that receives mixed domestic and industrial wastewater, has been upgraded by introducing anaerobic ponds and water hyacinth-filled canals to pretreat the wastewater before entering into the main fish ponds (Mukherjee 1998).

Wastewater-fed fish farm in a model town Kalyani, West Bengal, has also incorporated pretreatment of wastewater prior to its reuse in fish ponds (Jana and Datta 1996; Jana et al. 1996; Jana 1998, Saha (Das) and Jana 2002a, b, c). Partially treated urban wastewater is sequentially passed through a series of anaerobic, facultative and fish-growing maturation ponds, and finally effluents are discharged into the river canal of Ganges. An average retention time of 5 days is maintained throughout, and a BOD_5 level of 10–20 mg 1^{-1} of pond water should be continuously maintained for better fish growth. It was observed that the facultative ponds were the most dynamic, accounting to 22–69% of the total reclamation of the waste stabilization ponds (Jana 2011). Further studies in Kalyani wastewater treatment plants using waste stabilization ponds have revealed that reclamation of wastewater was the function of the distance from the source to the outlet (Lahiri et al. 2015) and that the water quality remained congenial for fish growth at the downstream was evident from the rising trends of the values of respiratory enzyme SDH in the fish procured from the first maturation pond to the last maturation pond of the waste stabilization pond system (Lahiri et al. 2015). This was evident even from the determination of respiratory enzyme, SDH activity of fishes growing across the sewage effluent gradients (Mukherjee and Jana 2007).

Apart from sewage treatment plant developed by the Central Institute of Freshwater Aquaculture (CIFA), Rahara, West Bengal, and working for decades, sewage-fed fish culture system has also been developed in other states of India such as Maharashtra (Nagpur), Madhya Pradesh (Bhopal), Chhattisgarh (Bhilai), Tamil Nadu (Chennai) and Haryana (Karnal) (FAO 2005, Kumar et al. 2014).

4.5 Production Pathway in Wastewater-Fed Aquaculture Systems

As is known, domestic urban wastewater is loaded with organic matter which is acted upon by the vast array of microbial activity resulting into release of nutrients required for biological production (Lahiri et al. 2015). Solar energy-driven photosynthetic activity of microalgae in the shallow wetlands resulted in oxidative state that favoured the mineralization process conducive to production of fish food required for fish growth (Fig. 4.1). Due to shallow nature and penetration of sunlight at the pond bottom, there develops a massive bloom of blue-green algae. Excess concentration of phosphate and nitrogen can lead to over-eutrophication and cause excessive vegetative growth (Jiménez 2006; Qadir et al. 2007). Therefore, in many cases, large-bodied macrophyte (*Eichhornia crassipes*) stands are made along the margin of the culture units in enclosures to absorb excess nutrients and some pollutants that are present in wastewater. Such approach establish a

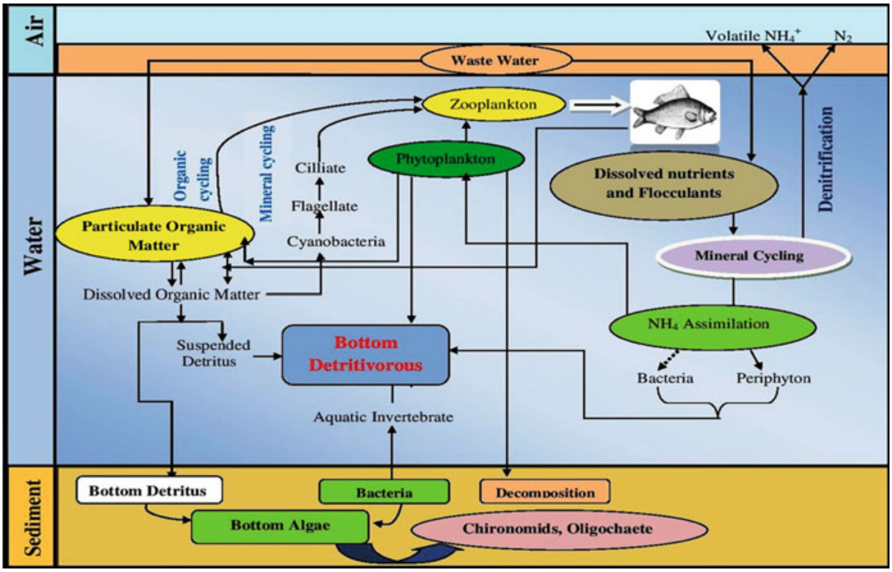


Fig. 4.1 Diagrammatic pathway of production in wastewater aquaculture suitable for fish and production

competitive inhibition upon the algal bloom and ensures overall environmental health for production of food chain in right direction. In the partially treated wastewater fish culture ponds, organic wastes are converted into fish biomass through grazing detritus food chain mechanism using the ecological principle of recycling through microbial biogeochemical nutrient cycle and grazing detritus food web (Jana 2011). Judicious selection of fish species is another key factor for effective utilization of sewage in fish culture. Omnivorous and bottom-grazing fishes directly consume the organic detritus of sewage-fed ponds and thereby help to keep the pond bottom aerobic through bioturbation activity. The suitable species for culture are Indian carp, Israeli carp, silver carp, bighead carp, grass carp, common carp, hybrid buffalo, catfish, largemouth bass, tilapia, freshwater prawn, etc. (Jana 2011). Introduction of herbivorous fish helps in consumption of edible microalgae and make the system energy efficient due to shorter food chain of fish. Accumulation of detritus in pond bottom are favourable for detritivores which directly consume billions of heterotrophic organisms and creates short loop in energy transfer and enhances ecological efficiency of the system.

4.6 Emerging Areas of Allied Activities in Wastewater Aquaculture Systems

4.6.1 Biofloc Technology

Biofloc technology (BFT) in aquaculture is the cohabitation of microbial communities and fish that aims to solve two major issues in fish production – wastewater treatment and protein addition (Westra 2013). As wastewater is usually rich in dissolved and particulate matter, it is possible to recover excess nitrogen incorporated into bacterial cells as microbial protein by manipulating a suitable carbon: nitrogen ratio (Hargreaves 2013). The technology is based upon zero or minimal water exchange to maximize biosecurity while minimizing external environmental factors. Principle of wastewater treatment by bioflocs (BFs) is extensively used in the treatment of domestic and industrial wastewater (activated suspension systems). BFs are highly porous, amorphous aggregations of microorganisms, particles and other constituents held together by extracellular polymeric substances (Chu and Lee 2004). Therefore, biofloc techniques might be a green alternative to capital-intensive wastewater treatment systems in terms of nutrient recovery and amelioration of the aquaculture environment in situ as well.

4.6.2 Hydroponics

Integration of hydroponic cultivation into a wastewater treatment system has been proposed as an ecological alternative, where nutrients can be removed from wastewater (Norstrom 2005; Bawiec et al. 2016). Hydroponic production systems have potential for the treatment of domestic wastewater (Vaillant et al. 2003; Rababah 2007) and reuse of wastewater in intensive aquaculture systems (Keeratiurai 2013). The root system of the aquatic plants changes the living conditions for the microorganisms and affects the performance of nitrifying and denitrifying bacterial activities of the wastewater flowing through the biological treatment system (Schrammel 2014). More details of the hydroponics system have been discussed in Chap. 9 of this volume.

4.7 Analyses of Reusing Wastewater

4.7.1 Economic Impact

The safe use of wastewater and excreta also has social equity issues. Wastewater and excreta are often seen as resources which help to improve food security and positively impact household nutrition and, thus, health. Wastewater-fed aquaculture ponds provide an economically viable source of high protein through recycling of organic residues in the eco-friendly balanced system and thus maximizing waste recycling and reuse and converting wastes into wealth. Moreover, fish grows very fast in tropical wastewater-fed ponds and thus replaces the expensive supplementary diet and conventional chemical fertilizers (Jana 2011). Few studies have quantified the economic gains from nutrients in wastewater under actual field conditions. At a conservative estimate, 800 mg of sewage can yield an annual out turn of 60,000 tons of NPK fertilizers. According to studies in Ghana, the greatest factor influencing farmers' profits is not so much the yield obtained, but the ability to produce crops that are in high demand and low supply, at the right time, the result being that they can be consistently sold at above average prices (Cornish et al. 2001). In the Mezquital Valley, Mexico, the availability of wastewater instead of freshwater as irrigation water caused land rents to increase from US$170 to $350–950 per year (Jiménez 2005). In Quetta, Pakistan, farmers paid 2.5 times more for wastewater than for freshwater (Ensink et al. 2004). With low investments and quick returns, this practice is lucrative and enables many farmers to leap over the poverty line (Danso et al. 2002). In many West African countries, it is especially attractive to poor migrants looking for jobs in the city (Faruqui et al. 2004). In a cost-benefit analysis of grey water reuse systems constructed in residential schools in India, the internal and external benefits far outweighed the costs (Godfrey et al. 2009).

4.7.2 Ecological Impact

While the criteria of recycle and reuse of wastewater, sludge and excreta in agriculture and allied activities differ between regions, their use, be it directly, indirectly, diluted or not, has a number of advantages alongside the well-known risks as well (WHO 1989, 2006a, b, c; Scott et al. 2004). The wastewater aquaculture has a unique capacity for reclamation through nutrient recovery thereby controlling eutrophication. Considerable reduction of organic and BOD loads of sewage is made before its use in aquaculture. In general, there was about 30% reduction of the BOD load of raw domestic sewage (120 and 400 mg/l) by the primary treatment of sedimentation.

Eco-sanitation has been well conceptualized and realized in wastewater-fed aquaculture. Human urine or faeces obtained from source-separating dry toilet are profitably recycled for the production of vegetables in agriculture or algal biomass or fish biomass in aquaculture. This provides double benefits to the society in terms of protecting the environment from open defecation and pollution and promoting the philosophy of recycling waste into wealth, in the form of human urine into bio wealth. It is almost analogous to the second law of thermodynamics at the energy level, where highly concentrated state is toxic but transformed into more and more diluted form creating the benign environment for biological production (Jana 2011; Lahiri et al. 2015).

4.7.3 Analyses of Human Health Issues

At least one tenth of the world population is thought to consume foods produced by irrigation with wastewater (Smit and Nasr 1992). Among the disadvantages of using untreated or partially treated wastewater, sludge or excreta, the most obvious are the health risks from pathogens (WHO 2006a, b, c). Excreta-related diseases are often approximated by using gastrointestinal illness or diarrhoea as an indicator. A reference level of risk of 10^{-6} disability-adjusted life years (DALY) is approximately equal to a 1 in 1000 annual risk of contracting a mild, self-limiting diarrhoea with a low case fatality rate (e.g. caused by *Rotavirus*) (WHO 2004). Moreover, pathogens may be reintroduced into communities that have no natural immunity to them, resulting in disease outbreaks (Frost et al. 1995; Kapperud et al. 1995). Moreover, risks are not limited to farmers but every stakeholders, viz. farmers and their families, crop handlers, consumers of the produce and those living on or near the areas where wastewater, sludge or excreta is used. However, observed responses may vary considerably between developing and developed countries. This is because pathogen distributions and concentrations, to which these groups are exposed, are very different, as are the living conditions and the level of resistance to disease between developing and developed countries (Jiménez 2007;

Jiménez and Wang 2006). Furthermore, the statistics on food safety are unreliable because laboratory standards are so low in most developing countries.

The fishermen of EKW have developed empirical skills in handling the wastewater and optimizing fish production over the years, and estimates of organic loading rates are 6–22 kg BOD_5/ha giving minimum dissolved oxygen levels of 2.5 – 4.5 mg/1. Total coliform counts of 10^5–10^6/100 ml in the influent sewage to the ponds and 10^2–10^3/100 ml in the pond water have been reported. *Vibrio parahaemolyticus*, the second most important diarrhoea-causing agent (after *V. cholerae*) in the Kolkata area, has been found in the intestines of fish from the sewage-fed ponds but not in fish muscles. Heavy metals in sewage fed to the ponds have reportedly been below levels which would pose a risk to the ecosystem, the fishermen or the consumers (Strauss and Blumenthal 1990). The health of consumers would depend on the microbiological quality of the fish, the extent of cooking the fish before eating. It is likely that fishes reared in ponds under good conditions with relatively low levels of total coliforms over the growing season are of good enough quality for human consumption provided the fish are well cooked and high standards of hygiene are maintained during fish preparation. On the whole, the public health effects of sewage fertilization of aquaculture ponds in Calcutta are not well understood. This warrants the need for further scientific microbiological and epidemiological studies.

4.7.4 Microbial Analyses of Fish

Information of the microbiological quality of fish raised in wastewater-fed aquaculture systems have been used to recommend criteria for acceptable bacterial levels in fish pond water and fish muscle. For example, Buras et al. (1987) raised fish (tilapia and silver carp) in experimental ponds over a whole growing season and concluded that the 'threshold concentration' was 1×10^4 bacteria/100 ml based on standard plate counts (SPC). The role of faecal coliforms as adequate indicators of fish contamination was questioned, as they were not always detected in the muscles of fish, whereas other bacteria were recovered; the use of bacteria (SPC) as an indicator was proposed. However, it is useful to review the level of faecal coliforms for comparative purposes; the level of faecal coliforms in the water was around 3×10^2 FC/100 ml. Moscoso and Florez (1991), however, found that when tilapia were grown in a combined WSP/aquaculture system in Peru, bacteria penetrated the fish muscle when the water exceeded 10^5 FC/100 ml and concluded that maximum level of faecal coliforms in the pond water should be 1×10^4 FC/100 ml. This would be achievable by a maximum concentration of 1×10^5 FC/100 ml in the effluent of the WSP used to feed the aquaculture pond.

Current guidelines or standards for the microbiological quality of fish (Strauss 1995; Leon and Moscoso 1996) showed that the standard plate count is used in conjunction with an *E. coli* or coliform level in most cases. The rejection levels set for the quality of fish were 10^6 SPC/g and *E. coli* 500/g (ICMSF 1995), 5×10^4

SPC/g and 0.7 $\times$ 10^3 coliform/g in the USA (Leon and Moscoso 1996) and 10^5 SPC/g and 10^1 *E. coli*/g in Sweden (Strauss 1995). These levels are less strict than those proposed by Buras et al. (1987) for fish raised in excreta-fed systems, who recommended that the total aerobic bacterial concentration in fish muscle should not exceed 50 bacteria/g. This is probably because ICMSF regulations are for fish contaminated mainly by handling and were not set up to include fish raised in excreta-fed systems (Edwards 1992).

There are sufficient evidences to suggest that the tentative faecal coliform guideline of 10^3 FC/100 ml (WHO 1989) for the fish pond water is the right order of magnitude and insufficient data to warrant a reduction of this level to 10^2 FC/100 ml or a relaxation to 10^4 FC/100 ml (WHO 1989). This implies that the quality of the water can be around 10^4–10^5 FC/100 ml, depending on the size of the fish pond and the amount of dilution that occurs. However, the water quality should remain constant over the growing season as fluctuations in the quality of the influent water would reduce the quality of the fish (Buras et al. 1987). Mara et al. (1993) and Mara (1997) stated that regular monitoring of water quality be made to ensure that the fish pond does not contain more than 1000 FC/100 ml. Microbial quality of fish ponds (Table 4.2) using wastewater from secondary treatment plants has to be improved by the use of a polishing pond prior to the effluent being discharged into a fish ponds.

4.7.5 Chemical Analyses of Fish

The health-based targets for chemical contaminants of wastewater usually occurred in anaerobic ponds in which most heavy metals settle out under anaerobic conditions or by maintaining alkaline conditions in fish ponds, which cause metals to form insoluble precipitates that settle out of the water column (WHO 2006a, b, c). There is also a possibility of chelation of different metals that are present in wastewater. However, WHO (2006a, b, c) guidelines (Table 4.3) are to be followed for a consistent level of health protection in different settings, vegetables and fish. Each country may adopt their own standards based on their national environmental, sociocultural and economic conditions.

4.8 Waste Systems and Safety Issues

The issue of safety including the aesthetics of using wastewater in agriculture and allied activities has been debated for long, and such debates generated two contrasting opinions from the developed and developing worlds. Accordingly several guidelines were framed at different times (AATSE 2004; USEPA 2004; EPA 1986; Jimenez 2005). Joint efforts by the WHO, FAO and United Nations Environment Programme (UNEP) to encourage resource recovery resulted in a

Table 4.2 Microbial quality targets for waste-fed aquaculture (after SEEHD 2009)

Media	Viable trematode eggs (including schistosome eggs where relevant) (number/100 ml or/ g total solids[a])	*E. coli* (number/ 100 ml or/ g total solids[a,b])	Helminth eggs[c] (number/100 ml or/ g total solids[a,d])
Product consumers			
Pond water	Not detectable	$\leq 10^4$	≤ 1
Waste water	Not detectable	$\leq 10^5$	≤ 1
Treated excretes	Not detectable	$\leq 10^6$	≤ 1
Edible fish flesh or plant parts	Infective metacercariae (presence or absence per fish or plant) or detectable or non-infective	Codex Alimentarius Commission specifications[c]	Not detectable
Aquacultural workers and local communities			
Pond water	Not detectable[f]	$\leq 10^5$	≤ 1
Waste water	Not detectable[f]	$\leq 10^4$	≤ 1
Treated excretes	Not detectable[f]	$\leq 10^5$	≤ 1

[a]Excreta is measured in grams of total solids (i.e. dry weight): 100 ml of wastewater/excreta contains approximately 1–4 g of total solids

[b]An arithmetic mean should be determined throughout the irrigation season. For pond water and product consumers, for example, the mean value of $\leq 10^4$ *E. coil* per 100 ml should be obtained for at least 90% of samples in order to allow for the occasional high-value sample (i.e. with 10^5 or 10^6 *E. coli* per 100 ml)

[c]Applicable when emergent aquatic plants are grown and when there is high contact with wastewater, excreta contaminated water or contaminated soils

[d]An arithmetic mean should be determined throughout the irrigation season. The mean value of 1 egg per L should be obtained for at least 90% of samples in order to allow for the occasional high-value sample (i.e. with >10 eggs per L)

[e]The Codex Alimentarius Commission does not specify microbial qualities for fish flesh or aquatic plants; rather, it recommends the adoption of hazard analysis and critical control point (HACCP) principles as applied from production to consumption

[f]Viable schistosome eggs where relevant

regulatory framework to support worldwide the reuse of wastewater, grey water and excreta in agriculture and aquaculture (Jiménez and Asano 2008; WHO 2006a, b, c). The WHO (WHO 1989, 2006a, b, c) guidelines are the most appropriate for developing countries. These new guidelines are more supportive of the difficult sanitation conditions in most developing countries and have suggested a multiple barrier approach for the long-term achievement of a universal health-based target (Ensink and Hoek 2007). However, they are difficult to apply where treatment is rudimentary or lacking and when thousands of farmers already use polluted water sources because they have no alternative. Here, different strategies for health risk reduction are needed.

Table 4.3 Standard for chemical concentrations in fish and vegetables (WHO 2006a, b, c)

Chemicals	Standard for fish and fish products (mg/kg)	Source of standard	Standard for vegetables (mg/kg)[a]	Source of standard
Heavy metals				
Arsenic	NS		0.2	Codex (2003)
Cadmium	0.05–1.0	EC (2001)	0.2	Codex (2003)
Lead	0.2	Codex (2003)	0.2	Codex (2003)
Methyl mercury	0.5–1.0	Codex (2003)	NS	
Organics				
Dioxins[b]	0.0000004	EC (2001)	NS	
DDT, TDE	5.0	USFDA (1998)	NS	
PCBs	2.0	USFDA (1998)	NS	

NS no standard
[a]General standard for leafy vegetables except for arsenic, which is fruit based
[b]Dioxins that bind other polychlorinated, coplanar aromatic compounds with similar properties

In view of emerging crisis of water in coming years, safe reuse of wastewater in different sectors of industries, agriculture, street cleaning, etc. has been advocated in developed countries.

4.9 Conclusions

The importance of recycle and reuse of wastewater in aquaculture has been widely addressed with achievable consensus among different school of opinions. Though the reuse systems differ from the developed to the developing world with variable application of sanitary mechanisms of wastewater treatment, the ecological and social implications were clearly discernible. The developing countries especially situated in tropical and subtropical areas are inherently gifted with tropical climate and abundant sunshine that are conducive to wastewater treatment and beneficial use. However, with the increasing demand for biological produce through best management practices, adoption of strict quality control measures for safe human consumption of wastewater raised fish and vegetables in aquaculture will continue to be assessed and reassessed.

References

AATSE Australian Academy of Technological Sciences and Engineering (2004) Water recycling in Australia, a review undertaken by AATSE, Victoria, Australia, p 229. ISBN:1875618 80 5

Abbasi T, Abbasi SA (2010) Enhancement in the efficiency of existing oxidation ponds by using aquatic weeds at little or no extra cost. The macrophyte-upgraded oxidation pond (MUOP). Biorem J 14:67–80

Abdalla AL, Ambrosano EJ, Vitti DMSS, Silva FJC et al (1987) Water hyacinth (*Eichhornia crassipes*) in ruminant nutrition. Water Sci Technol 19:109–112

Alaerts GJ, Mahbubar MDR, Kelderman P et al (1996) Performance analysis of a full-scale duckweed covered sewage lagoon. Water Res 30:843–852

Ayers RS, Westcot DW (1985) Water quality for agriculture. Irrigation and drainage Paper 29, Rev. 1. FAO, Rome, p 174

Bawiec A, Pawęska K, Pulikowski K et al (2016) Seasonal changes in the reduction of biogenic compounds in wastewater treatment plants based on hydroponic technology. J Ecol Eng 17:128–134

Bhamoriya V (2004) Wastewater irrigation in Vadodara, Gujarat, India: economic catalyst for marginalized communities. In: Scott CA, Faruqui NI, Raschid-Sally L (eds) Wastewater use in irrigated agriculture: confronting livelihood and environmental realities. CAB International in Association with IWMI, IRDC, Colombo/Ottawa, pp 127–134

Buras N, Duek L, Niv S, Hepher B, Sandbank E et al (1987) Microbiological aspects of fish grown in treated wastewater. Water Res 21:1–10

Cavallini JM (1996) Aquaculture using treated effluents from the San Juan stabilization ponds, Lima, Peru. CEPIS, Pan American Center for Sanitary Engineering and Environmental Sciences, Lima

Chu CP, Lee DJ (2004) Multiscale structures of biological flocs. Chem Eng Sci 59:1875–1883

Cornish GA, Aidoo JB, Ayamba I (2001) Informal irrigation in the peri-urban zone of Kumasi, Ghana. An analysis of farmer activity and productivity, DFID’s Water KAR Project R7132 Report OD/TN 103. HR Wallingford, Wallingford, p 40

Danso G, Drechsel P, Wiafe-Antwi T, Gyiele L et al (2002) Income of farming systems around Kumasi. Urban Agric Mag 7:5–6

Easa ME-S, Shereif MM, Shaaban AI, Mancey KH et al (1995) Public health implications of wastewater reuse for fish production. Water Sci Technol 32:145–152

Edwards P (1985) Aquaculture: a component of low cost sanitation technology. World Bank technical paper number 36. Integretated resource recovery series. The World Bank, Washington, DC, p 45. ISBN: 0-8213-0527-1

Edwards P (1992) Reuse of human wastes in aquaculture: a technical review. Ecology 7:1–8

Edwards P (2000) Aquaculture, poverty impacts and livelihoods, vol 56. Natural Resource Perspectives, ODI, London, pp 1–4

Ensink JH, van der Hoek W (2007) Editorial: new international guidelines for wastewater use in agriculture. Tropical Med Int Health 12:575–577

Ensink J, Mahmood T, van der Hoek W, Raschid-Sally L, Amerasinghe F et al (2004) A nationwide assessment of wastewater use in Pakistan: an obscure activity or a vitally important one? Water Policy 6:197–206

EPA The Environment Protection Act (1986) Ministry of Environment and Forest, Department for Environment, Forest and Wildlife

FAO Food and Agriculture Organization of the United Nations (2005) National aquaculture sector overview. India. In: Ayyappan S (ed) National aquaculture sector overview fact sheets. FAO Fisheries and Aquaculture Department, Rome. http://www.fao.org/fishery/countrysector/naso_india/en

Faruqui N, Niang S, Redwood M et al (2004) Untreated wastewater reuse in market gardens: a case study of Dakar, Senegal. In: Scott C, Faruqui N, Raschid-Sally L (eds) Wastewater use in irrigated agriculture: confronting the livelihood and environmental realities. CABI Publishing, Wallingford, pp 113–125

Frost JA, McEvoy MB, Bentley CA, Andersson Y et al (1995) An outbreak of *Shigella sonnei* infection associated with consumption of iceberg lettuce. Emerg Infect Dis 1:26–29

Gersberg RM, Elkins BV, Lyon SR, Goldman CR et al (1986) Role of aquatic plants in wastewater treatment by artificial wetlands. Water Res 20:363–368

Ghermandi A, Bixio D, Thoeye C et al (2007) The role of free water surface constructed wetlands as polishing step in municipal wastewater reclamation and reuse. Sci Total Environ 380:247–258

Ghosh D (1990) Wastewater fed aquaculture in the wetlands of Calcutta – an overview. In: Edwards P, Pullin RSV (eds) Wastewater fed aquaculture, Proceedings of the International Seminar on Wastewater Reclamation and Reuse for Aquaculture, Calcutta, India, December 6–9, ENSIC, AIT, Bangkok, pp 49–56

Ghosh D (1995) Integrated wetland system (IWS) for wastewater treatment and recycling, for the poorer parts of the world with ample sunshine, basic manual, PN-ABU-593. Office of Environment and Urban Programs, Center for Environment, USAID, Arlington

Ghosh D, Sen S (1987) Ecological history of Calcutta's wetland conversion. Environ Conserv 14:219–226. https://doi.org/10.1017/s0376892900016416

Godfrey S, Labhasetwar P, Wate S et al (2009) Greywater reuse in residential schools in Madhya Pradesh India – a case study of cost benefits analysis. Resour Conserv Recycl 53:287–293

Gunnerson CG (1984) Research and development in integrated resource recovery (An interim technical assessment). UNDP project GLO/80/004

Hargreaves JA (2013) Biofloc production systems for aquaculture. SRAC Publication No. 4503, pp 1–12

Homsi J (2000) The present state of sewage treatment. International report. Water Supply 18:325–327

Hussain I, Raschid L, Hanjra M, Marikar F, Van der Hoek W (2001) A framework for analyzing socioeconomic, health and environmental impacts of wastewater use in agriculture in developing countries. Working Paper 26, International Water Management Institute (IWMI), Colombo, Sri Lanka, p 31

ICMSF International Commission on Microbiological Specifications for Foods (1995) Micro-Organisms in Foods 2: sampling for microbiological analysis: principles and specific applications, 2nd edn. The International Commission on Microbiological Specifications for Food. Blackwell Scientific Publications, University of Toronto Press, p 275. ISBN: 0802056938

Jana BB (1998) Sewage-fed aquaculture: the Calcutta model. Ecol Eng 11:73–85

Jana BB (2011) Managing the downstream pollution problems and poverty reduction in the tropical developing world: relying on the integration of nature's library, traditional knowledge and ecological sanitation. Procedia Environ Sci 9:201–208

Jana BB, Datta S (1996) Nutrient variability in six sewage fed tropical fishponds. In: Staudenmann J, Schonborn A, Etnier C (eds) Recycling the resource, ecological engineering for wastewater treatment, vol 5–6. Environmental Research Forum, Pfaffikon, pp 379–382

Jana BB, Dutta S, Saha S et al (1996) Reclamation of eutrophic waters: nutrient removal by water hyacinth in response to qualitative and quantitative variations of fertilizers. In: Staudermann J, Schonborn A, Etnier C (eds) Recycling the resources; ecological engineering for wastewater treatment, vol 5–6. Environmental Research Forum, Pfaffikon, pp 331–336

Jimenez B (2005) Treatment technology and standards for agricultural wastewater reuse. Irrig Drain 54:22–33

Jimenez B (2006) Irrigation in developing countries using wastewater. Int Rev Environ Strateg 6:229–250

Jimenez B (2007) Helminth ova control in sludge: a review. Water Sci Technol 56:147–155

Jimenez B, Asano T (2008) Water reclamation and reuse around the world. In: Jimenez B, Asano T (eds) Water reuse: an international survey of current practice, issues and needs. IWA Publishing, London, p 648

Jimenez B, Wang L (2006) Sludge treatment and management. In: Ujang Z, Henze M (eds) Developing countries: principles and engineering. IWA Publishing, London, pp 237–292

Kapperud G, Rorvik LM, Hasseltvedt V et al (1995) Outbreak of *Shigella sonnei* infection traced to imported iceberg lettuce. J Clin Microbiol 33:609–614

Keeratiurai P (2013) Efficiency of wastewater treatment with hydroponics. ARPN J Agric Biol Sci 8:800–805

Keraita B, Jimenez B, Drechsel P (2008) Extent and implications of agricultural reuse of untreated, partly treated and diluted wastewater in developing countries. Agric Vet Sci Nutr Nat Resour 3:15

Khalil MT, Hussein HA (1997) Use of wastewater for aquaculture: an experimental field study at a sewage-treatment plant, Egypt. Aquac Res 28:859–865

Kumar D, Anand M, Hiremath S, Asolekar R et al (2014) Integrated management of wastewater through sewage fed aquaculture for resource recovery and reuse of treated effluent: a case study. APCBEE Procedia 10:74–78

Lahiri S, Sarkar (Paria) D, Jana BB et al (2015) Evaluating the ecological resilient driven performance of a tropical waste stabilization pond system using ecological signature of biological integrity. J Ecol Eng 16:97–107

Leon G, Moscoso J (1996) Curso de tratamiento yuso de aguas residuals. OPS/CEPIS/PUB96.20. Lima, Perú

Li SF (1996) Aquaculture and its role in ecological wastewater treatment. In: Etnier C, Guterstam B (eds) Ecological engineering for wastewater treatment proceedings of the international conference at Stensund Folk College, Sweden, March 24–28th, 1991, 2nd edn. CRC Press, Boca Raton, pp 37–49

Low KS, Lee CK, Tai CH et al (1994) Biosorption of copper by water hyacinth roots. J Environ Sci Health A 29(1):171–188

Mann RA, Bavor HJ (1993) Phosphorus removal in constructed wetlands using gravel and industrial waste substrata. Water Sci Technol 27:107–113

Mara DD (1997) Design manual for waste stabilisation ponds in India. In: Vigneswaran S (ed) Water and wastewater technology, vol 2. Lagoon Technology International, Leeds, p 325. ISBN: 978-1-84826-194-5

Mara DD, Edwards P, Clark D, Mills SW et al (1993) A rational approach to the design of wastewater fed fish ponds. Water Res 27(12):1797–1799

Morrice C, Chowdhury NI, Little DC et al (1998) Fish markets of Calcutta. Aquac Asia 3:12–14

Moscoso CJ, Alberto FM (1991) Reuso en Acuicultura de las Aguas Residuales Tratadas en las Lagunas de Estabilización de San Juan, Sección I: Resumen Ejecutivo. CEPIS, Lima

Mukherjee M (1998) Clever manipulation of fishery and recreational activity on any wetland offers an ecofriendly approach towards employment generation, Meenbarta, Special Issue on Wetland, 16th June 1998. Department of Fisheries, Government of West Bengal, Calcutta, pp 47–52

Mukherjee S, Jana BB (2007) Water quality affects SDH activity, protein content and RNA: DNA ratios in fish (*Catla catla*, *Labeo rohita* and *Oreochromis mossambicus*) raised in ponds of a sewage fed fish farm. Aquaculture 262:105–119

Norstrom A (2005) Treatment of domestic wastewater using microbiological process and hydroponics in Sweden. Doctoral thesis, Department of Biotechnology, Royal Institute of Technology, Stockholm, Sweden, p 54. ISBN:91-7178-030-0

Oron G, De-Vegt A, Porath D et al (1988) Nitrogen removal and conversion by duckweed grown on wastewater. Water Res 22:179–184

Ou ZQ, Sun TH (1996) From sewage irrigation to ecological engineering treatment for wastewater in China. In: Staudenmann J, Schönborn A, Etnier C (eds) Recycling the resource, Proceedings of the Second International Conference on Ecological Engineering for

Wastewater Treatment, School of Engineering Wädenswil-Zürich, Transtec Publications, Zurich, pp 25–34

Pettersson A, Adamsson M, Dave G et al (2000) Toxicity and detoxification of Swedish detergents and softener products. Chemosphere 41:1611–1620

Poole W (1996) Natural wastewater treatment with duckweed aquaculture. In: Staudenmann J, Schonborn A and Etnier C (eds) Recycling the resource, Proceedings of the second International conference on ecological engineering for wastewater treatment, School of Engineering Wädenswil-Zürich, September 18–22th, 1995, Transtec Publications, Zurich, pp 303–306

Prein M (1996) Wastewater fed aquaculture in Germany: a summary. In: Staudenmann J, Schönborn A and Etnier C (eds) Recycling the resource, Proceedings of the second International conference on ecological engineering for wastewater treatment, School of Engineering Wädenswil-Zürich, 18–22th September, 1995, Transtec Publications, Zurich, pp 155–160

Qadir M, Wichelns D, Raschid-Sally L, Minhas PS, Drechsel P, Bahri A, McCornick P et al (2007) Agricultural use of marginal-quality water – opportunities and challenges'. In: Molden D (ed) Water for food, water for life. A comprehensive assessment of water management in agriculture. Earthscan, International Water Management Institute, London/Colombo, pp 425–457

Rababah A (2007) Hydroponics removal of wastewater's contaminants for the generation of commercially valuable plants and environmentally sound effluent for the dead sea communities. Jordan J Civil Eng 1:273–286

Rahman AKA (1992) Tilapia in Bangladesh. In: Balayut EA (ed) Paper contributed to the workshop on tilapia in capture and culture-enhanced fisheries in the Indo-Pacific Fishery commission countries, 27–29 June 1991, Bogor, Indonesia. FAO Fisheries Report No. 458, Supplement, FAO, Rome, pp 139–142

Rodrigues AM, Oliveira JFS (1987) High-rate algal ponds: treatment of wastewater and protein production: IV – Chemical composition of biomass produced from swine wastes. Water Sci Technol 19:243–248

Saha (Das) S, Jana BB (2002a) Determination of water hyacinth biomass/water area ratio for effective reclamation in simulated models of wastewater at two nutrient levels. Int J Environ Stud 59:623–634

Saha (Das) S, Jana BB (2002b) Nutrient removal potential of emergent (*Scirpus articulatus*) and floating (*Lemna major*) macrophytes: a comparison *in situ* hypertrophic mesocosms. Int J Environ Stud 59:489–502

Saha (Das) S, Jana BB (2002c) Fish-macrophyte interaction – a low-cost reclamation strategy for wastewater. Ecol Eng 21:21–41

Santos EJ, Silva EHBC, Fiuza JM, Batista TRO, Leal PP (1987) A high organic load stabilisation pond using water hyacinth – a "BAHIA" experience. Water Sci Technol 19:25–28

Schrammel E (2014) A cost benefit analysis of hydroponic wastewater treatment in Sweden, Swedish University of Agricultural Sciences, Uppsala, Sweden. ISSN 1990–6145, 8: 1–36

Scott CA, Faruqui NI, Raschid-Sally L et al (2004) Wastewater use in irrigated agriculture: confronting the livelihood and environmental realities. CABI Publishing, Wallingford

SEEHD (Sustainable Engineering and Environmental Health for Development) (2009) Wastewater stabilization system repairs and improvement completion Tela Vieja, Atlántida, Honduras. California State University, Chico, p 53

Shereif MM, Mancey KH (1995) Organochlorine pesticides and heavy metals in fish reared in treated sewage effluents and fish grown in farms using polluted surface waters in Egypt. Water Sci Technol 32:153–161

Shereif MM, Easa ME-S, El-Samra MI, Mancy KH et al (1995) A demonstration of wastewater treatment for reuse applications in fish production and irrigation in Suez, Egypt. Water Sci Technol 32:137–144

Smit J, Nasr J (1992) Urban agriculture for sustainable cities: using wastes and idle land and water bodies as resources. Environ Urban 4:141–152

Snyman H (2008) South Africa. In: LeBlanc R, Matthews P, Roland P (eds) Global Atlas of excreta, wastewater sludge, and biosolids management: moving forward the sustainable and welcome uses of a global resource. UN-Habitat, Nairobi, pp 514–525

Strauss M (1995) Health (pathogen) considerations regarding the use of human waste in aquaculture. Environ Res Forum 5(6):83–98

Strauss M (1996) Health (Pathogen) considerations regarding the use of human waste in aquaculture, EAWAG, Dübendorf, Switzerland. www.eawag.ch/organization/abteilungen/sandec/publikationen/publications_wra/downloads_wra/human_waste_use_healh__pathogen__risks_in_aquaculture.pdf

Strauss M, Blumenthal UJ (1990) Human waste use in agriculture and aquaculture – utilization practices and health perspectives. International reference centre for waste disposal (now NDEC), Dubendorf, Switzerland. Report no. 08/90, 52

UNEP United Nations Environment Programme (2002) Global environmental outlook 3, Geo-3. UNEP, Earthscan publications Ltd, London/Sterling, p 425. ISBN: 92-807-2088-0

UNHSP United Nations Human Settlements Programme (2008) In: LeBlanc R, Matthews P, Roland P (eds) Global atlas of excreta, wastewater sludge, and biosolids management: moving forward the sustainable and welcome uses of a global resource. UN-Habitat, Nairobi, p 632

USEPA United States Environmental Protection Agency (2004) Guidelines for water reuse. EPA/625/R-04/108. Environmental Protection Agency, Washington, DC, p 485

Vaillant N, Monnet F, Sallanon H, Coudret A, Hitmi A et al (2003) Treatment of domestic wastewater by an hydroponic NFT system. Chemosphere 50:121–129

Van der Hoek W (2004) A framework for a global assessment of the extent of wastewater irrigation: the need for a common wastewater typology. In: Scott CA, Faruqi NI, Raschid-Sally L (eds) Wastewater use in irrigated agriculture. Confronting the livelihood and environmental realities. CABI Publishing, Wallingford, pp 11–24

Vymazal J (2010) Constructed wetlands for wastewater treatment. Water 2:530–549

Westra C (2013) Effects of carbon source and particle size on nitrogen cycling in aggregated "Bio-Floc" microbial communities. Semester in Environmental Science. Independent Project, 1–24

WHO (1989) Health guideline for use of wastewater in agriculture and aquaculture, WHO Technical Report Series, No. 778. WHO, Geneva, p 72. ISBN:0512-3054

WHO (2004) *Enterobacter sakazakii* and other micro-organisms in powdered infant formula. Meeting report, WHO/FAO. Microbiological risk assessment Series No. 6, FAO, Rome, p 51. ISBN:92 4 156262 5 (WHO)

WHO (2006a) Guidelines for the safe use of wastewater, excreta and greywater, Volume 1: Policy and regulatory aspects. World Health Organization, Geneva. p 95. ISBN:92 4 154682 4

WHO (2006b) Guidelines for the safe use of wastewater, excreta and greywater, Volume 2: Wastewater use in agriculture. World Health Organization, Geneva. p 191. ISBN:92 4 154683 2

WHO (2006c) Pesticide residues in food-2005 evaluations. Part II—Toxicological. Geneva, World Health Organization, Joint FAO/WHO Meeting With the support of the International Programme on Chemical Safety (IPCS) on Pesticide residues. Geneva, Switzerland, 20–29 September 2005, p 523. ISBN:978 92 4 166521 6

WHO and UNICEF (2000) Global water supply and sanitation assessment 2000 Report, pp 1–87

Zirschky J, Reed SC (1988) The use of duckweed for wastewater treatment. J Water Pollut Control Fed 60:1253–1261

Chapter 5
Recycling of Sewage in Aquaculture: Decadal Technical Advancement

R. N. Mandal, P. P. Chakrabarti, B. N. Paul, D. N. Chattopadhyay, A. Das, A. Hussan, and P. Jayasankar

Abstract Freshwater is indispensable for sustenance of life on earth, but is rapidly becoming a scarce resource. A centre on wastewater aquaculture was established during the 1970s in Rahara, Kolkata, which initiated research on recycling of sewage water for production of fish through nutrient recovery. Huge volume of sewage water has been treated through different convenient modes and monitored for probable hazards of sewage water before its utilization in aquaculture. Both chemical and biological contaminants were reduced by 80% by different treatment methods. Using specialized farming management protocols through a series of culture trials, it was possible to achieve the fish yield to the tune of around 5.0 t/ha/year. Different aspects of farming such as species selection, stocking density, species ratio, choice of species groups, stocking and harvesting relation and postharvest techniques were considered. Following the WHO guidelines of risk involved in sewage-fed aquaculture, different parameters such as microbial loads, heavy metals and herbicides after sewage intake were analysed and found below safe limits. Using bioassay trials, the impact of sewage with different sewage dilutions has been optimized. Health and hygiene of handlers were critically assessed, but no adverse impacts have been observed. Sewage-fed aquaculture has great potential to develop into an effective alternate system of fish production in the backdrop of freshwater scarcity and increased farm income, though consistent monitoring is entailed from the health and hygiene perspectives.

Keywords Wastewater · ICAR-CIFA · Aquaculture · Fish · Safety issue

Contents

R. N. Mandal (✉) · P. P. Chakrabarti · B. N. Paul · D. N. Chattopadhyay · A. Das · A. Hussan
Regional Research Centre, ICAR-Central Institute of Freshwater Aquaculture, Kolkata, India
e-mail: rnmandal2003@yahoo.com

P. Jayasankar
ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar, Orissa, India

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_5

5.1 Introduction

Water is finite in quantity with unequally distributed both in space and time (Sharma and Bharat 2009). However, freshwater is always regarded as most precious renewable resources essential for sustenance of human civilization, though its supply is steadily decreasing due to increasing population, injudicious utilization, human intervention and climate change (Sarala et al. 2009; Mandal et al. 2015). Freshwater is essential for drinking purpose for people and livestock (Sharma and Bharat 2009), biota and agricultural production. In India, water is already a scarce resource and will become further scarcer in the foreseeable future. It is predicted that water availability per capita will be reduced from 1820–1902 m^3/year in 2001 to as low as 1401 m^3/year in 2025 (Gupta and Deshpande 2004; Sharma 2005). Hence, there is an urgent need to utilize this precious resource through proper management and formulation of well-planned strategy (Mandal et al. 2015). As freshwater allocation for aquaculture is limited, recycling of already used water like domestic sewage has immense relevance in utilization for aquaculture. As reported, 100 l of wastewater in the form of domestic sewage are discharged per person/day in and around Kolkata (Jana 1998). This appears to be a similar scenario of all the metro cities in India.

Total annual discharge of sewage in the towns and cities of India contains 90 mt of nitrogen, 32 mt of phosphorus and 55 mt of potassium valued Rs. 6.10 crores (Chakrabarti et al. 2011). This huge amount of nutrients contained in domestic sewage needs to be harnessed through the proper treatment; otherwise it would create water pollution through its drainage into open system. Once sewage is recycled in aquaculture through its intake under controlled manner from the sources, it fertilizes water through necessary nutrient input. Transfer of nutrients occurs among abiotic and biotic components including bacteria, plankton and heterotrophs in the trophic level.

Application of sewage is a win-win strategy providing livelihood resources, abatement of surface water pollution and water conservation. Substantial evidences (Ghosh et al. 1980, 1985, 1988; Jhingran and Ghosh 1988; Jhingran 1991; Jana 1998; Datta et al. 2000; Ayyappan 2000; Chakrabarty 2002; Bhakta and Jana 2006; Bunting 2007; Mukherjee and Jana 2007; Dasgupta et al. 2008; Jena et al. 2010) suggested that recycling of sewage has been beneficial for the production of fish crop and allied activities. Fish reared in such system has been reported to be safe for human consumption (Bhowmik et al. 1997). The present chapter attempts to highlight the involvement of the Central Institute of Freshwater Aquaculture (CIFA) in the decadal technical advancement of sewage-fed aquaculture by conducting a series of trials with optimization of dilution of sewage, selection of species combination and their ratio, hazard analysis, criterion for safe consumption, etc. in view of fish production for the benefit of both fish farmers and fish eaters.

5.2 A Brief History of Research Activities

Fish farmers around the periphery of the East Kolkata City in India started to use huge amount of domestic sewage for fish culture as early as the 1930s. Sewage-fed fishery in East Kolkata Wetlands (EKW) of West Bengal, India, is locally called ‘bheries’ and recognized as potential model of sewage-fed aquaculture (Edwards 1992, 2008; Jana and Datta 1996; Jana 1998; Nandeesha 2002). During the 1970s, ICAR-CIFRI, Barrackpore, took initiative for starting waste-fed aquaculture system at Rahara, about 18 km north of Kolkata City (Sahoo et al. 2012). In 1987 freshwater aquaculture unit at Rahara was separated from ICAR-CIFRI, Barrackpore, and was recognized along with all its facilities as part (Wastewater Aquaculture Division) of the newly formed Central Institute of Freshwater Aquaculture (CIFA). Since its birth as waste-fed system, this centre has been utilizing the primary treated sewage emanating from sewage treatment plant of the Titagarh Municipal Corporation under Kolkata Metropolitan Water and Sanitation Authority (KMWSA) located at Titagarh, 24 Parganas (N), West Bengal. With this long journey, considerable efforts have been made to assess the potentials of wastewater for increasing the efficiency of water use in fish farming (Fig. 5.1).

Not that a simple utilization of sewage in fish farming was considered to be its ultimate destination but that a timely research with major thrust given on sewage-related issues as classification, characterization, post effect of sewage utility, safe fish for consumption, health and hygiene of consumers was emphasized through the critical scientific analyses. Besides, integrated activities such as fish-prawn culture, agriculture (paddy-cum-fish) and horticulture have been continued as a part of holistic approach in sewage-fed aquaculture. Low-cost culture systems have been developed at the farm during the last few decades. By this way the centre is providing the low-cost technology to fish farmers in our country through sewage intake as a cheap external input in aquaculture, with the following objectives.

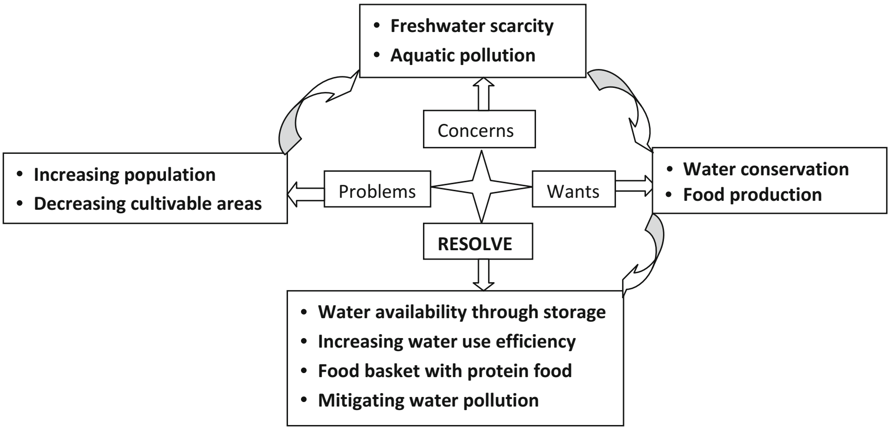


Fig. 5.1 There are four avenues interlinked that initiate from 'Problem' and ends to 'Resolve'; each of all the four avenues represents certain statement that touch human life and sustenance of its civilization

- To recycle wastewater for development of low external input in aquaculture systems
- To undertake basic and applied research for evaluation of production performance and assessment of quality fish safe for human consumption
- To assess nutrient harvest by application of unit wastewater effluent
- To develop sewage-based agro-/aqua-horticulture integrated farming systems
- To produce fish food organisms by utilizing wastewater
- To act as a nodal centre for training and dissemination of various technologies related to freshwater aquaculture and also to provide consultancy services on other related matters

5.3 Treatments of Sewage

Aquaculture generally uses sewage water only when it is found suitable for its reuse. Direct application of raw sewage is avoided. Therefore, raw sewage was treated before its utilization in culture ponds for reduction of microbial load and contaminants (Fig. 5.2).

Several natural, innovative, alternate approaches of wastewater treatment have been practised over the years in different parts of the world. Efficacy of varying treatments has been evaluated for their economic viability, operational ease and system sustainability (Edwards 1992, 2008; Oron 1994; Jana and Datta 1996; Jana 1998; Ayyappan 2000; Jena et al. 2010). Systematic treatments (Fig. 5.3) reduce the organic load and BOD (biochemical oxygen demand)—the determining factor of

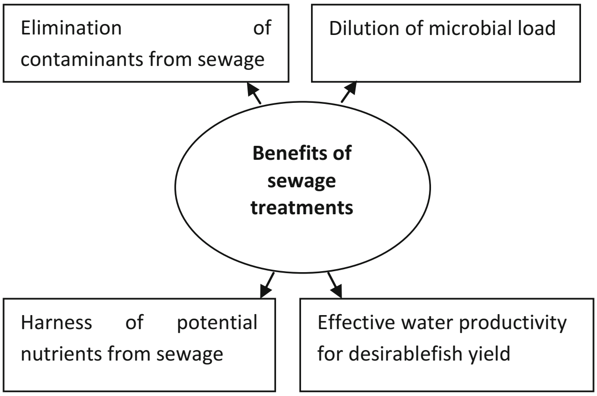
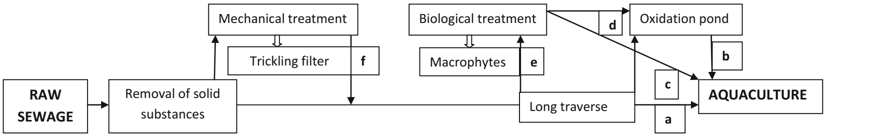


Fig. 5.2 Benefits of sewage treatment that serve four important purposes



Raw sewage → removal of solid wastes → long traverse → aquaculture; b, raw sewage → removal of solid wastes → long traverse → oxidation pond → aquaculture; c, raw sewage → removal of solid wastes → long traverse → biological treatment → aquaculture; d, raw sewage → removal of solid wastes → long traverse → biological treatment → oxidation pond → aquaculture; e, raw sewage →removal of solid wastes → mechanical treatment →long traverse → biological treatment → aquaculture; f, raw →sewage → removal of solid wastes → mechanical treatment→long traverse → oxidation pond → aquaculture

Fig. 5.3 Different treatment ways of raw sewage and its utilization in aquaculture

the degree of quality of sewage. The reduction of these two factors results in an increase of DO (dissolved oxygen) and pH, the standard limit of these parameters essential for survival and growth of fish. Raw sewage emanating after domestic sources is allowed to pass through a common channel, and then its solid substances are eliminated through iron-made net sieve, a common practice usually adopted everywhere. The raw sewage is undergone a distinctive treatment procedures as per requirements.

5.3.1 Mechanical Treatments

The Regional Research Centre of ICAR-CIFA, Rahara, has been treating sewage through its own technological intervention. The farm receives primary treated sewage through 1.5 km-long pipeline by gravity from Titagarh Sewage Treatment Plant under Kolkata Metropolitan Water and Sanitation Authority (KMWSA). Raw sewage is mechanically treated through trickling filter. Then a required amount of primary treated sewage after its discharge of sewage treatment plant (STP) is stored in a circular cemented pit constructed in the farm. A critical monitoring with repeated chemical analyses of available treated sewage is done at this juncture. Considering the chemical characteristic of treated sewage, it may be incorporated into rearing ponds directly or kept putting in stabilized ponds temporarily or undergone a repeated biological treatment.

5.3.2 Biological Treatments

5.3.2.1 By Duckweeds

Different stages of biological treatment using duckweeds are considered to be a viable technology of sewage treatment (Oron 1994; Ayyappan 2000; Jena et al. 2010) in the perspective of sustainable aquaculture. Raw sewage water is allowed by gravity to pass through linearly constructed and interconnected ponds covered with respective duckweeds starting from *Spirodela polyrrhiza*, then *Lemna minor*, to *Wolffia arrhiza* based on their higher efficacy of nutrient accumulation. Retention period of sewage in each duckweed-covered pond may be for 3–5 days, depending on the quantity of organic load contained in particular sewage, with provision of intermittent staggering walls in order to allow longer traverse distance and much retention time of the sewage. Once the pond is fully covered with weed mat, 50% of the same would be harvested, allowing growing space for residual weeds (Ayyappan 2000; Jena et al. 2010).

5.3.2.2 By Macrophytes

Sewage is received from GAP through long pipeline by gravitational force and entered into fallow wetlands through cemented pipeline before being drained into aquaculture ponds. Major portion of wetlands is covered with *Colocasia* sp., an emergent vegetation which can accumulate contaminants, including heavy metals. Partially treated sewage is then moved from upward to downward marshy area covered with *Typha* sp. dominated vegetation. Partially treated sewage is directed into aquaculture ponds. Periphery of the pond is covered with water hyacinth. Such process of bioremediation of sewage water through aquatic macrophytes comprising *Colocasia esculenta*, *Typha angustata* and finally *Eichhornia crassipes* was operated with three-tier treatments. This 'biological treatment system' had been potentially efficient in reducing the levels of physico-chemical parameters of sewage water (Mandal et al. 2016).

Waste recycling system that has been evolved in Kolkata is considered to be unique in the world in transforming waste into consumable products and is involved in garbage-based vegetable farms, wastewater-fed fish farms and paddy fields. The Rahara Wastewater Aquaculture Farm of the Central Institute of Freshwater

Aquaculture (CIFA), Captain Bheri, Mudialy Farm and Kalyani Fish Farm are some of the few examples of scientifically managed sewage-fed fisheries in and around Kolkata (Lahiri et al. 2015; Sarkar et al. 2017).

5.4 Optimization of Physico-chemical Parameters

Treatments of sewage reduce unwanted physico-chemical properties in one way and increase desirable properties in another. However, treatment of sewage depends upon factors like retention time, temperature, pH, solar radiation and presence of predators (Rangeby et al. 1996). Biological treatment has an effective role: microbial load may decline remarkably as total coliform and faecal coliform went down by 87% and 92.5%, respectively. The load of pathogenic bacteria was reduced to minimum due to provision of staggering walls in the duckweed ponds. BOD, total ammonia nitrogen and phosphate were reduced by 80%, 88% and 71%, respectively. There was concomitant increase in DO and pH by 10% and 1705% (Bhowmik et al. 1997; Jena et al. 2010; Mandal et al. 2015). Increasing the traversing distance may affect the reduction of coliform bacteria to the extent of 60–99.9% of aerated lagoon system (Fernandez et al. 1992) and 93–94% through facultative, aerobic and oxidative pond system (Neiwoloak and Tucholski 1995). Garcia and Becares (1997) reported the removals of total coliforms and faecal coliforms with a hydraulic retention time of 3 days while treating with macrophytes. Increasing biomass of macrophytes leads to reduce the BOD load along with nitrogen and phosphorus amounts proportionately and enhances the amount of DO and pH conducive to fish growth and development (Mandal et al. 2015). Aquatic macrophytes are known to be reliable and highly efficient to reduce organic load remarkably (Mann and Bavor 1993) due to their rapid growth to high biomass by accumulating nutrients. They can also tolerate nutrient-laden wastewater while growing. Their operational ease of harvesting and processing afterwards as fish feed due to low fibre content (Naskar et al. 1986) is an additional benefit. This may be considered a comprehensive solution for the treatment of domestic sewage (Jena et al. 2010).

5.5 Properties of Sewage

5.5.1 Physico-chemical Properties

Composition and concentration of domestic sewage vary greatly, with times and places. Used after domestic needs, all the materials are mixed with water and pass through sewerages. Organic compounds, detergents and mineral elements, along

Table 5.1 Selective physico-chemical parameters of sewage in different grades

Sl.No.	Parameter	Raw sewage	Treated sewage	Moderate sewage	Pond water
1	pH	6.1	7.0	7.5	7.5
2	Total solids	720	250	200	80
3	Total Alkalinity	300	240	190	170
4	Total nitrogen	25	15	10	1.0
5	P_2O_5	08	05	02	0.15
6	BOD_5	400	200	80–100	10–18

All the values except pH are in mg/L (Source: Mandal et al. 2015)

with a scanty amount of pharmaceuticals, hormones and other materials, are found in domestic sewage. Generally, raw sewage comprises about 99% water, and the rest form solid material, including organic solids (70%), of which protein is 65%, carbohydrate 25%, and fat 10%. Inorganic solids (30%) include silt and minerals (Chakrabarti et al. 2011). However, characteristic of domestic sewage which is eventually used in aquaculture depends upon the source of waste, the process of its treatment, dilution and distance it runs in an aquaculture system in which it is used. All these factors lead to the degree of quality of sewage to be purposeful for its utilization in fish culture. There is great variation of physico-chemical parameters of sewage in different grades through treatments. The raw, treated and moderate sewage, with average value of selective parameters (Table 5.1), may be considered as strong, medium and weak sewage, respectively (Jana 1998). The moderate sewage undergoes rational treatment unless it is found suitable to be incorporated in culture ponds with an appropriate ratio of freshwater and sewage water as 4:1or 3:1 (Mandal et al. 2015).

5.5.2 *Microbial Load*

Quality of sewage depends on the amount of microbes present in it and their degree of adversity to aquatic biota including fish. Also harmful effect of microbes may affect human health. Most common microbes present in raw sewage include *Escherichia coli*, *Staphylococcus aureus* and *S. epidermidis,* with the MPN/100 ml recorded as 125×10^6, $41.6 \times 10^5$and 16.28×10^4, respectively, in raw sewage, treated sewage and fish-reared pond (Bhowmik et al. 1997). Protozoa, helminthes, fungi and virus are also noticed, and even quite a large number of bacteria remain present, though most of them are non-pathogenic (Bhowmik et al. 1997).

5.6 Sewage Application and Nutrient Recovery

Application of sewage brings changes in quality of water and biological characteristics of aquaculture ponds. However, appropriate amount of sewage intake is the hallmark of sewage-fed aquaculture. Uncontrolled sewage intake may damage fish crops seriously; BOD levels rise suddenly that develops stress to fish crops, leading to mass mortality of fish (Chattopadhyay et al. 1988; Jana 1998). Application of sewage into ponds has some limitations. It was concluded that the utilization of domestic sewage in the range of 8000–19,000 million ha/year may be useful to supply required nutrients (mg/l) as NH_4N (0.1–1.5) and P_2O (0.4–4.0), for fish farming without any adverse impact on fish. Mandal et al. (2015) have calculated that 1 l of treated sewage may generate an average amount of 0.05 g nutrients in the form of N and P and conserve 99% of water (Datta et al. 2000). Intake of 1.0 l sewage effluent has been found to yield an average amount of 0.30 g biomass in the form of fish reared in such sewage-fed water bodies. Potentiality of sewage is quantified in terms of nutrients added as fertilizer inputs in culture system. Calculation shows that 469 kg ha^{-1} of nitrogen and 62.7 kg/ha of phosphorus in the form of ammonia nitrogen (NH_4-N) and phosphate (P_2O_5) were available as fertilizer when an amount of 10.538×10^3 m^3 ha^{-1} sewage effluent was applied in sewage-fed pond for 8.5-month culture period (Datta et al. 2000). This amount of sewage in terms of fertilizer input has been responsible for production of fish yield about 3.2 t/ha/8.5 months (Datta et al. 2000). Others have also reported the relevance of sewage intake for fish production (Ghosh et al. 1980; Jana 1998; Jena et al. 2010). They advocated that the incorporation of sewage in fish culture ponds facilitates to increase water productivity and make aquatic system vibrant through addition of required nutrients. A comparison of water qualities between a sewage-fed and a commonly fertilized fish pond has shown that the former exhibited significantly higher values of BOD, N, P and Cl^{-1} (Chattopadhyay et al. 1990). In Hungary, nearly threefold more sewage at 150 m^3/ha/day was applied for fish yield (Olah 1990). Zhang (1990) reported that the rate of intake in China varied from season to season ranging from 1 to 5% of the volume of pond water at an interval of 4–15 days. Usually during winter, some farms used to take wastewater as basal fertilizer at 10% or more of the total pond water volume. Potentiality of sewage depends upon the condition of particular water body in which sewage is required as fertilizer input conducive to fish growth and survival. Fish yield is related to both gross primary productivity (GPP) and net primary productivity (NPP) of pond water. An optimal productive pond for aquaculture after intake of sewage should have GPP values between 650 and 850 mg C/m^3/h and NPP between 250 and 450 mg C/m^3/h (Saha et al. 2001). This condition is considered to be one of the suitable criteria that may favour desirable fish production due to sufficient amount of DO in pond water (Mandal et al. 2015). Nutrient-enriched sewage water results in high production of diversified plankton required for favourable growth of fish (Bhowmik et al. 1993; Boyd and Tucker 1998). Phytoplankton production increases rapidly due to fertilization through sewage, constituting about 80% of the total plankton population, ranging between 65,000 and 1,20,000 nos/L. and zooplankton being about 20%, with the range of 20,000–45,000 nos/L (Mandal et al. 2015). Three types of algal groups are found prevalent in sewage-fed water; green algae are the most dominating one compared to blue green algae and diatoms. Diatoms represent as the major constituent of benthic community. Phytoplankton population in sewage-fed ponds dominates over zooplankton during most of the culture period. Zooplankton appears to be visible distinctly with dominance of cladocerans, when density of phytoplankton population declines (Mandal et al. 2015). The values of Shannon diversity index for Myxophyceae, Euglenophyceae and Chrysophyceae were higher in facultative pond compared to maturation ponds, whereas that of Bacillariophyceae was more dominant in the latter than in the former in Kalyani sewage-fed ponds. The P/R ratio varied from 1.365 to 5.729 in different ponds investigated. The sum of total scores for different optimal conditions for fish growth also increased spatially exhibiting two clear-cut zones: the facultative pond with dominance of blue green algae with greater carbon sequestration potential and the maturation ponds with the benign environment for fish growth mediated through microalgae-zooplankton grazing and detrital food chain (Sarkar et al. 2017).

5.7 Fish Farming

Aquaculture comprises a number of interrelated steps for the cultivation of fish crop and its desirable yield. A package of practices for sewage-fed aquaculture (Fig. 5.4) has been developed to benefit fish farmers through scientific interventions, including (a) pond environment and (b) biotic components.

5.7.1 Pond Management

Effective pond management leads to an efficient use of nutrients in soil and water, proper ecosystem functioning and increase in biological productivity. All these factors regulate the activation of microbes and interaction among biotic and abiotic components, thus making an efficient ecosystem through dynamics of nutrients, leading to sustenance of sewage-fed aquaculture (Mandal et al. 2015). Usually, no supplementary feeding or chemical fertilizer is required during the culture period since supply of sewage effluents adds nutrients which stimulate the production of planktons. Sewage-fed ponds require continuous supply of sewage or periodically depending on pond area, water volume, availability of wastewater, seasonal condition with regard to temperature fluctuations and dilution of pond water due to monsoon rains (Mandal et al. 2015). Topography of the site should ideally be flat or

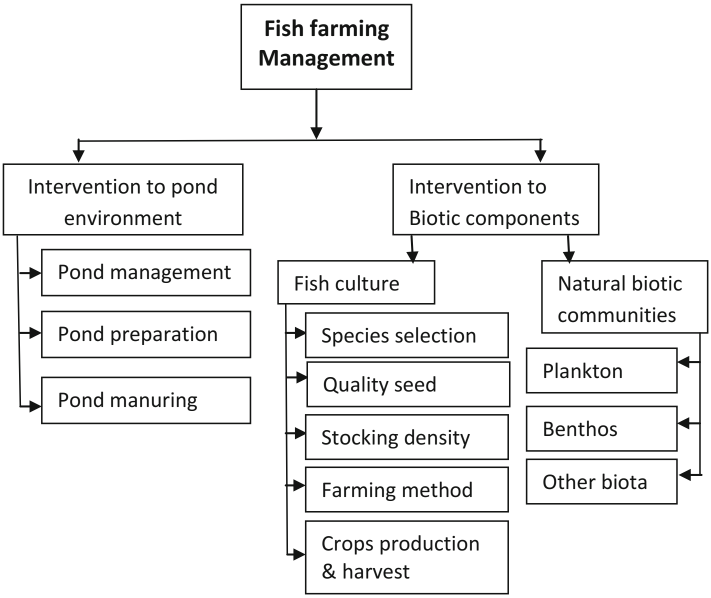


Fig. 5.4 A diagrammatic view of sewage-fed fish farming management

gently sloping towards the outlet so that treated wastewater can be taken into pond preferably by gravitation to minimize running expenses (Nandeesha 2002). In such systems freshwater supply to the pond is also required in addition to freshwater already stored in the pond.

5.7.1.1 Pond Preparation

Pond preparation is a basic requirement in aquaculture practice for production of the desirable yields (Edwards 1992, 2008; Datta et al. 2000; Nandeesha 2002; Jena et al. 2010). Sewage-fed fish farm requires a little less depth than that of a normal freshwater fish farm as sewage tends to increase the turbidity of water (Datta et al. 2000). Ponds are prepared prior to fish culture. Usually initial procedure is dewatering of pond through machine-operated pump or any other means. Dewatering of pond means to expose pond bottom to sunlight, and 2–3 weeks exposure to sunlight leads to a complete drying up of pond bottom. Dewatering of pond eradicates unwanted fish species and also makes de-siltation easy (Datta et al. 2000; Nandeesha 2002). It has been advocated for tillering the bottom soil up to 6–10 cm through raking after drying, followed by application of lime at 400–500 kg/ha. All these steps are needed for maintenance of proper oxidation, desired level of pH, eradication of parasite and their cysts and removal of obnoxious gases from the bottom soil (Nandeesha 2002). Sometimes, mahua oil cake at 2000–2500 kg/ha is applied for provision of developing suitable environment to increase the availability of food and space necessary for culture species to be stocked in pond prior to intake of sewage (Datta et al. 2000; Mandal et al. 2015).

5.7.1.2 Pond Manuring

Optimal loading of sewage effluent in aquaculture pond results in effective fertilization of pond water that leads to a vibrant ecosystem functioning of sewage-fed aquaculture. Sewage intake allows the pond ecosystem to remain aerobic throughout the day and night during the culture period (Mandal et al. 2015). Generally BOD level of raw domestic sewage amounts to 400 mg/l (approx.) which comes down in the range of 40–132 mg/l through simple sedimentation process (Edwards 1992, 2008; Jana 1998; Datta et al. 2000; Chakrabarti et al. 2011; Mandal et al. 2015). Resultant sewage is known as primary treated sewage water. Recipient aquaculture pond determines the amount of primary treated sewage and the frequency for sewage intake required for its system. This is often determined through physico-chemical analyses of sewage water. Even seeing water colour and fish motility may also be helpful to guide farmers the requirement of sewage in culture system. Green colour of water, low transparency and minimal surfacing of fish at dawn to gulp air are few indicators of hygienic pond condition (Chakrabarti et al. 2011). Chattopadhyay et al. (1988) reported maintenance of pond water BOD at a range of 10–20 mg/l to be helpful in maintaining an aerobic condition as well as good productivity level in sewage-fed fish ponds. Optimal rate of sewage intake is essential to achieve desirable scale of fish yield. Evidently low production of fish biomass was recorded from 20 to 5 kg/d/ha, when the amount of sewage intake was higher than 250 m^3/d/ha and below than 150 m^3/d/ha (Olah 1990). One study revealed that net production of 1440–2400 kg/ha was achieved in Hungary when the ponds were fed with 150 m^3/d/ha of sewage water (Olah 1990). Low intake of sewage creates nutrient deficiency, whereas higher intake than required amount results in depletion of DO leading to mass mortality.

5.7.2 Sewage-Fed Aquaculture

In sewage-fed aquaculture, water as such is not considered ideal for fish culture. The wastewater has to get ready for fish farming by the removal of excess nutrients. In such system, judicious selection of fish species is important for desired results. Species which are selected in sewage-fed aquaculture need to be adaptable for effective utilization of natural food organisms (Nandeesha 2002; Datta et al. 2000; Chakrabarti et al. 2011; Mandal et al. 2015).

5.7.2.1 Species Selection and Their Food Habits

Four main categories of fish are selected in preference to the feeding habits: herbivorous, detritivorous feeder, carnivorous and omnivorous (Fig. 5.5). Herbivorous feed on microalgae, including phytoplankton, and are most efficient users of energy as directly feeding on producers. Detritus feeders feed on dead organisms, organic and decayed matters at the bottom of the pond. Detritus foods comprise plants and animal organic matter. Carnivorous fish feed on small-size organisms including annelid larvae, insect larvae, crustaceans and molluscs. Omnivorous species feed on both plant and animal matter (Mandal et al. 2015). In sewage-fed ponds, Indian carps, catfish and prawn have been successfully standardized to grow. With variable graded levels of sewage concentration, species are tested to tolerate the limits of sewage grades. Age groups of the same species vary in tolerable limits of graded levels of sewage. Indian major carps, namely, catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*) and calbasu (*Labeo calbasu*), have been standardized for rearing in sewage-fed ponds (Ghosh et al. 1980, 1988; Datta et al. 2000). Indian minor carps such as Reba carp (*Cirrhinus reba)* and bata (*Labeo bata*) and minnows like mourala (*Amblypharyngodon mola*) have also been reared in sewage-fed system, with intake of low concentration of primary treated sewage in Rahara Fish Farm. Exotic carps such as silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) have been reared along with indigenous species with suitable ratio of species and their stocking density (Ghosh et al. 1988; Datta et al. 2000). Besides, two species of tilapias (*Oreochromis niloticus* and *O. mossambicus*) have remarkably been grown

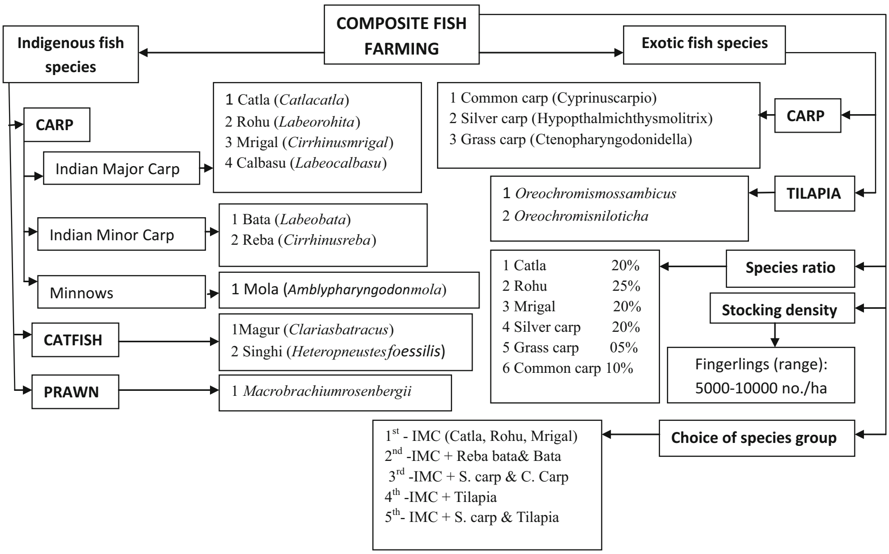


Fig. 5.5 Composite fish farming in sewage-fed system

in sewage-fed system. Their efficacy of considerable sewage-tolerable limits has attracted farmers for their acceptance as one suitable component of fish species in sewage-fed culture. Both the species of tilapia constitute 5–30% of species stocked as seen in different sewage-fed farms (Mandal et al. 2015). Some farmers stock pangas (*Pangasianodon hypophthalmus)* in the condition of comparatively high organic loaded water since they are biologically hard organism with capacity of survival at low DO level, even up to 3.0 mg/l. Indian catfish like *C. batrachus* and *H. fossilis* are also incorporated growing in sewage-fed aquaculture. They are grown in shallow water body during rainy season as a part of integrated culture practice in paddy-cum-fish culture system considering their higher market price as well as consumers' preference. Attempts were made to culture high-value species like giant freshwater prawn, *Macrobrachium rosenbergii*, in sewage-fed ponds and yields were encouraging.

5.7.2.2 Quality Seeds

Quality of seed has been a matter of concern. Instances of low-quality seed production for immediate gains are many. For example, hybrid seeds of carps produced in many hatcheries perform poorly in sewage-fed system. There has been an attempt to solve the issue in collaboration with respective state fishery departments. Creation of awareness to produce and use good-quality seeds, along with regulations like certification/accreditation of hatcheries, would go a long way to improve quality of seeds produced in the country.

5.7.2.3 Stocking Density and Species Ratio

Fish farming requires appropriate stocking density of fish to be reared either in monoculture or in polyculture. Every system has its own carrying capacity. Fish seeds are also stocked within the carrying capacity of sewage-fed aquaculture (Datta et al. 2000; Nandeesha 2002; Edwards 2008; Chakrabarti et al. 2011; Mandal et al. 2015). Usually, fingerlings of 10–15 g in size are stocked in sewage-fed pond culture (Datta et al. 2000), which is comparatively of bigger size compared to those stocked in normal ponds. However, it may vary depending on fish seed availability, the size which is amenable to sewage-fed water, carrying capacity of the pond, etc. (Nandeesha 2002; Edwards 2008). Stocking density may range between 5000 and 10,000 fingerlings ha^{-1} practised during the months of August and September (Datta et al. 2000). Datta et al. (2000) established a standard combination and ratio of species in sewage-fed system for desirable fish yields (Fig. 5.5).

5.7.2.4 Farming Methods

Two methods of fish farming have been adopted. In the first system fish are stocked and harvested as a whole after 6–10 months. In the second system, multi-stocking and multi-harvesting are carried out throughout the culture period as is being practised in East Kolkata Wetlands (Nandeesha 2002). Both have commercial importance and economic viability. Nevertheless, the latter system is more responsive to market demand and economically feasible to farming community. Fish is stocked several times in a year depending on the intensity of operation. Once the water turns completely green, stocking of fish is initiated. Biological purification of the sewage occurs due to photosynthetic activity in the pond. Before stocking, fish are kept in hapas in the pond to test pond condition through survival. If the results are positive, large-scale stocking takes place. Fish are grown mostly on the natural food growing in the pond. Sewage is drawn at regular interval at 2–3% of the total volume of pond water. A dip treatment of potassium permanganate solution would be given to the fingerlings before releasing them into ponds as remedial measure against infection since they are grown in sewage-fed water. Composite fish culture is practised to harness the potentiality of entire pond ecosystem and to make the pond environment sustainable (Ghosh et al. 1999; Datta et al. 2000; Chakrabarti et al. 2011). In this practice, right species with proper size suitable to sewage-fed culture is required. Also maintenance of distinct ratio of different species is considered based on their appropriate niche (Fig. 5.5). IMC is adopted well growing in this system with production of desirable yields. Exotic species may also be combined with IMC in composite culture practice. Silver carp is the proper candidate to maintain pond ecosystem when algal bloom is excessive. Release of silver carp in sewage-fed pond helps in controlling algal bloom, which otherwise can grow excessively and results in oxygen depletion in ponds. Tilapia is also suitable for monoculture practice; even in high organically loaded pond, tilapia is able to survive and is beneficial to farmers. In some farms, both *L. bata* and *C. reba* are cultured as a part of monoculture practice and their growth was found remarkable (Ghosh et al. 1985, 1999; Datta et al. 2000).

5.7.2.5 Fish Production and Harvest

With a view to achieving sustainable aquaculture system, the researchers have standardized fish production in sewage-fed system over the decades (Table 5.2). In sewage-fed pond, five species of indigenous carps, namely, catla, rohu, mrigal, reba and bata, and two species of exotic carps, such as silver carp and common carp, are preferred. Sometimes, grass carp is released in specific condition. Other important species include *Amblypharyngodon mola,* giant freshwater prawn (*Macrobrachium rosenbergii)* and catfish like magur (*Clarias batrachus)* and

Table 5.2 Fish production in sewage fed aquaculture with variable stocking density and species ration

Fish group	Species	Culture practice	Farming method	Stocking density (no./ha)	Species ratio	Duration (months)	Production Kg/ha
Carp	(a) *Catla catla*,	Polyculture	Single stocking and single harvesting	(a) 2500	5:10:5:10:1	12	3400–4000
	(b) *Labeo rohita*,			(b) 5000			
	(c) *Cirrhinus mrigala*			(c)2500			
	(d) *Hypopthalmichthys molitrix*			(d) 5000			
	(e) *Cyprinus carpio*			(e) 500			
	Cirrhinus reba	Monoculture	Single stocking and single harvesting	1.5–2.0 lakhs	–	10	5175.3
	(a) *Labeo bata*,	Polyculture	Single stocking and single harvesting	(a) 1.5–2.0 lakhs	30–40:1:2	(a) 10.6	(a) 3705.6
	(b) *Cirrhinus reba*			(b) 5000		a.(b) 12	(b) 3236.5
	(c) *Catla catla, Labeo rohita, Cirrhinus mrigala*			(c) 10000			(c) 3479.3
	(a) *Labeo bata*,	Polyculture	Single stocking and single harvesting	(a) 5000	1:2	12	3897.7–4039.0
	(b) *Catla catla, Labeo rohita, Cirrhinus mrigala*			(b) 10000			
	(a) *Labeo bata*,	Polyculture	Single stocking and single harvesting	(a) 5000	1:1:2	12	6810.6
	(b) *Cirrhinus reba*			(b) 5000			
	(c) *Catla catla, Labeo rohita, Cirrhinus mrigala*			(c) 10000			
	Amblypharyngodon mola[a]	Polyculture	–			12	25–50
Catfish	*Clarias batrachus*	Monoculture	Single stocking	50,000	–	6	257
Prawn	*Macrobrchium rosenburgii*	Polyculture	Single stocking	–		10	250–370

[a]combination with other fish species

singhi (*Heteropneustes fossilis*). Repeated stocking and multiple harvesting practices are adopted to fetch higher yield with better returns. Monoculture of freshwater prawn in wastewater-fed system also revealed tremendous potentiality. The growth pattern of different cultivable species in wastewater-fed system varies according to the species ratio and pond productivity (Sahoo et al. 2012). Generally it is observed that silver carp grows fastest among the carps.

Comparison of fish production between sewage-fed culture and feed-based practice revealed that fish production from feed-based practice was recorded to be 15.5% more than that in sewage-fed system, with same species combination and duration (Datta et al. 2000; Mandal et al. 2015). Freshwater composite carp culture system using feed, lime and fertilizers in different regions of India revealed the production in the range of 1988.44–5250.66 kg/ha/year (Routh and Tripathi 1988) which is quite compatible to this low-cost production system (Roy and Ghosh 1987; Rai et al. 1996). Jhingran and Ghosh (1990) reported the higher fish production in the range of 5002.4–6791.0 kg ha^{-1} $year^{-1}$, with stocking density ranging between 10,000 and 24,000/ha in sewage-fed ponds. Zhang (1990) documented net fish production of 700–11,963 kg/ha/year from waste-fed aquaculture in China. Harvest takes place twice a month to obtain table size fish for consumption after 3 months from stocking of fingerlings. After completion of one cycle of harvest, fish are restocked at 1.0 kg of fingerlings for every 5 kg of fish harvested. Fish are left undisturbed for the subsequent fortnight, and harvesting will start again after that period.

Human health and the environmental issues are the most important concerns in the use of sewage water in aquaculture. Harvested fish are kept in clean freshwater ponds for 2 weeks or more prior to marketing or consumption, as to get rid of any possible contamination of xenobiotic compounds. Depuration helps in reducing possible microbial accumulation in fish tissues. Harvested fish usually undergo rechecking with certain features: coming out of foul smell, faded lustre of skin, dull appearance and slow movement. Harvested fish with these features need to be kept in depuration for 24–72 h in freshwater ponds. Depuration helps to instill freshness and attractiveness in the fish produced. Fish grown under this kind of culture system remains safe for human consumption as evident from several analyses of edible muscle tissues of cultured fish. More and above, washing of dressed portions of fish fillet during processing and a normal procedure of cooking result in complete elimination of any possible microbial load.

5.7.3 Biotic Communities

Sewage-fed system constitutes a variety of organisms, all of which are not required for fish consumption. However, organisms which serve as food contents need to be estimated as they are related to the growth of reared fish. The nutrient-rich status of sewage water favours high production of natural fish food organisms. Among different kinds of fish food organisms, phytoplankton production is generally high, and they also form the base trophic level of any food chain (Bhowmik et al. 1993; Mandal et al. 2016). Phytoplankton constitutes about 80%, and zooplankton forms about 20% of total plankton population. *Microcystis*, *Scenedesmus*, *Ankistrodesmus*, *Nostoc* and *Chlorella* are the dominant species among phytoplankton. Phytoplankton bloom develops, and consequently *Brachionus*, *Daphnia*, *Moina* and *Cyclops* also flourish as they directly feed on phytoplankton. These planktons serve as food organisms and favour the fast growth of Indian major carps and exotic carps. Bottom biota of sewage containing small worms and insects serve as excellent food for some catfish species as well as for common carp and Java carp. The most common microbes present in raw sewage include *Escherichia coli*, other coliform species and *Staphylococcus aureus*. The MPN counts of coliforms in raw sewage varied between 10^8 and 10^9/100 ml. The permissible limits of microbial load for fish culture range between 1×10^3 and 1×10^4/100 ml. Protozoa, helminthes, fungi and virus are also noticed, and even quite a large number of bacteria remain present, though most of them are non-pathogenic.

5.8 Risk Assessment

WHO (2006) recommended the bacterial quality standards and threshold concentration for fish muscle. This may be considered to be the standard precautionary measures for aquaculture practice until any other guidelines from authentic body/organization are issued:

1. A minimum retention period should be 8–10 days for raw sewage.
2. The maximum of total bacterial population should be 1×10^5/ml sewage-fed water.
3. Fish ponds should be free of viable trematode eggs.
4. Sewage effluent should be suspended 2 weeks before fish harvest.
5. Harvested fish should be held for few hours to facilitate evacuation of gut contents.
6. A total bacteria population should be <50 no/g of fish muscle and no *Salmonella*.
7. There should be good hygiene in handling and processing of sewage-fed fish, along with cooking well.

Pal and Das Gupta (1992) reported that microbiological quality of fish in sewage-fed water bodies is better than that of freshwater fish from many other water bodies polluted unintentionally. It may be argued that fish grown in sewage-fed water under strict monitoring is safer for human consumption than wild fish caught from polluted and unregulated water surface (Edwards 2000). In this connection, risk assessment includes following conditions in view of safe fish for consumption.

5.8.1 Microbial Load

Microbial load is considered an important factor in sewage-fed aquaculture for risk assessment. There have been many studies on sewage-fed systems including raw sewage, primary treated sewage and sewage-fed water. Different strains of microbial loads (cfu × 100/ml) were recorded from the raw sewage (Bhowmik et al. 1997, 2000), with the following range: total coliform, 30.0–180.0 × 10^6; faecal coliforms, 6.2–59.0 × 10^6; faecal streptococci, 61.0–110 × 10^6; total pseudomonads, 35.0–120 × 10^6; and heterotrophic bacteria (cfu × 1/ml), 9.0–13.8 × 10^4. When that raw sewage was added into fish pond water, these bacterial loads were found very low in quantity (cfu × 100/ml), with the following range: total coliforms, 16.28–47.4 × 10^4; faecal coliforms, 1.3–10.29 × 10^4; faecal streptococci, 3.0–9.3 × 10^4; total pseudomonads, 49.7–92.0 × 10^4; and heterotrophic bacteria (cfu × 1/ml), 7.8–24 × 10^4. The reason for reduction of bacterial loads may be due to long distance traverse of raw sewage from its source to the eventual destination of sewage-fed pond via stabilized pond. Sometimes, stabilized ponds covered with macrophytes are found much effective for reducing microbial load (Mandal et al. 2015). Microbial load was examined in different organs of fish reared in sewage-fed system, which indicated the following status: gut > slime > gills > muscle. Different strains of bacterial load (cfu × 100/ml) as total coliforms, faecal coliforms, faecal streptococci, total pseudomonads and heterotrophic bacteria (cfu × 1/ml) have been recorded as 1.8–5.4 × 10^2, nil, 1.7 × 10^3–9.3 × 10^2, 2.6–4.1 × 10^2 and 2.4–4.4 × 10^3, respectively, from 1.0 g of muscle (Bhowmik et al. 2000). Fish muscle used for human consumption exhibits minimal microbial load or nil as considered to be safe for human health, even though this negligible amount may be killed by culinary process (Mandal et al. 2015). In practice fish muscles are used for human consumption, which in fact exhibits the lowest amount of microbial loads among other organs. However, there are measures such as long traverse of raw sewage, bioremediation (mainly use of macrophytes) and short deposition in stabilized pond which are altogether beneficial ways to reduce microbial loads from predominant population to suitable limit, not to be harmful in fish culture (Buras 1988). Also, biological treatment system through phytoremediation, involving different ponds in the series, could reduce microbial load up to 99% as reported (Rangeby et al. 1996; Bhowmik et al., 1997, 2000; Jena et al. 2010). The reduction of bacterial load in stabilization and facultative ponds, in turn, facilitates to the growth of different phytoplanktons that leads to oxygenation in culture ponds (Ghosh et al. 1988).

5.8.2 Heavy Metals and Toxicity

Sewage is mostly rich in organic substances which are released after domestic uses. Nevertheless, domestic sewage has been examined repeatedly for assessment of heavy metal concentration. The analysis showed that different concentrations (ppm) of heavy metals like Mn, Cu, Cr, Pb and Zn vary in the range of 0.05–5.0, apart from As (ppb) and Cd (ppb) with <1.234 in primary treated sewage water. When muscle and gills of four species such as catla, rohu, mrigal and bata are examined, concentration (ppm) of Mn, Cu, Cr, Pb and Zn remained in the range between 0.063–2.092 in gills and 0.015–0.109 in muscles against the permissible limit in the rage of 0.2–5.0 (Mandal et al. 2015). Primary treated sewage water contained very negligible amounts of heavy metals far below than permissible limit. Fish reared in such sewage-fed water is found safe for human consumption. Moreover, bioremediation through macrophytes has been tested as proven technique to remove heavy metals from sewage water, if any (Sengupta et al. 2012; Raychoudhury et al. 2007). Nevertheless, fish reared in sewage-fed water bodies need to undergo repeated analyses that can ensure its acceptability to consumers in respect of safety issue.

Eight common agricultural pesticides such as alpha-endosulfan, beta-endosulfan, endosulfan sulfate, chlorpyrifos, monocrotophos, malathion, mancozeb and carbaryl were analysed from fish samples reared in sewage-fed aquaculture. However, no residues of these pesticides were detected at the limit of 0.01 mg/kg of fish sample (Mandal unpublished). Bioassay trial has been conducted to examine the toxicity levels of sewage on fish and its intake in aquaculture for fish rearing. LC_5, LC_{50} and LC_{95} values of wastewater for the fish on 96 h of observation were 24.35%, 52.88% and 70.0% mortality, respectively. Acute toxicity values of domestic wastewater were measured using different species of fish as test organisms at different times (Sarkar et al. 1993; Bhowmik et al. 1995). The 96 h LC_{50} for fry of *Cyprinus carpio* was 34% in domestic wastewater (Ghosh et al. 1985). Lower range of LC_{50} values (31–33%) was reported for fry of *Labeo rohita* (Sarker et al. 1993). Survival of IMC fingerlings exposed to 96 h LC_{50} was found to be about 50% mortality (Mandal unpublished). When fingerlings were exposed to 40% concentration, survival record was 80% for 96 h observation (Mandal et al. 2013). Factors like maturity, physiology and genetic configuration vary species wise to respond to toxicity; nevertheless, less than 50% dilution of primary treated sewage was suitable for rearing fish subject to incorporation of moderate sewage effluent. The fish exposed to such sewage water was found active and behaved normally (Mandal et al. 2015).

5.9 Conclusions

Recycling of wastewater can provide plenty of freshwater available for aquaculture. There is an increasing concern about freshwater shortage in the context of global warming and climate change. Global warming may cause changes in the rainfall pattern and disrupt freshwater supplies in the foreseeable future. Recycle of treated sewage effluent in aquaculture has been tested as an instance to enhance water productivity of the system. Use of domestic sewage is of a high relevance to provide nutritional as well as livelihood security for the farmers. Quality and fish-rearing practices in such waters are evaluated considering an important environmental issue and found safe for health and hygiene of handlers and fish consumers. Utilization of sewage in aquaculture serves two important purposes: (1) transformation of misplaced nutrients into fish biomass and (2) water conservation in the context of increasing freshwater scarcity. Through prolonged research activities, it has been possible to establish the sewage-fed aquaculture as a reliable and responsible system to both fish farmers and consumers through its relentless scientific interventions and uncompromising commitment.

Acknowledgement Authors would like to thank the director of ICAR-CIFA for his consistent support for writing this article and the facilities provided. Contributions made by the scientists of ICAR-CIFA, including erstwhile CIFRI, who used to put a lot of efforts over the decades to reach an accomplishment of the targeted objectives in sewage-fed aquaculture, are gratefully acknowledged.

References

Ayyappan S (2000) Duckweed and fish based aquaculture sewage treatment system: status and prospects. In: Jana BB, Banerjee RD, Guterstan D, Heeb J (eds) Waste recycling and resources management in the developing world. University of Kalyani/India and International Ecological Engineering Society, Kalyani/Wolhusen, pp 59–63

Bhakta JN, Jana BB (2006) Determination of optimal dilution ratio of anaerobic pond effluent of domestic sewage for sewage-fed culture of common carp fry. J Experimental Zool 9(1):39–48

Bhowmik ML, Sarkar UK, Pandey BK (1993) Plankton abundance and composition in sewage fed fish ponds. J Inland Fish Soc India 25:23–29

Bhowmik ML, Pandey BK, Sarkar UK (1995) Influence of domestic sewage on fish and incidence of microbial population. In: Thomas PC (ed) Current and emerging trends in aquaculture. Daya Publishing House, New Delhi, pp 35–38

Bhowmik ML, Chattopadhyay A, Manna NK (1997) Biological treatment of sewage with reference to reduction of microbial load, nutrients and fish growth. J Inter Des 1(2):121–125

Bhowmik ML, Chakrabarti PP, Chattopadhyay A (2000) Microflora present in sewage fed system and possibilities of their transmission. In: Jana BB, Banerjee RD, Guterstan D, Heeb J (eds) Waste recycling and resources management in the developing world, University of Kalyani/India and International Ecological Engineering Society, Kalyani/Wolhusen, pp 71–77

Boyd CE, Tucker CS (1998) Pond aquaculture water quality management. Kluwer Academic Publisher, Norwell

Bunting SW (2007) Confronting the realities of wastewater aquaculture in peri-urban Kolkata with bioeconomic modeling. Water Res 41(2):499–505

Chakrabarti PP, Ghosh PK, Mukhopadhyay PK, Jayasankar P (2011) Urban sewage water recycling through aquaculture. Everything about water, September, 36–39

Chakrabarty NM (2002) Potentiality of carp production in sewage-fed ponds. In: Ayyappan S, Jena JK, Mohan Joseph M (eds) Proceedings of the fifth Indian fisheries Forum, pp 13–16

Chattopadhyay GN, Saha PK, Ghosh A, Karmakar HC (1988) A study on optimum BOD levels for fish culture in wastewater ponds. Biol Wastes 25:79–85

Chattopadhyay GN, Saha PK, Karmakar HC, Ghosh A (1990) Soil and water qualities of a wastewater fish pond with relation to productivity. In: Natarajan P, Jayaprakash V (eds)

Proceedings of the National Seminar on Aquaculture developments in India – Problems and prospects, Trivandram, 27–29 November, pp 151–156

Dasgupta S, Pandey BK, Sarangi N, Mukhopadhyay PK (2008) Evaluation of water productivity and fish yield in sewage fed vis- a- vis fertilized based carp culture. Bioresour Technol 99:3499–3506

Datta AK, Roy AK, Saha PK (2000) Comparative evaluation of sewage fed and feed based aquaculture. In: Jana BB, Banerjee RD, Guterstan D, Heeb J (eds) Waste recycling and resources management in the developing world. University of Kalyani/India and International Ecological Engineering Society, Kalyani/Wolhusen, pp 97–104

Edwards P (1992) Reuse of human wastes in aquaculture (a technical review). Ecology 7(7):1–8

Edwards P (2000) Wastewater fed aquaculture: state- of- the- art. In: Jana BB, Banerjee RD, Guterstan D, Heeb J (eds) Waste recycling and resources management in the developing world. University of Kalyani/India and International Ecological Engineering Society, Kalyani/Wolhusen, pp 38–49

Edwards P (2008) An increasingly secure future of wastewater fed aquaculture in Kolkata, India. Aquacult Asia Xiii:3–9

Fernandez A, Tejedor C, Chordi A (1992) Effect of different factors on the die-off of faecal bacteria in a stabilization pond purification plant. Water Res 26:1093–1098

Garcia M, Becares E (1997) Bacterial removal in three pilots scale wastewater treatment systems for rural areas. Water Sci Tecnol 35(11 &12):197–200

Ghosh A, Rao LH, Saha SK (1980) Culture prospects of *Sarotherodon mossambicus* in small ponds fertilized with domestic sewage. J Inland Fish Soc India 12:79–80

Ghosh A, Saha SK, Roy AK, Chakraborti PK (1985) Package of practices for using domestic sewage in carp production. Aqua Ext Manual 8:1–19

Ghosh A, Chattopadhyay GN, Mukherjee AB (1988) A modular project for recycling sewage effluents through aquaculture and its economic viability. Internnational Seminar on Wastewater reclamation and reuse for aquaculture, Calcutta, Economic and social Commission for Asia and the Pacific, Ministry of Agriculture, Government of India and Department of Fisheries, Government of West Bengal, India, pp 35–41

Ghosh C, Frijns J, Lettinga G (1999) Performance of silver carp (*H. molitrix)* dominated integrated post treatment system for purification of municipal wastewater in a temperate climate. Bioresour Technol 69(3):255–262

Gupta SK, Deshpande RD (2004) Water for India in 2050: first-order assessment of available options. Curr Sci 86(9):1216–1224

Jana BB (1998) Sewage-fed aquaculture: the Calcutta model. Ecol Engg 11:73–85

Jana BB, Datta S (1996) Nutrient variability in six sewage-fed tropical ponds. Environ Res Forum 5–6:379–382

Jena JK, Patro B, Patri P, Khuntia CP, Tripathy NK, Sinha S, Sarangi N, Ayyappan S (2010) Biological treatment of domestic sewage through duckweed-cum-fish culture: a pilot-scale study. Indian J Fish 57(4):45–51

Jhingran VG (1991) Fish and Fisheries of India. Hindustan Publishing Corporation (India), 3rd, Delhi

Jhingran AG, Ghosh A (1988) Aquaculture as a potential system of sewage disposal- a case study. J Indian Fish 20(2):1–8

Jhingran AG, Ghosh A (1990) Productive utilization of sewage effluent through aquaculture-case studied in India. In: Edwards P, Pullin RSV (eds) Wastewater fed aquaculture, Proceedings of International Seminar on Wastewater reclamation and reuse for aquaculture, 6–9 December, Calcutta, India, 1988, XXIXX + 296 P. Environmental sanitation information Centre, Asian Institute of Technology, Bangkok, Thailand, pp 91–98

Lahiri S, Sarkar D, Jana BB et al (2015) Evaluating the ecological resilient driven performance of a tropical waste stabilization pond system using ecological signature of biological integrity. J Ecol Eng 16:97–107

Mandal RN, Charabarti PP, Paul BN, Pandey BK, Chattopadhyay DN, Jayasankar P (2013) Optimal level of domestic sewage water standardized for survival of IMC juveniles. In: Abstract no. CAO-7, International symposium on towards green technologies in fisheries, 21–23 May, CIFT, Cochin

Mandal RN, Chakrabarti PP, Jayasankar P (2015) Sewage fed aquaculture: a viable proposition for fish production through nutrients recovery and water conservation, in effect of abating water pollution. In: Singh RP, Sarkar A (eds) Waste management. Nova scientific Publication, USA, pp 93–113

Mandal RN, Chattopadhyay DN, Pandey BK, Paul BN, Chakrabarti PP, Jayasankar P (2016) Promotion of sewage-fed aquaculture through public private partnership. In: Sinha VRP, Keshavnath P, Sharma AP, Mohanty BP (eds) Public private partnership in aquaculture. Narendra Publishing House, Delhi, pp 235–247

Mann RA, Bavor HJ (1993) Phosphorus removal in constructed wetlands using gravel and industrial waste substrata. Water Sci Technol 27:107–113

Mukherjee S, Jana BB (2007) Water quality effects SDH activity, protein content and RNA: DNA ratios in fish (*Catla catla, Labeo rohita, Oreochromis mossambicus*) raised in ponds of a sewage-fed fish farm. Aquaculture 262:105–114

Nandeesha MC (2002) Sewage fed aquaculture systems of Kolkata – a century old innovation of farmers. Aquacult Asia vii(2):28–32

Naskar KR, Banerjee AC, Chakrabarty NM, Ghosh A (1986) Yield of *Wolffia arrhiza* (L.) from cement cisterns with different sewage concentrations, and its efficacy as carp feed. Aquaculture 51:211–216

Olah J (1990) Wastewater fed fish culture in Hungary. In: Edwards P, Pullin RSV (eds) Wastewater fed aquaculture. In: Proceeding of the international seminar on wastewater reclamation and reuse for aquaculture, 6–9 December, Calcutta, India, 1988, XXIXX + 296 P. Environmental Sanitation Information Centre, Asian Institute of Technology, Bangkok, Thailand, pp 70–90

Oron G (1994) Duckweed culture for wastewater renovation and biomass production. Agric Water Manag 26:27–40

Pal D, Das Gupta C (1992) Microbial pollution in water and its effect on fish. J Aquatic Animal Health 4:32–39

Rai SP, Roy AK, Datta AK, Das CR, Ghosh JK (1996) A record production from integrated farming system utilizing sewage enriched water. J Ind Fish Assoc 26:33–40

Rangeby M, Johanson P, Pernrup M (1996) Removal of faecal coliforms in a wastewater stabilization pond system in Mindelo, Cape Verde. Water Sci Techol 34(11):149–157

Raychoudhury S, Salodkar S, Sudarshan M, Thakur AR (2007) Integrated resource recovery at east Calcutta wetland: how safe is these? Am J Agric Biol Sci 2(2):75–79

Routh M, Tripathi SD (1988) Effects of various inputs on fish production under composite fish culture in different regions in India. In: Joseph M (ed) The first Indian fisheries forum. In: Proceeding of the Asian Fisheries Society, Indian Branch, Mangalore, pp 45–48

Roy AK, Ghosh A (1987) Utilisation of sewage to increase fish production. Environ Ecol 5 (1):126–132

Saha T, Manna NK, Som Majumder S, Bhattacharjee IN (2001) Primary productivity of the Subhas sarobar Lake in East Calcutta in relation to some physico-chemical parameters. Pollut Res 20:47–52

Sahoo PK, Mohanty J, Das PC, Mohanta KN, Barik NK, Jayaasankar P (2012) CIFA: 25 years of freshwater aquaculture research. Central Institute of Freshwater Aquaculture, Bhubaneswar

Sarala DJ, Joseph B, Karunakaran K, Anurdha B, Ramadevi K (2009) People's attitude for water. Current Sci 96(8):1296–1302

Sarkar UK, Pandey BK, Bhowmik ML (1993) Toxicity of domestic sewage on fry of *Catla catla* (Ham.), *Labeo rohita* (Ham.) Environ Ecol 11(2):439–441

Sarkar D, Lahiri S, Jana BB (2017) Reponses of structure, function and C- sequestration potential of microalgae to nutrient enrichment across the sewage effluent of tropical waste stabilization pond system. Ecohydrology and Hydrobiology (in press)

Sengupta A, Rana T, Das B, Bhattacharjee S (2012) Wasatewater aquaculture by the Mudialy Fisherman's cooperative society in Kolkata, West Bengal: an example of sustainable development. J Appl Aqua 24:137–146

Sharma R (2005) Climate and water resources of India. Curr Sci 89:818–824

Sharma D, Bharat A (2009) Conceptualizing risk assessment framework for impacts of climate change on water resources. Curr Sci 96(8):1044–1052

WHO (2006) Guidelines for the safe use of wastewater, excreta and greywater, vol 2: wastewater use in agriculture. World Health Organization, Geneva. ISBN:92 4 154683 2, p 191

Zhang ZS (1990) Wastewater fed fish culture in China. In: Edwards P, Pullin RSV (eds) Wastewater fed aquaculture. Proceedings of international seminar on Wastewater reclamation and reuse for aquaculture, 6–9 December, Calcutta, India, 1988, XXIXX + 296 p. Environmental Sanitation Information Centre, Asian Institute of Technology, Bangkok, Thailand, pp 3–12

Chapter 6
Wastewater-Fed Aquaculture in East Kolkata Wetlands: State of the Art and Measures to Protect Biodiversity

Sasidulal Ghosh

Abstract East Kolkata Wetlands (EKW) have been recognized internationally as an important Ramsar Site with its long history of metamorphosis from saltwater area to freshwater aquaculture system fed with wastewater. It has been rendering livelihood opportunity to a large number of people in and around Kolkata through production of cheap protein source of food fish. This large-scale wetland system is utilized for wastewater treatment cum fish farming. The chapter attempts to focus important facts relating to wastewater-fed aquaculture, along with unique features that characterize such wetlands sustainable over the times. Nevertheless, this wetland system is now facing concerns which need to be resolved for benefits of fish farmers and fish consumer as well. Some measures have been addressed for sustainable management of the wetland system that would provide ecosystem service to cater the benefit of protein food production for present and future generations.

Keywords Wastewater · EKW · Aquaculture · Biodiversity

Contents

S. Ghosh (✉)
Bidhannagar Agro & Fisheries Projects Pvt. Ltd., Kolkta, West Bengal, India
e-mail: ghosh1955india@gmail.com

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_6

6.1 Introduction

The world is now in a critical phase with increasing population over decreasing resources. The developing world as a whole has been predominantly rural but is rapidly becoming urban. In 1975 only 27% of people in the developing world used to live in urban areas, whereas in 2000 it became 40%. Projected prediction suggests that developing worlds will turn to be 56% urban by 2030. The urban populations will face two major challenges: (1) supply of protein foods and (2) disposal of human waste. A study conducted in Kolkata Metro, India, shows that for every 115.6 l of potable water supplied to households, 92.5 l become wastewater. This shows that more is the urbanization; much is the wastewater generation leading to excessive pressure on urban sanitation and threat to open water pollution. The cumulative effect may also threaten biodiversity in general, particularly sustenance of human life. The Millennium Development Goals (MDGs) formulated some measures in terms of respective 'GOALS' to mitigate the concerns as much as in the use of wastewater in agriculture. The important goals with respect to wastewater use in agriculture are as follows:

Goal 1: 'Eliminate extreme poverty and hunger' – fish raised in waste-fed system is contributing to human nutrition through protein supplementation.
Goal 7: 'Ensure environmental sustainability'.

Wastewater treatment through aquaculture in East Kolkata Wetlands (EKW) has been an innovative approach practised by local fish farmers. The recycling of wastewater in aquaculture has its potential of resource recovery in terms of nutrients utility through food chain of fishes. This is a proven and an age-old alternative low-cost sanitation system that is linked to livelihood option and nutritional security of common people. The present chapter highlights the facts and features with respect to concerns and possible measures.

6.2 Facts

6.2.1 Location and Weather

The EKW lies between the river Hooghly on the West and the Kulti Ganga in the East, with geographical location: lat. 22° 25′N–22° 40′N and long. 88° 20′E–88° 35′E. Three major seasons as winter, summer and monsoon are recognized. Temperature ranges between 12 and 40 °C, and rainfall recorded between 150 and 200 cm, with humidity 80% as an average and wind speed ranging from 2.9 to 7.0 km ph. Solar radiation varies between 150 and 250 Langley/day. This tropical location has been suitable for trapping a huge amount of solar radiation that helps in treating wastewater through ecological functions and improving wastewater quality for fish farming.

6.2.2 Genesis

The East Kolkata Wetland is a part of the mature delta of the river Ganga, its tributaries and distributaries. Since the early fifteenth century, the river Ganga changed its main course from the Bhagirathi to the Padma River. This eastward shift in the course of the main flow of the river Ganga brought metamorphic changes in the process of delta building in the lower Gangetic plain. As a result, a number of distributaries and tributaries were cut off from upland flows. The mouths of some small distributaries opened directly into the Bay of Bengal and were influenced by tidal action. One such tidal channel has been the Bidyadhari River that used to deposit silt in this area. Since then, the process of natural deposition and raising the level of the spill area ceased to function, and this incomplete process of delta building did not allow the low-lying areas behind the Hugli levee, to the east of Kolkata, to rise higher. The East Kolkata Wetlands now remain as remnants of the vast stretches of the salt lakes, which once extended beyond the present international boundary of Bangladesh. The land to the east of Kolkata in general slopes to the east and south-east, with the natural drainage in those directions.

6.2.3 Metamorphosis of EKW: From Brackish to Freshwater Aquaculture

Prior to 1830, the low-lying region with saltwater lakes acting as spill reservoirs for the Bidyadhari was utilized for farming of brackish water fish such as bhetki (*Lates calcarifer*), parse (*Liza parsia*), bhangar (*Mugil tada*), prawns (*Macrobrachium rosenbergii*), etc. The area was gradually rendered derelict on account of the receding Bidyadhari spill channel. The poor upflow of the Bidyadhari and the cessation of tidal flow converted the entire area into a vast derelict swamp. The diversion of city wastewater and storm water into the Salt Lakes caused a gradual change in the aquatic environment from saline to nonsaline. This led to the changes in the culture of fish in the region, especially in terms of species. In 1929, a leading fish producer of this region successfully experimented with the process of farming fish in wastewater-fed ponds. Gradually, the wastewater-grown fish became prominent with species such as rohu (*Labeo rohita*), catla, (*Catla catla*), mrigal (*Cirrhinus mrigala*) and exotic ones such as silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) along with tilapia (*Oreochromis mossambicus*), walking catfish (*Clarias batrachus*), etc.

With drying up of the tidal flow, subsequently intake of city wastewater was introduced into this wetland – an innovative approach to keep EKW continuing alive from being wasteland. The intake of wastewater was not only used for fish culture but also used for irrigation of crops and vegetables cultivated in this region. This practice saved the livelihood of thousands of fishermen, which was threatened by the drying up of brackish water fisheries of EKW. In 1992, a case study on the East Kolkata Wetlands was presented in the expert committee meeting of the Ramsar Convention, the only example of 'wise use' of wetland from India, which included one important wetland among 17 other case studies selected from all over the world. That was the beginning of an effort which led to the declaration of the East Kolkata Wetlands as a Ramsar Site, a new dimension in the EKW conservation strategy. The resource-recovery system created and developed in East Kolkata Wetlands by the local innovators through the ages is the largest in the world. It is also the only wetland area by the side of a metropolitan city where the government has introduced development controls to conserve the water bodies and plans to develop it as a unique urban facility for environmental improvement.

6.2.4 Potentiality of EKW

The production of fish in EKW varies from 3.0 to 6.0 tones/ha/year, thereby creating eco job 2 to 2.5 person/ha/year directly and 1–1.5 person/ha/year indirectly. Blending of local wisdom with scientific knowledge of aquaculture, the yield can be increased up to twofold more without supplementary feed and aeration. In this case, the fish pond serves as stabilization pond, and the self-purification capacity enables to reduce the chemical and biological toxicity of urban wastewater. The current land use pattern includes the following:(a) 5852.14 ha corresponding 46.82% of a total land areas used for fisheries and aquaculture, (b) 5852.14 ha as 37.75% of a total land areas used for agriculture, (c) 602.78 ha as 4.82% of a total land areas used for garbage dumping including farming and (d) 1326.52 ha as 10.61% of a total land areas used for human settlement.

6.3 Features

6.3.1 Characteristics of Wastewater in EKW

Wastewater is the main potential ingredients for pisciculture in EKW. The characteristics of wastewater is not uniform round the year, it actually varies not only place to place but also from hour to hour at the same place depending on the climate conditions, availability of water, dietary habits, social customs, etc. The average values of some parameters are given in Table 6.1.

6.3.2 Aquaculture in EKW, Known as LEISA

In EKW the conventional option in wastewater treatment has been replaced by an ecological design of wise use of wetland. The relook of wetland utility aims to reduce pollution and reuse nutrients that have ensured enhancement of food production and livelihood security of the local community through both aquaculture and agriculture. The high organic load of wastewater-fed fishery is degraded by the microbial-algal-animal complex activity that enables organic wastes to recycle into fish biomass through ecosystem dynamics. This ecological process that is the basis of resource recovery from organic wastes has enabled farmers to be capable of growing fish at higher yield with minimal production cost, known as LEISA (low external input sustainable aquaculture).

6.3.3 Different Models of Wastewater-Fed Aquaculture

Based upon the physico-chemical characteristics of wastewater, climatic condition, land availability, etc., different models or designs (Table 6.2) are available for wastewater treatment through aquaculture to achieve the desired reduction of pollutants and harnessing the potential nutrients in economic-driven activities (WHO 2005).

Table 6.1 Physico-chemical parameters of aquaculture ponds of East Kolkata Wetlands (EKW)

Parameter	Raw sewage to fishery	Sewage-fed culture water	Outlet water for agriculture	Effluent standard for inland surface water[a]
Temperature (°C)	32.0	29.27	29.0	40
pH	7.2	7.70	7.5	5.5–9.0
Transparency (cm)	Nil	15	10	10
Total dissolved solid (ppm)	675	455	130.0	2100.0
TSS (ppm)	211	123	65.0	100.00
BOD (ppm)	128.4	25.0	17.9	30.0
DO (ppm)	Nil	3.9	4.5	4.0
Alkalinity (ppm)	273.7	130.0	130.0	83.0
Phosphate (ppm)	2.94	0.8	0.8	0.2
Nitrate (ppm)	3.7	2.41	2.41	0.8
Free ammonia (ppm)	40.0	1.04	0.5	1.2
Lead (as Pb) (ppm)	0.57	Trace 0.09	Trace	0.1
Cadmium (as Cd) (ppm)	032	Trace 0.12	Trace	2.0
Chromium (as Cr) (ppm)	5.80	Trace 0.08	Trace	2.0
Zinc (as Zn) (ppm)	0.56	Trace 0.44	Trace	5.0
Coliform (cfu/100 ml)	$10^{4.5}$	$10^{1.5}$	$10^{1.5}$	<5000 cfu/100 ml
Faecal coliform (cfu/100 ml)	$10^{3.5}$	10^{1}	10^{1}	<5000 cfu/100 ml
Salmonella sp. (cfu/100 ml)	10^{5}	10^{1}	10^{1}	<5000 cfu/100 ml

[a]CPCB, Govt. of West Bengal

6.3.4 Status of Wastewater-Fed Aquaculture in EKW

The total area of EKW comprises 5852.14 ha, including 3200.55 ha for a total perennial aquaculture wetlands, 698.22 ha for a total non-operating area and 1953.37 ha for a total non-functional area. On the other hand, wastewater flow released daily to EKW from Kolkata City accounts 1300 mld (approx.), and wastewater availability for aquaculture is 320 mld (approx).

The wastewater management strategies vary depending upon wastewater availability, carrying capacity of pond, market demand, operational cost, work culture of the workers/member of piscicultural unit, etc. The farmers fill up ponds with wastewater, which is then left for 2 weeks for natural purification and stabilization before introduction of fish. Subsequently, ponds may be topped up with wastewater

Table 6.2 Different models or designs of wastewater utility and their features

Design	Features
Obstructed flow system	Wastewater directly received by fishes; land is not a constraint
Waste stabilization system	Wastewater stored in oxidation ponds in order to suspend organic load and growth of plankton followed by its release to aquaculture ponds
Flow-through system	Wastewater treated through series of ponds and then used for fishes
Dilution of wastewater	If the BOD level of wastewater is more than 50 mg/l, then it is necessary to dilute by adding freshwater
Duckweed culture	In absence of sufficient quantity of water and land to reduce BOD level below 50 mg/l, 'duckweed culture model' is a good option. Duckweed helps in reducing the pollutant level in wastewater and also serves as food for fishes
Effective microorganism (EM)-based system	In extremely land scarce situation, wastewater can be treated by microorganism-based system [consisting of lactic acid bacteria (aerobic and anaerobic), yeast and *Actinomycetes*, etc.

continuously or periodically depending on availability of wastewater and season. Farmers have learned by experience the methods of culturing herbivorous and omnivorous fish such as Chinese carp, Indian major carps and tilapias. Using traditional methods, the quality of wastewater-fed ponds is assessed by observing water colour, light penetration in water and fish surfacing behaviour in the early morning when dissolved oxygen level of pond water declined to their lowest level after respiration of aquatic organisms during the night. This lesson led to conceive the idea of wastewater-fed aquaculture.

6.3.5 Aquaculture Strategies

Farmers of EKW usually adopt a specific aquaculture practice using traditional knowledge by the way of their experiences which is as follows:

- Obstructed flow-through system with multiple stocking and multiple harvesting (Fig. 6.1)
- Water column – 0.6–0.8 m generally, except ponds de-silted when water column is more than 2 m
- Wastewater intake – 50–200 m^3/ha/day (100–200 days/year) due to lack of wastewater
- Species cultured: seven to eight species. *Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*, *Labeo bata*, *Hypophthalmichthys molitrix*, *Cyprinus carpio*, *Oreochromis mossambicus* and *Oreochromis niloticus* in different ratios, basically depending upon wastewater availability and water column and size of fingerling at the time of introduction 5–20 g
- Stocking density: 500–1200 kg/ha

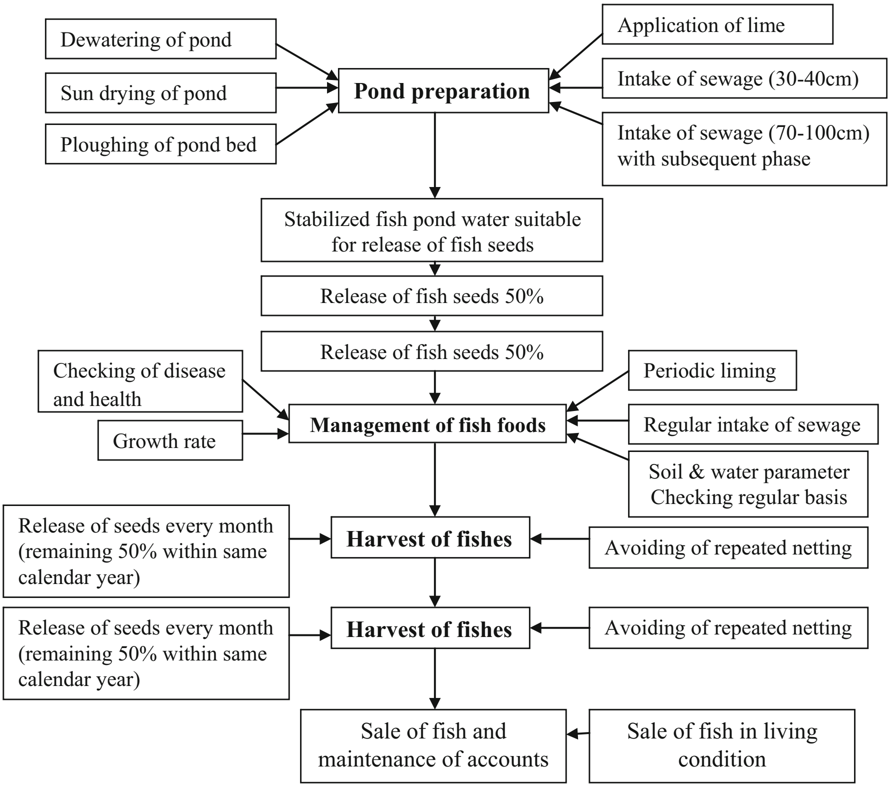


Fig. 6.1 Method of wastewater-fed aquaculture, including multiple stocking and multiple harvesting

- Harvesting throughout the year (100–300 days/year)
- Harvesting size – 50–250 g for IMC and 200 g to 1 kg for exotic crap
- Production: varies from 3–6 tonnes/ha/year depending on availability of wastewater (Table 6.3)

Farmers generally follow a few specific tips for wastewater-fed aquaculture in EKW as:

1. Desired inflow rate of wastewater is 150–200 m^3/ha/day (not 400 m^3/ha/day that may create eutrophication).
2. Added wastewater should not consume more than 1–2 mg/l of dissolved oxygen/ hr.
3. Avoid hot and cloudy day for intake of wastewater.
4. Transparency limit – 25 to 35 cm should be maintained.
5. Algal count – at least 100 million cells/l.
6. Polyculture, multiple stocking and multiple harvesting policy.

Table 6.3 Intake of wastewater and fish yield in East Kolkata Wetlands (WKW)

Different waterbodies	Water depth (m)	Intake of wastewater (%)		Fish production (tonnes/ha/year)
		Gravity flow	Pumped	
1	2	50	Nil	6.00
2	1.5	20	40	5.50
3	1	30	20	4.50
4	1	25	15	4.00
5	0.7	20	10	3.50
6	0.65	20	Nil	3.00

Source: (24-Parganas Fish Producer Association)

6.3.6 Marketing and People Participation

Generally fishes are sold in living condition to get better realization. About 90% of the harvested fishes were marketed in the morning and the rest in noon (Ghosh 2004). There are seven auction centres for sale of fishes. The total quantum of fish sold through these auction centres is 19,135 tones/year, of which more than 80% fish is supplied from EKW. Average sale price varies from Rs. 70–80/– per kg in auction market. A total work force comprises 17,000 people out of almost 72,000 inhabitants residing around 12,500 ha as per 1991 census.

6.3.7 Environmental Benefit

Not only that aquaculture practice in EKW produces fish by utilizing organic-laden water, but also it renders unbelievable environmental benefits to the entire vicinity and its people; otherwise, it creates both aquatic and land pollution that could hamper normal health of residents. The summary of benefits is mentioned below:

- Each hectare of shallow waterbody can remove about 237 kg of biochemical oxygen demand/day.
- Organic loading rate in fishery is 20–70 kg/ha/day. It is a source of nutrients for plankton production, and it reduces the siltation rate in river mouth.
- Support biodiversity.
- Ecological environmental value of EKW is around Rs. 3030 million/year (for flood control, siltation, extensive food chain, livelihood support, carbon sequestration and sanitation).

6.4 Concerns

6.4.1 Poor Infrastructure

Despite a Ramsar Site recognized worldwide as its utility for fish production and livelihood option, still EKW suffers from poor infrastructure for optimal uses of resources. These are:

1. Lack of sufficient wastewater supply from Kolkata Municipal Corporation to the fisheries sector of EKW.
2. Lack of up scaling of aquaculture facilities.
3. Lack of government policy and implementation measure to support wetland practice encourages ecological sound design for environment protection.

6.4.2 Safety of Fish Yield

In aquaculture, a product-oriented practice being, public health concerns have been raised with regard to the suitability for consumption of fish/shellfish from such system. The level of heavy metals, antibiotic residue and microbial counts are reported to be less than the permissible limit.

6.4.3 Threats to Fish Diversity

In EKW, there were as high as 80 species of fish during the 1960s. Later, it was identified 32 fish species. Further, *Jalabhumi Bachao Committee* recently surveyed fish species diversity in EKW during submission of proposal for protection of endangered fishes of EKW and identified 45 species (Table 6.4). The rich fish germ plasm resources of EKW have been suffering from various serious anthropogenic stresses leading to overall exploitation of genetic resources. The reasons which are responsible for such destruction include habitual destruction, over-exploitation, aquatic pollution, disease, introduction of exotics and alien species, lack of awareness about the importance of biodiversity and lack of proper policy implementation to restore it. Out of 45 species, 11 species are generally cultured on regular basis, and 7 new indigenous species were introduced for culture during the last 2 years. Three species of exotic crocodile fish by accident were introduced in EKW, and successful populations are now found in enormous quantity. Some species such as *Nandus nandus* (meni), *Xenentodon cancila* (kakila), etc. were available in EKW in the 1980s, but now these species are not available. In the present scenario, it is essential to conduct a detail survey of EKW for up-to-date information about species diversity and categorize their scale of

Table 6.4 Diversity of fish species in East Kolkata Wetlands (EKW) and their status

Species	Status
Catla catla (catla), *Labeo rohita* (rohu), *Cirrhinus mrigala* (mrigal), *Labeo bata* (bata), *Labeo calbasu* (calbasu)	Commonly cultured Indian carps (5)
Hypophthalmichthys molitrix (silver carp), *Ctenopharyngodon idella* (grass carp), *Aristichthys nobilis* (big head carp), *Cyprinus carpio* (common carp), *Oreochromis mossambicus* (tilapia), *Oreochromis nilotica* (Nile tilapia)	Commonly cultured exotic species (6)
Lates calcarifer (bhetki), *Liza parsia* (parse), *Mystus gulio* (nona tengra)	Brackish water species reintroduced in EKW by some farmer (3)
Ompok pabda (pabda), *Chitala chitala* (chital), *Cynoglossus cynoglossus* [baspah (flat fish)], *Piaractus brachypomus* (rupchanda)	Some farmers introduced to culture in recent years (4)
Pangasius pangasius (pangus), *Mystus vittatus* (tengra)	Traditionally culture by some farmer of EKW (2)
Clarias gariepinus (African catfish/Thai magur), *Pangasianodon hypophthalmus* (hybrid pangus), *Puntius javanicus* (Javaputi)	Some farmers used to culture these species, though they are negative culture species (3)
Amblypharyngodon mola (morula), *Puntius ticto* (tit punti), *P. Sophore* (sarpunti), *Salmostoma bacaila* (chela), *Colisa fasciata* (boro kholisha), *Aplocheilus panchax* (techaka), *Mastacembelus pancalus* (pacal), *Pisodonophis boro* (kuchia), *Notopterus notopterus* (Pholui), *Clarias batrachus* (Magur), *Heteropneustes fossilis* (singhi), *Channa striatus* (shol), *C. punctatus* (lata/taki), *C gachua* (chang), *Mystus armatus* (ban), *Anabas testudineus* (koi)	Species endangered in EKW (16)
Chanda nama (chanda), *C. ranga* (ranga chanda), *Glossogobius giuris* (belay)	Small species available in good number in EKW (3)
Crocodile fishes: *Pterygoplichthys disjunctivus, P. anisitsi, P. multiradiatus*	Accidentally introduced in EKW. From the last 4–5 years, these fishes were recorded in good number (3)

threat as per availability, somewhat in the lines of IUCN, AFS and NBFGR such as extinct, critically endangered, endangered, vulnerable, near threatened, lower risk, remote risk and no risk.

6.4.4 Major Events Causing Concerns to EKW

Aquaculture as well as an entire EKW is under tremendous anthropogenic pressure leading to actual tenure problem. The cumulative effect of these pressures including

Table 6.5 Chronology of major events of concerns to East Kolkata Wetlands (EKW)

Year	Project	Result	Remarks
1896	Cross damming of one of the most powerful tidal-spill channels of the Bidyadhari River	Silting aggravated in the Bidyadhari River	–
1897–1898	Canalization of the Bhagore Khal and construction of the Bamanghata lock to facilitate inland navigation	Further deterioration of the Central Lake Channel	Around 1900 saltwater fisheries existed in the Salt Lakes. In 1904, a warning was given regarding alarming deterioration of the Bidyadhari River
1910	Construction of Krishnapur Canal – shooter route joining the New Cut Canal with the Bhangore Khal	More than 78 Sq. km of the spill area of the Bidhyadhari River was out off	In 1913 a second warning was given. In 1928 the Bidyadhari River was officially declared as dead by the government of Bengal. During 1930, first wastewater feed fisheries was started and proved successful
1940	Wastewater outfall of the city was changed from south-east to east, to the Kulti Gong or Kulti River	This was a necessity as the Bidyadhari River had died	–
1962–1967	Salt Lake reclamation for the extension of the city	Huge conversion of wetland into urban areas. Aggravation of drainage problems of the city during the monsoon	–
1980s	Construction of Eastern Metropolitan Bypass		–

government agencies and private entrepreneur who does not consider its ecological importance due to short-sight short-term planning has led to the shrinkage of these wetlands. The natural state of this low-lying area was interfered with expansion of the city of Kolkata with necessities of drainage and waste disposal and later also reclamation for city extension at different times (Table 6.5).

During 2000, *Jallabhumi Bachoo Committee* was formed with members of 10,000 local people to protect destruction and felling of wetland. One major event they resisted was the formation of Asian Gateway which they won eventually by the verdict of honourable High Court. Another upcoming threat to this wetland is the proposed ‘Eastern Link Highway’. The plan is to start the highway from the Barasat bypass which run through Rajarhat Township and back site of Kolkata Leather Complex and connect with National Highway 117 at Shirakol. If the road goes through the wetlands as it is planned, then the EKW will be at a serious stake.

Table 6.6 Constraints to peri-urban (PU) aquaculture based on the perception of firm managers ($n = 56$)

Constraint	Respondents affected (%)	Mean rank assigned by participants	Overall ordinal rank
Uncertain wastewater supply	86	1.1	1
Financial problems	25	2	2.5
Declining wastewater quality	9	2	2.5
Poaching	34	2.5	4
Labour problem	30	2.6	5.5
Siltation	23	2.6	5.5
Management problem	5	3	8
Poor road infrastructure	5	3	8
Poor seed quality	2	3	8
Limited access to electricity	9	3.2	10
Disease	29	3.3	11
Threat from land developers	7	4	13
Law and order problem	4	4	13
Inundation during flooding	2	4	13
Declining production	5	4.3	15
Transport pTransport problems	2	5	16

6.4.5 Some Constraints to EKW

In August 2002, Institute of Aquaculture, University of Stirling, Scotland, published 'Situation Analysis in Peri-urban Kolkata'. The paper summarized some constraints in EKW through response of correspondence of EKW community. The results are summarized in Table 6.6.

6.5 Measures

It is realized that conservation measures are essential to protect such important wetlands from further degradation (Ghosh 2005). Conservation is to be encouraged for the existence of species that includes some steps such as identification, cataloguing and prioritization of species as per their RED data categories. Some measures are to be taken as:

6.5.1 In Situ Conservation

In situ conservation of fish can be done through the maintenance of fish germ plasm resources in their natural habitat or man-made ecosystem in which they occur. Major advantages of in situ conservation include (1) continued co-evolution wherein the wild species may continue to co-evolve with other forms, providing the breeders with a dynamic source of resistance that is lost in ex situ conservation, and (2) national parks and biosphere reserves may provide less expensive protection for the wild relatives than ex situ measures. In situ conservation can be achieved through the following practices: (1) ranching, (2) protected areas (sanctuaries, biosphere reserves, etc.), (3) conservation aquaculture, (4) threatened or endangered species designation and (5) restoration of damaged and degraded habitat.

6.5.2 Ex Situ Conservation

The threatened species are conserved outside their natural habitats. The two main pillars of the ex situ conservation programme are (1) live gene bank or resource centre and (2) gamete bank. A mini gene bank with cryopreserved milt of several threatened and commercial species presently exists at the National Bureau of Fish Genetic Resources (NBFGR), Lucknow, India. Other ex situ conservation programmes include tissue banking, registration of germ plasm,and DNA barcoding.

6.5.3 Some Specific Recommendation for Enhancing Fish Biodiversity in EKW

With a view to save the world's largest wastewater recycle region, it is urgent to adopt proper and balanced methodologies for enhancing fish diversity (Ghosh and Ghosh 2003). The endangered species of EKW can be divided into two broad groups, viz., (1) candidate species having economic importance for culture and (2) fishes having ornamental values. Out of the 27 endangered species in EKW, 15 species can be selected as candidate species for culture and the remaining 12 as ornamental fish, especially for export. Besides culture of economically important fishes, standardizing and transferring the captive breeding and seed rearing technology of ornamentally valued small fishes of EKW are common among fishers. This will open a new avenue of employment in EKW and also play a role in restoration of fish biodiversity. Some measures are:

1. As most of the endangered fish species in EKW are smaller in size, mesh-size regulation during harvesting of fishes from grow-out pond is a suitable option

for protection against random catching of endangered fishes. Mesh size should be more than 4–5 cm for harvesting of marketable fish.
2. Total restriction on use of insecticide, pesticides and other harmful chemicals in pisciculture in EKW.
3. Strict monitoring to restrict the entry of heavy metals and other harmful chemicals in city wastewater and thus reducing the pollution load of incoming wastewater to the fisheries of EKW.
4. Over-removing of earth from the bed of pond by Rajarhat New Town Authority be restricted, and it should be limited as per suggested cutting depth of 0.80 metre (average).
5. Restrict fragmentation of bigger pond into small ponds.
6. Restrict unapproved exotic species culture and if so should be declare as punishable offence.
7. During liberation of fish seed, certain unwanted and exotic variety of fishes are coming from different places of West Bengal and entering into EKW system. Establishment of a fish seed centre within EKW can resolve this problem.
8. Protect existing natural habitat of endangered species of EKW. Government should take initiative to declare some bio-protected zone for endangered species.
9. Captive breeding and seed production of endangered fishes of EKW.
10. Awareness amonglocal people related to EKW regarding importance of endangered species for biodiversity and environment. Policymakers and implementer agencies also be educated about the biodiversity importance for our world.

6.5.4 Marketing Chain in EKW

The postharvest scenario in the fisheries unit in EKW and its distribution system play an important role in completing economic cycle. Daily harvested fish is brought to auction centre usually in the morning and also in noon/afternoon through carriers/packers. Generally quantity of fish carried by carriers per consignment is 12–16 kg live fish or 20 kg dead fish. The rate of carrying fish by carriers is varying between Rs. 4.00 and Rs. 7.50 per kg depending upon sale price of fish, distance, etc. Farmers have no free access to sale the product where they get maximum; they have to engage carriers for selling fishes. Out of total production, the fisher/producer sells 97% and 3% disposed of by way of subsistence payment to labourers, consumption by residential staff and charity/donation made during festivals. The operating chain may be represented diagrammatically as follows (Fig. 6.2).

In auction market, the aratdars (i.e. kata owner) charge commission to seller as well as from buyer (wholesaler/retailer). The commission is charged as a percentage of cash sales, and the rate varies between 1% and 2% for buyer and 2% and 5% for seller. The peak business month is between April and September; remaining months are lean period of culture and production. More than 19,235 tonnes of fish per year are sold through seven auction centres of this region. Out of the entire fish

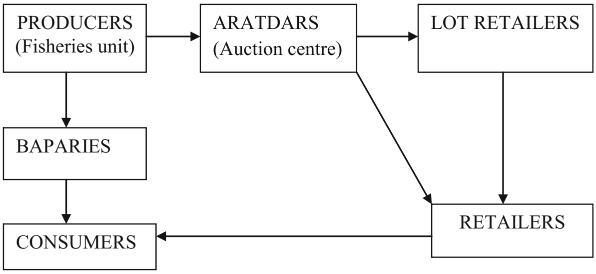


Fig. 6.2 Marketing chain in East Kolkata Wetlands (EKW)

Table 6.7 Auction centre and total quantity of sale/centre/day

Sl. no.	Auction market	Nos. of stalls	Police station	Total quantity of fish sold (kg/day)
1.	Bamanghata	60	Bhangor	9000
2.	Bantala	55	Bidhannagar	11,000
3.	Chowbhaga	75	Teljala	6750
4.	Krishnapur	54	Rajarhat	8100
5.	Gangajoware	25	Sonarpur	3250
6.	Chingrighata	42	Tiljala	12,600
7.	Garia	25	Garia	2000

sale through these centres, more than 15,592 tonnes (>81%) from EKW and the remaining of about 19% fishes come from adjoining area of EKW. The locations of the auction market are at seven strategic points catering to diverse retail market mentioned in Table 6.7.

Major fish supplies to Kolkata City from EKW are mainly through aratdars. The aratdars in their turn put the fish for auction to retailers and lot retailers. The lot retailers take the fish to retail market and put the same for auction again to a section of retailers. A portion of the daily supply (very small) also goes directly to retailers from the collectors or 'beparies' who purchase the fish at fishing sites. The retailers purchase the fish and sell the same to consumers in market.

Due to monopolistic control of fish trade in different stages by a handful of middleman, the producers receive low prices for their products while consumers have to pay high prices for what they purchase. In general the producer in recent year gets around Rs.70.00/kg (average) of live fish, but in fish market, consumer purchases it not less than Rs. 120.00/kg. The middleman consume 40% margin, whereas the producers hardly get margin during course of production. Day by day the economic viability of fish production in EKW is reducing due to higher production cost in compare to selling price. It is the middlemen who are absorbing the margin of profit by depriving the producers.

6.5.5 Measures for Protection of EKW

Some recommendations for maintaining good ecosystem health and quality fish (Saha 2004):

1. Follow site selection and standard design norms (site specific).
2. Follow guidelines for use of domestic wastewater in aquaculture.
3. Follow management practice of wastewater feed aquaculture.
4. Use settling ponds, before intake of wastewater to culture ponds, and velocity of outflow water from settling ponds should be 'silting velocity'. It is observed that disease is less in obstructed flow system compared to flow-through system.
5. Treat seed of fishes before liberation in ponds (dip treatment with NaCl solution at 2.5% for 3–5 min, formalin treatment at 250 mg/l, group treatment with $KMnO_4$ (at 5 kg/ha for 48 h). Outsourced seed first should be released in a hapa/pond and keep for 2–3 days, and after treatment, it may be released to grow-out pond.
6. Avoid overstocking.
7. After every crop, sun-dry the pond bed if unit is small (below 1 ha), once in a year for big pond (below 10 ha) and once in 4–5 years if size of the pond is above 10 ha. Plough the pond bottom and apply lime after drying.
8. Apply lime in regular interval especially during change of monsoon.
9. Application of chlorine at 1 ppm or iodine in regular interval.
10. Regular inspection of soil and water quality parameters, fish health and growth.

Different measures and incident to protect wetland and fisheries in EKW:

1. PUBLIC (People United for Better Living in Kolkata) is responsible for 1993 Kolkata.
2. Fisheries department, Govt. of West Bengal, formed institute of wetland management and ecological design during 1987–1988. This was the first step to highlight EKW in international level.
3. *Jallabhumi Bachoo Committee* (10,000 member local people) movement during 2000 against extension of urbanization and implementation of different project in EKW and finally won over such step.
4. Government's declaration of 'East Kolkata Management Authority' in 2002 for the conservation and sustainable uses of EKW.
5. Fisheries department, Govt. of West Bengal, has organized 8 fisheries co-operatives and 24 fish production groups in EKW to improve physical structure and culture of fish through different government programme and soft-term loan, viz., NCDC loan etc.

6.5.5.1 Physical Improvement of EKW

Physical improvements of EKW were started on and from 1999 to support fisheries units and waste recycle region.

1. In 1999, HIDCO de-silted Nalban Fisheries as trial basis to till up low-lying area of Rajarhat Township. Since 1999 to up to date, HIDCO (2003) (West Bengal Housing Infrastructure Development Corporation Ltd. 2003) de-silted more than 150 lakh cum earth from approx 800 ha fish pond.
2. The West Bengal housing board constituted a committee under notification No. 86/HI/NTP/IM-3/99(pt) dated 18 February 2003 for 'physical development of bheries within EKW and waste recycling region (WRR)'. The committee suggested design of fish pond and wastewater supply (72 million litre/day (mld) to the northern part of waste recycling region (WRR) from New Township, Rajarhat. Accordingly works on wastewater supply structure are under process. This will feed wastewater where wastewaters supply from KMC in very low. 600 ha of pisciculture area of EKW will be benefited and existing production will be enhanced by 60 to 100%. The committee also estimated an expenditure of Rs. 251 crore for physical development of much required 2500 ha piscicultural area of EKW (USAID, INDIA 2006).
3. In 2007 EKW Management Authority de-silted different wastewater feed feeder canal, as a result the existing area are getting more wastewater related to Vidhyadhar Channel No. 1 and 3 and new area (which was previously converted to agri-land from fishery) came under piscicultural activities due to supply of wastewater.
4. Under MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act) scheme through South 24-Parganas District Administration the EKW Management Authority de-silted 3 km of Bidhyadhari Fishery Feed Canal (Bantala to Saintala).

Requirements to enhance production from EKW (Ghosh 2007):

1. Inflow of wastewater is required at 320 million litres a day (mld) at existing condition of piscicultural area and will be required at 869 mld in the future after enhancement of water column to 1.5 m for the entire piscicultural area of EKW. This needs to be ensured first. In dry season GTS level 9 needs to be maintained after Bantala site and in rainy season use proposed pumping system for feeding wastewater to piscicultural units.
2. De-silt all feeder canals and strengthen all dykes of fisheries to support 1–2 m water column.
3. Infrastructure, viz., road, electricity, freshwater supply, etc., needs to ensure better operation and scientific culture.
4. Technology up-gradation along with species diversification is required for quality fish production based on market demand.

5. Refresher training of fisher/producer of EKW.
6. Financial support and insurance facility which are lacking required utmost.
7. Land policy should be on stream lined.
8. Overall management and work culture; for that support from local leader to farmer/producer community is essential, besides government support.

6.6 Conclusions

FAO estimated that an additional 40 million tonnes (world demand) of aquatic food will be required by 2030 just to maintain current level of consumption. Recycling and reusing of water is one of our prime necessities to cater future demand of freshwater and food. WKW is a striking example of low external input sustainable aquaculture and agriculture site. Sewage is well known as a readily available biodegradable nutrient-rich resource, and aquaculture provides an opportunity for not only converting this waste into valued protein food but also a biological means for wastewater treatment which is most important in the context of current freshwater scarcity scenario.

Acknowledgement Author likes to thank Dr. Ajmal Hussain, Scientist, RRC, ICAR-CIFA, Rahara, and Kalyani Field Station for his help in preparation of manuscript.

References

Ghosh SD (2004) Opportunity of fish processing and value addition through sustainable aquaculture in the EKW. Sept 2004 (Institute of Engineer, West Bengal Circle Publication)

Ghosh D (2005) Ecology and traditional wetland practice (2005, lesson from wastewater utilization in the East Calcutta wetlands, world view, Kolkata, India)

Ghosh SD (2007) State level workshop on bankable model – scheme in fisheries sector, 15th February, (organize by NABARD)

Ghosh D, Ghosh SK (2003) Rehabilitating biodiversity (WWF June 2003)

HIDCO (2003) Project report of physical development of bheries within EKW and waste recycling region (Phase – I)

Saha CC (2004) Construction and design of wastewater fish farm. In: Training manual, ICAR-CIFA. Rahara, West Bengal

USAID, INDIA (2006) Transforming water and wastewater services in urban India: lessons from International Best Practice

WHO (2005) National workshop on assessment of current and futuristic water quantity standard in India

Chapter 7
Fish Diseases in Wastewater Aquaculture and Remedial Measures

Manas Kr. Das

Abstract Water quality and biological factors strongly affect the growth of fish in aquaculture ponds. Deterioration of water quality and adverse biological factors, regardless of the nature of aquaculture ponds, would cause poor ecosystem health and disease occurrence in the cultured fishes. Wastewater-fed aquaculture is a well-established climate-resilient practice that contributes substantially to inland fish production in India and elsewhere. Enhancement of fish production in such systems is, however, limited by suboptimal conditions of water quality and disease occurrences. Investigations in wastewater fish culture wetlands revealed various stressors that affect fish growth and production. These stressors are (1) suboptimal diurnal as well as seasonal water quality with DO level fluctuating from 0 to 18.0 mg/l, high CO_2 (nil–16.0 mg/l), high unionized ammonia (0.11–0.42 mg/l) and low transparency ($<$14 cm) throughout the culture period and (2) biological stressors manifested by the abundance of urceolariid ciliates (*Trichodina*, *Tripartiella* spp.) in the hyper-mucus-secreting fish gills. The stress caused by the multiple stressors are physiologically manifested in the resident fish populations by significant changes in the levels of stress-sensitive blood parameters such as haematocrit, plasma cortisol, cholesterol, glucose, chloride and lactic acid levels. Morphological alterations are exhibited in the form of hyperplasia, hypertrophy and oedema in the gills, proliferation of mucous cells and decrease in chromatophores in fish skin. These factors affect the growth of fish as reflected by the reduced condition factor. Stressed fish in such systems become prone to various infectious and noninfectious diseases such as fin and tail rot, dropsy, bacterial gill disease, saprolegniasis, trichodiniasis, myxosporean diseases, dactylogyrosis, argulosis, ergasilosis, hypoxia and algal toxicosis. Rapid assessment of the fish health needs to be conducted using the health assessment index (HAI) method and necessary remedial measures be adopted.

M. K. Das (✉)
Fisheries Resource and Environmental Management Division, Central Inland Fisheries Research Institute (ICAR), Barrackpore, West Bengal, India
e-mail: mkdas412@rediffmail.com

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_7

Keywords Wastewater · Fish diseases · Health assessment index · Stressors · Remedial measures

Contents

7.1 Introduction

The production of fish in ponds fertilized with wastewater is a common practice in many parts of Asia. Nowadays the sewage-fed fishery is well established because it is more attractive than that of the intensive fish farming practices using supplementary feeds (WHO 2006). The biodegradability of these wastes forms the basis for sewage treatment converting waste into economic resource for recycling. The tropical climate is ideal for the conversion of human wastes into high-protein microalgae due to favourable temperature and light throughout the year. The sewage effluents in fish ponds mediated by diverse groups of microorganism act in the manner as organic fertilizers and liberate nitrogen, phosphorus and trace elements which stimulate the production of fish food organisms in the aquatic systems. It is estimated that at present there are more than 130 wastewater aquaculture units in India covering above 10,000 ha water area. Almost 80% of these are located in West Bengal where sewage is extensively used as fertilizer for fish ponds (Bhowmick et al. 2011). One of the major sewage-fed fisheries is the East Kolkata Wetland (EKW) fisheries . In this system of culture, domestic sewage and storm water within the city of Kolkata are mostly carried through combined sewers, and nearly 4000 ha of wetlands (bheries) are used for aquaculture (Jana 1998; Das 2002). Normally, multiple stocking and multiple harvesting are adopted, and fishes are reared for 3–5 months, depending on the growth of the fishes to reach marketable size. However, deterioration of water quality and adverse biological factors are frequently encountered in these wastewater-fed aquaculture ponds rendering them prone to occurrences of fish diseases. The fish health problems limit the fish yield ranging from 1500 to 2000 kg/ha in EKW systems. Therefore the major management constraint in such system is to maintain optimal water quality for reducing the stress-induced disease outbreak. The present chapter is an attempt to highlight the causes of different fish diseases encountered in wastewater-fed systems and their remedial measures for development.

7.2 Fish Habitat Characteristic and Culture Practices in Wastewater Farms

Habitat characteristics of sewage-fed waterbodies are important for the culture practices adopted by fish farmers. In general culture operations commence with the entry of initially screened raw sewage into the ponds. This effluent requires stabilization for a few days (5–7 days), and after 12 days the pond contents are disturbed by repeated netting and manual agitation with split bamboos for oxidation, mixing for quick recovery of desirable water quality for fish farming. After 25 days of initial filling with sewage when sufficient plankton population is observed, the bheries are stocked at 7000–10,000/ha with fingerlings (10–25 g) of catla (*Catla catla*), mrigal (*Cirrhinus mrigala*), rohu (*Labeo rohita*), common carp (*Cyprinus carpio*) and tilapia (*Oreochromis mossambicus*). Thereafter, sewage is applied 7 days/month for 3 h during morning hours to fertilize the ponds at an estimated rate of 130 m^3 sewage/ha/day. In low and medium saline bheries, *Liza parsia* and *Mugil gulio* are also cultured. In some bheries, where scientific method is followed, stocking density may go up to 15,000/ha. Intermediate harvesting is done after 120 days of rearing and continued up to pond draining after 300 days in March and April.

The water quality parameters in wastewater-fed waterbodies are subjected to diurnal and seasonal variations during the year. These variations often act as stressors of short or long duration and cause physiological and morphological deleterious changes in fish, predisposing them to disease outbreaks. In studies conducted year round in a typical wastewater-fed East Kolkata Wetland (EKW), the Kantatala bheri revealed clear-cut diurnal and annual variations of water quality (Dutta et al. 2005).The physico-chemical parameters recorded in this wastewater system (Table 7.1) showed that the variations of total alkalinity, hardness, dissolved oxygen, unionized ammonia and pH are in the range of 175–204 mg/l, 180–210 mg/l, 2.3–8.6 mg/l, 0.11–0.42 mg/l and 7.8–9.2, respectively. Diurnal study of these parameters exhibited high fluctuation in

Table 7.1 Physico-chemical characteristics of Kantatala bheri in East Kolkata Wetland (EKW)

Months	Parameters							
	Air temp. (°C)	Water temp. (°C)	Transparency (cm)	Total alkalinity (mg/l)	Hardness (mg/l)	DO (mg/l)	pH	Unionized Ammonia (mg/l)
Jan'01	20.0	18.0	15.0	204.0	210.0	8.6	8.0	0.27
Feb'01	21.0	19.0	13.0	190.0	196.0	7.3	8.4	0.29
Mar'01	30.0	28.0	14.0	195.0	200.0	7.0	8.7	0.39
Apr'01	32.0	30.0	14.0	190.0	194.0	5.1	8.8	0.42
May'01	35.0	32.0	15.0	192.0	201.0	3.7	9.0	0.35
Jun'01	36.0	33.0	12.0	186.0	192.0	5.1	8.1	0.12
Jul'01	32.0	30.0	12.0	190.0	210.0	8.3	8.3	0.11
Aug'01	32.0	30.0	11.0	178.0	188.0	2.3	7.8	0.18
Sep'01	31.0	29.0	13.0	175.0	180.0	3.4	8.3	0.25
Oct'01	30.0	28.0	10.0	190.0	198.0	5.7	8.6	0.26
Nov'01	25.0	22.0	14.0	185.0	196.0	4.6	9.2	0.30
Dec'01	20.0	19.0	11.0	182.0	194.0	8.0	8.7	0.28
Range	20.0–36.0	18.0–33.0	10.0–15.0	175.0–204.0	180.0–210.0	2.3–8.6	7.8–9.2	0.11–0.42
Mean	28.6	26.5	12.8	188.0	196.5	5.7	8.4	0.2
S.D	5.710	5.435	1.642	7.716	8.404	2.076	0.416	0.095
S.E	1.648	1.569	0.474	2.227	2.426	0.599	0.120	0.027
C.V%	19.919	20.511	12.796	4.102	4.275	36.067	4.906	35.774

Source: Dutta et al. (2005)

pH (6.7–8.5) during the post-monsoon period. The 18 h cycle exhibited a wide difference in dissolved oxygen (nil–18.0 mg/l), pH (6.7–9.0) and free CO_2 (nil–16.0 mg/l).

The average transparency of 13 cm recorded is lower than the optimum requirement of 15–40 cm for fertilizer-based aquaculture systems (Boyd 1982). High organic loadings of sewage resulting in massive algal bloom are responsible for low transparency throughout the culture period. Accumulation of carbon dioxide recorded after sunset is an important factor causing stress to fish. High concentration of carbon dioxide causes the lowest values of DO available to the fish particularly during the early morning when highest concentration of carbon dioxide is accumulated. High levels of unionized ammonia (0.11–0.42 mg/l) present in these culture ponds throughout the year are sufficient to cause gill damage and retard fish growth. Boyd (1982) suggested that free ammonia concentration of 0.52 mg/l would cause 50% reduction in fish growth.

The bacterial load at bottom soil ranged from 10^5/g to 10^7/g. This is due to higher concentration of nutrients of soil water interphase. The comparatively high bacterial load in the soil and water is an indication of eutrophic condition. The high microbial consumption of dissolved oxygen (1.8 mg/l/h) observed by Das et al. (2002) in sewage-fed bheries indicates exhaustion of DO for a few hours at night, creating stressful conditions for fish.

7.3 Fish Stress in Wastewater Aquaculture

Stressors in wastewater-fed fish ponds are manifested by the abiotic as well as biological stressors, and their interactions have pronounced detrimental impacts on fish.

7.3.1 General Impact on Stress-Sensitive Haematological Parameters of Fish Population

Extensive studies on the impact of various abiotic stressors of low dissolved oxygen and high unionized ammonia on the stress-sensitive physiological parameters of fish (*Labeo rohita*) reared in wastewater system (Table 7.2) conducted by Das et al. (1999) and Dutta et al. (2005) reveal that the fishes in sewage-fed bheries are exposed to long-term hypoxic condition due to low dissolved oxygen levels especially during the nightfall. As a result, the haemoglobin and haematocrit levels in fishes increase to cope with the stressful conditions. It is suggested that the reduction in fish growth in the wastewater systems was due to an increase in energy expenditure for ventilation that decreases the amount of energy available for growth (Soivio and Oikari 1976; Kramer 1987). The increase in the blood sugar level of

Table 7.2 The mean, standard error and CV% of physiological parameters of *Labeo rohita* fingerlings reared in Kantatala bheri (EKW)

Parameters	Jun'01	Aug'01	Oct'01	Dec'01	Mean	SD	SE	CV%
Haemoglobin (gm/dl)	8.0	6.2	8.9	6.2	7.3	1.169	0.584	15.84
	(6.9–9.5)	(4.2–8.0)	(6.0–10.0)	(5.5–6.9)				
Haematocrit (%)	35.0	45.0	40.0	33.0	38.2	4.656	2.328	12.17
	(30.0–40.0)	(38.0–52.0)	(33.8–46.5)	(26.0–40.0)				
Leucocrit (%)	1.1	1.4	0.9	0.7	1.0	0.256	0.128	24.85
	(0.9–1.3)	(1.3–1.4)	(0.7–1.4)	(0.6–1.0)				
Plasma cortisol (ng/ml)	109.0	205.0	280.0	201.0	198.7	60.623	30.311	30.50
	(90.0–220.0)	(120.0–290.0)	(250.0–377.0)	(170.0–230.0)				
Plasma glucose (mg/dl)	122.0	114.0	70.4	80.0	96.6	21.851	10.925	22.61
	(80.0–145.0)	(80.0–138.0)	(50.0–117.0)	(30.0–100.0)				
Plasma chloride (mEq/l)	101.0	107.0	113.0	85.0	101.5	10.428	5.214	10.27
	(90.0–106.0)	(100.0–120.0)	(93.6–117.0)	(72.0–95.0)				
Plasma cholesterol (mg/dl)	191.0	184.0	150.0	221.0	186.5	25.243	12.621	13.53
	(178.6–228.0)	(120.0–218.2)	(89.6–199.0)	(175.0–285.0)				
Plasma protein (gm/dl)	1.9	2.6	3.4	3.0	2.7	0.553	0.276	20.29
	(1.7–2.0)	(2.2–2.7)	(2.0–3.5)	(2.5–4.2)				
Plasma lactic acid (mg/dl)	92.0	64.0	85.0	125.0	91.5	21.914	10.957	23.94
	(80.0–120.0)	(50.0–100.0)	(75.0–126.0)	(100.0–130.0)				
Fish length (mm)	115.0	145.0	182.0	215.0	164.2	37.705	18.852	22.92
	(110.0–121.0)	(145.0–158.0)	(165.0–200.0)	(190.0–300.0)				
Fish weight (gm)	14.0	42.0	62.0	95.0	53.2	29.524	14.762	55.44
	(13.0–20.0)	(39.0–47.0)	(58.0–82.0)	(70.0–100.0)				
Condition factor	1.0	1.2	1.1	0.9	1.0	0.169	0.084	16.39
	(0.9–1.1)	(1.1–1.3)	(0.7–1.1)	(0.7–1.0)				

Source: Dutta et al. (2005)

L. rohita in such system could be the effect of decrease in oxygen percentage of water and increase in ammonia levels (Hattingh 1976). It is known that low oxygen might considerably increase the toxicity of ammonia to fish, probably by its effect on respiratory flow, and ammonia reduces the oxygen-carrying capacity of the blood which increases the overall oxygen consumption (Lloyd 1961; Sousa and Meade 1977; Smart 1978). In such systems fishes are frequently subjected to concentrations higher than the optimum limit. Elevated CO_2 levels reduce the oxygen affinity and oxygen-binding capacity of the blood (Basu 1959) resulting in a reduced efficiency of oxygen uptake from the environment, thereby inhibiting fish growth (Klontz 1973).

It is evident that in sewage-fed waterbodies, considerable scope exists for interactions between reduced dissolved oxygen, elevated CO_2 and ammonia on respiratory physiology of freshwater fish (Pickering and Pottinger 1987). High plasma cortisol level recorded in the fishes enhanced their disease susceptibility by decreasing lymphocytes (Pickering 1984). Correlation between unionized ammonia and fish length and weight indicates that presence of high ammonia level in sewage fertilized wetlands adversely impacted on the growth of *L. rohita*. Reduced condition factor (0.7–1.3) of the reared *L. rohita* indicated poor health condition of fishes in these wastewater fish culture systems.

7.3.2 Effect of Ammonia and Crowding Stress on Fish Skin in Wastewater Ponds

The fish skin is multifunctional and involved in excretion, osmoregulation, defence against disease and adjustment of fish to a wide variety of environmental factors. It is therefore vulnerable to damage caused by water quality changes and infection. It is observed that the fishes from wastewater-fed farms have excessive secretion of slimy mucus on the surface. Examination of the skin revealed a proliferation of mucous cells in the epidermis indicating a stress condition. Fishes in such culture systems are subjected to sublethal concentrations of ammonia more so under high stocking densities.

L. rohita fingerlings exposed to unionized ammonia level of 0.13 mg/l for 24 h and crowding for 4 h showed a gradual increase in the number and decrease in the area of the chromatophores, whereas the mucous glands gradually decreased in their number and increased in area during the experimental period (Figs. 7.1 and 7.2). It indicated that the morphological changes of mucous glands and chromatophores resulted in excessive mucous secretion in *Labeo rohita* in response to the stress. Further studies revealed the activation of the hypothalamic-pituitary-interrenal (HPI) axis with increase in the hormones prolactin and cortisol. Pickering et al. (1982) showed that handling, confinement and water quality deterioration could all stimulate the HPI axis in teleost fish.

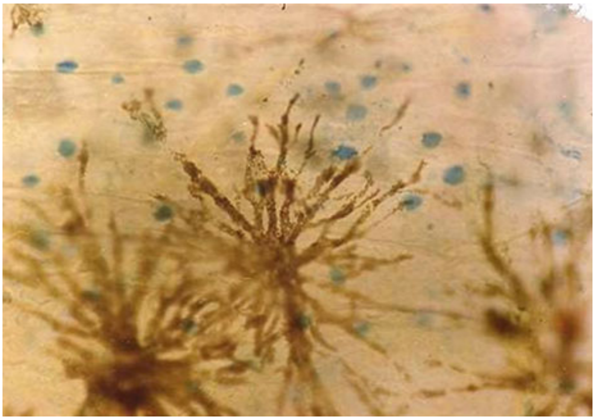


Fig. 7.1 A normal skin of *L. rohita* showing Alcian blue-stained mucous cells and dark branching chromatophore

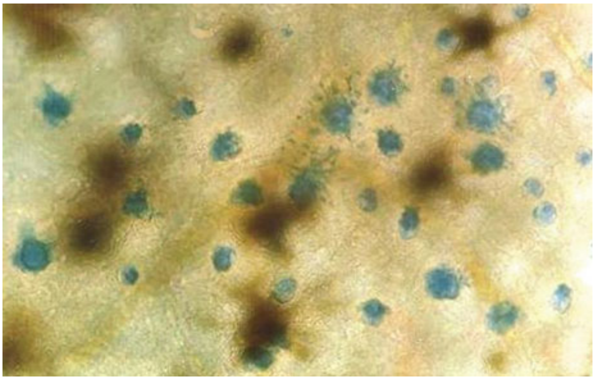


Fig. 7.2 Increase in area of mucous glands and decrease in area of chromatophores

7.3.3 Morphological Impact on the Gills of Fish

As the gills of fish serve as good indicator of water quality status of the habitat, alteration in the histological structure of the gills of cultured *L. rohita* serves as a good indicator for assessing health status of fishes in the wastewater-fed culture system. Investigations conducted by Das et al. (1994) and Acharya et al. (2005) on cultured *L. rohita* exposed to high ammonia and low oxygen levels in such systems showed varying degree of histological damage in the gills. Hyperplasia was more pronounced at the bases of secondary lamellae which led to formation of interlamellar bridges. Hyperplasia of the distal ends was also visible. Oedema was found at the bases of some secondary lamellae as respiratory epithelium of lamellae got detached from underlying tissue resulting in a space filled with fluid. Some swollen tips of secondary lamellae with leucocytic infiltration of matrix of primary lamellae were also observed. The presence of haematoma was found where pillar cell system was completely broken down and the epithelium enclosed a disorganized mass of cells and erythrocytes. Generally the epithelium remained intact but in some instance had ruptured and haemorrhage occurred (Figs. 7.3, 7.4 and 7.5).

Fig. 7.3 Hyperplasia at the bases of secondary lamellae with interlamellar bridges

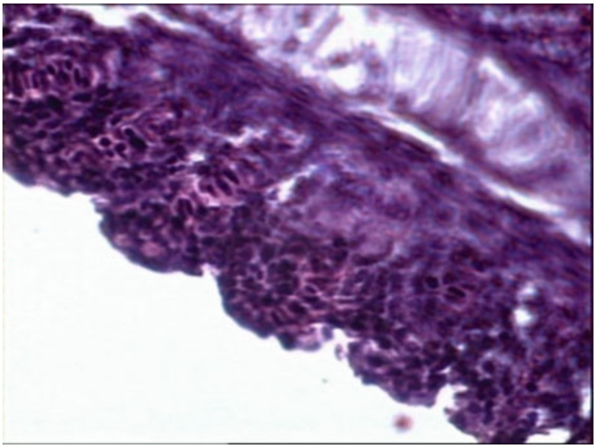


Fig. 7.4 Some swollen tips of secondary lamellae

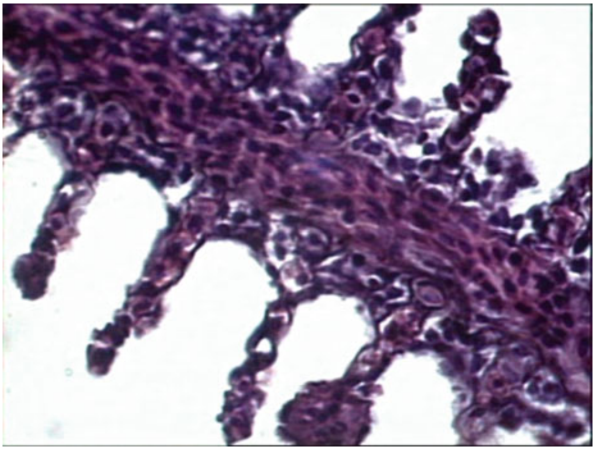


Fig. 7.5 Presence of haematoma in a fish raised in wastewater-fed system

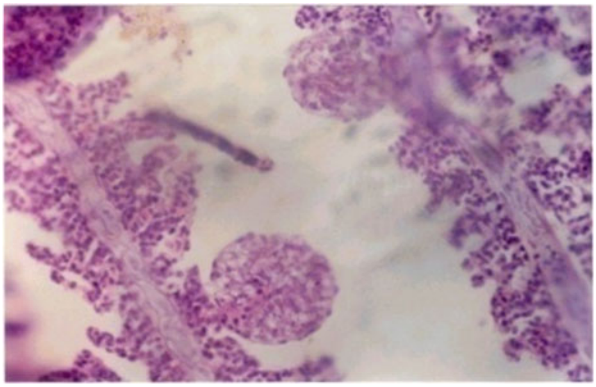


Table 7.3 Percentage-wise alterations in the histological structure of gill tissues of *L. rohita*

Characteristics	Waterbodies	
	Suguna beel (normal)	Kantatala bheri (sewage fed)
Hypertrophy	1%	5%
Epithelial lifting	–	2%
Hyperplasia	2	15%
Fusion of lamellae	–	6%
Mucous hyper-secretion	5%	25%
Haematomona	–	–
Formation of aneurysm	–	1%
Proliferation of chloride cells	–	4%
Formation of interlammelar bridges	–	5%
Leucocyte infiltration of gill epithelium	–	4%
Necrosis	–	–

A comparative assessment of fish cultured in a waterbody with optimal water quality condition and fish cultured in wastewater-fed wetlands revealed pronounced histological alteration in the gill structure of *L. rohita* in the latter. The suboptimal water quality prevailed in wastewater-fed wetlands affected higher percentage of cellular alterations such as hypertrophy, hyperplasia and fusion of lamellae in gills compared to the fish cultured under optimal conditions (Table 7.3).

7.3.4 Biological Stressors and Impact on Fish in Wastewater Fish Farms

Fishes cultured in wastewater ponds recorded high infestation of urceolariid ciliates of the genera *Trichodina* and *Tripartiella* in the gills of fish tested. The suboptimal water quality in such aquatic systems mainly due to high levels of ammonia accelerates the amount of mucous production from fish gills and causes changes in its consistency. As a result, greater amount of mucous substrate is available as feed for the ciliate parasites and consequently their number increase. Das et al. (1997) observed that the presence of trichodinids above 20 numbers in 1 drop (0.05 ml) of pooled fish gill mucus is indicative of suboptimal water quality and stress to fish.

7.3.5 Stress Due to Fish Cultural Practices and Impact on Fish in Wastewater Fish Farms

Fishes cultured in wastewater-fed aquaculture system are subjected to the stresses caused by handling, crowding and transportation. These effects often become additive or synergistic with those of other stimuli (low unionized ammonia and dissolved oxygen) already existing in the wastewater farms and can place a stress of considerable magnitude on the homeostatic mechanism of fishes (Wedemeyer et al. 1984). By conducting an experiment with crowding, handling and transportation stress on *L. rohita*, Dutta et al. (2002) observed gradual depletion of dissolved oxygen from initial 6.8 mg/l to 1.8 mg/l, UIA from nil to 0.1 mg/l and CO_2 from 2.0 to 6.6 mg/l resulting in hypoxia and ammonia toxicity during transportation. These stressors significantly altered the blood parameters creating stress to fish (Table 7.4). It is important that fish farm managers should understand the severity of stress due to cultural practices and the period needed for recovery in fish (Das 2011).

The plasma cortisol and plasma glucose levels increased significantly after 1 h of stress and continued to be so up to 24 h of recovery period. After 48 h, regulation of cortisol values occurred. On the other side, a significant decrease in plasma chloride was observed after 1 h of stress and continued up to 24 h of recovery period. Both glucose and chloride recovered its normal values within 48 h of recovery period. Thus the cultural practices of handling, crowding, transportation or a combination of all the three factors act as stress on the fish. It is suggested that for proper fish health management, fishes subjected to such stresses should not be further stressed within 48 h for metabolic recovery and then stocked into wastewater ponds (Das 2011).

7.4 Fish Diseases Encountered in Wastewater Fish Farms

Health problems arising due to stress in fishes cultured in sewage-fed wetlands are very common. Though mortality of fish may not always be encountered, physiological disorders would occur. This resulted in retarded growth and serves as a predisposing factor for various disease outbreaks. Investigations conducted in sewage-fed waterbodies recorded predominantly six types of disease (Das et al. 1994; Das 2011).The incidence of fish diseases in these waterbodies is higher in comparison to normal intensive fish-rearing farms using inorganic and other organic fertilizers and supplementary feeds. A comparison (Table 7.5) showed higher incidence of disease occurrence in the fishes reared in sewage-fed ponds than in fertilized composite fish culture ponds.

7.4.1 Infectious Diseases

7.4.1.1 Fin Rot and Tail Rot

Fin rot and tail rot diseases are very common in sewage-fed ponds. The tail and fin get necrosed and discoloured in affected fishes. This is mostly caused by mixed infections with *Aeromonas hydrophila* and *Pseudomonas fluorescens*. Improvement in water quality and reduction in stocking density are essential for long-term management of the disease.

Table 7.4 Physiological alteration in *L. rohita* subjected to handling, crowding and transportation stress and recovery

	Stress		Recovery			
	Control/hr	1 h	1 h	3 h	24 h	48 h
Parameters	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Haemoglobin (gm/dl)	6.9 ± 0.117	7.5 ± 0.165*	7.6 ± 0.221*	7.2 ± 0.104	7.1 ± 0.081	7.0 ± 0.064
Haematocrit (%)	34.2 ± 0.634	38.6 ± 0.998*	36.5 ± 0.06*	36.0 ± 0.9233	35.9 ± 0.635	33.5 ± 1.16
Leucocrit (%)	1.3 ± 0.063	1.14 ± 0.084	1.02 ± 0.089	1.03 ± 0.1022	0.95 ± 0.028*	1.04 ± 0.093
Plasma cortisol (ng/ml)	90 ± 3.17	180 ± 9.08**	185 ± 12.19**	170 ± 11.07**	140 ± 1.22**	90 ± 4.48
Plasma glucose (mg/dl)	95.18 ± 4.48	269.5 ± 4.75*	273 ± 3.38**	230.9 ± 7.090	150.2 ± 6.34**	100.9 ± 2.95
Plasma chloride (mg/dl)	117.6 ± 1.022	102 ± 0.634**	100 ± 1.022**	102.1 ± 1.418**	108 ± 1.112**	116 ± 1.268
Plasma protein (gm/dl)	2.3 ± 0.2156	2.7 ± 0.063	2.8 ± 0.141	1.8 ± 0.181	2.2 ± 0.152	2.0 ± 0.141
Plasma cholesterol (gm/dl)	274 ± 3.054	2.97 ± 4.634	321.5 ± 8.04**	290 ± 4.158	287.4 ± 2.172	285.2 ± 3.170
Plasma lactic acid (gm/dl)	102.4 ± 2.338	122.7 ± 2.159	108.2 ± 2.675	105.3 ± 1.445	103.8 ± 2.675	99.1 ± 1.902
Glycogen (mg/gm)						
Liver	8.0 ± 0.288	7.0 ± 0.317	7.2 ± 0.179	7.1 ± 0.147*	6.0 ± 0.152**	5.5 ± 0.158**
Muscle	4.2 ±0.442	3.2 ± 0.213	3.0 ± 0.487*	2.5 ± 0.165	3.2 ± 0.1022	4.3 ± 0.2156

*$P < 0.05$, ** $P < 0.01$ (*Source*: Dutta et al. 2002)

Table 7.5 Comparative prevalence of major fish disease in normal composite fish culture and sewage-fed fish culture facilities in North 24 Parganas, West Bengal

Disease	Host	% incidence	
		Normal composite fish culture ponds	Sewage-fed bheries
Gilldisease/gill rot	*Labeo rohita*,*Cirrhinus mrigala*	14.6	16
Dropsy/gas bubble disease	*Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*	7.2	15
Tail and fin rot	*Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*	4.6	15
Trichodiniasis	*Cirrhinus mrigala*, *Labeo rohita*	6	30
White gill spot disease	*Catla catla*, *Cirrhinus mrigala*	3	6
White scale spot disease	*Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*	4	10

Source: Das et al. 1994; Das 2002 and Paria and Konar (1999)

7.4.1.2 Dropsy

Dropsy is frequently encountered in late winter. Clinically, there is abnormal reddish fluid accumulation in the abdomen and in scale pockets leading to enlargement of the abdomen, ruffled loose scales, lethargy, pinpoint haemorrhages on the skin, etc. There may be terminal septicaemia. It is caused by virulent *Aeromonas hydrophila* and few other motile *Aeromonas* species. Remedial measures that reduce the morbidity are bath treatment to fish in 5 mg/l potassium permanganate for 2 min and application of 1–3 mg/l $KMnO_4$ in pond water.

7.4.1.3 Bacterial Gill Disease

Gills of Indian major carp cultured in wastewater ponds are affected by a number of bacteria, but *Flavobacterium branchiophila* is the most important one. Gills of affected fishes become discoloured, and gill fringes become uneven or torn, with grey patches of necrosis (Fig. 7.6). Morbidity and mortality go up to 100% and 50%, respectively. To control the disease problem, avoid overstocking and give aeration. Careful bath treatment with 1–2 mg/l $KMnO_4$ can control the disease.

7.4.1.4 Saprolegniasis

Saprolegniais is caused by various *Saprolegnia* species and is one of the major health problems in young carps cultured in wastewater. This disease in fish is characterized by a white to brown cotton-like growth consisting of colonies of

Fig. 7.6 Bacterial gill disease in *L. rohita* raised in wastewater-fed system

mycelium and filaments which appear as small to large patches on various parts of the body like fins, gills, mouth, eyes or muscle which can be treated by bath treatment with 3–4% common salt or 1:2000 $CuSO_4$ daily for 3–4 days or 1:1000 malachite green for 30 s.

7.4.1.5 Trichodiniasis

Various life stages of Indian major carp are frequently affected by this disease. Affected fishes exhibit pale-coloured gills with a creamish coating due to excessive mucous secretion and mild hyperplasia. Fishes loose condition and gasp for air on surface. The causative agents are urceolariid ciliate species of the genera *Trichodina* (Fig. 7.7), *Tripartiella* and *Trichodinella*. The treatment methods adopted are (1) water quality improvement, (2) diminishing stocking density of fish and (3) bath treatment of fishes with 2–3% NaCl or 100 mg/l formalin (4) pond treatment with 4–5 mg/l $KMnO_4$ or 25 mg/l formalin.

7.4.1.6 Myxosporean Disease

Myxosporean disease is most commom in wastewater aquaculture. Indian major carp gills are infested with white to creamish cysts ranging from 1 to 4 mm or more (Fig. 7.8). In heavy infection, the cysts assume a cauliflower shape blocking the entire respiratory surface of gill with excessive mucous secretion and hyperplasia. The causative agents are the encysted spores of *Myxobolus bengalensis*, *M. catlae*, *M. hosadurgensis* and *Thelohanellus catlae*. Besides the gills, scales and body surfaces are also heavily infected with the cysts in *C. mrigala* and *L. rohita*. The infective stage of the myxosporeans is the mature spore which is ingested by the fish from the waterbody. The spore though exposed outside is very resistant to chemicals. Thus the control measures are limited to prophylactic measures like

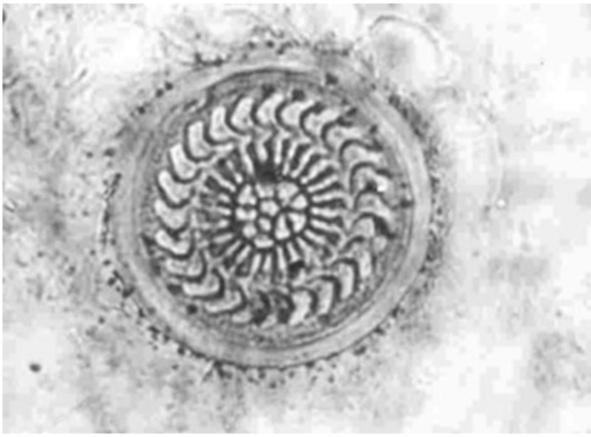


Fig. 7.7 Gill-infesting *Trichodina* sp. in a fish raised in wastewater-fed system

Fig. 7.8 Myxosporean gill spot disease in a fish raised in wastewater-fed system

(1) control spores from entering fish ponds and (2) segregation of age groups as fry and juveniles are more susceptible. Therapeutic measures done are disinfections of pond after dewatering with calcium oxide and drying for a month.

7.4.1.7 Dactylogyrosis and Gyrodactylosis

Fingerlings and adults of the cultured fishes are affected by trichodinids in general, and there are growth reduction and morbidity in affected fishes. The parasites can be controlled by therapeutics: (1) bath treatment with 3–5% NaCl for 10–15 min or 100 mg/l formalin with aeration and (2) pond treatment with 25 mg/l formalin or 5 mg/l $KMnO_4$.

7.4.1.8 Argulosis

The disease is quite common in wastewater ponds. Indian major carps are often affected by this parasite. The causative agent is the branchiuran parasites (Fig. 7.9) *Argulosus foliaceus*, *A. bengalensis* and *A. siamensis* in Indian fishes. The minimum period required for completion of the life cycle of *Argulus* sp. varies between 3 and 6 weeks. Argulosis occurs when parasitized fishes enter unaffected water areas. It is controlled by (1) bath treatment with 3–5% NaCl or 100 mg/l KMnO4 or 2000 mg/l lysol for 5–10 s, (2) pond treatment with $KMnO_4$ at 5 mg/l and (3) mechanical removal of *Argulus* sp. sticky eggs by hanging bamboo mats or corrugated sheet in the water area and its removal and drying in the sun after a week for killing the eggs. Pesticides are generally used by farmers, but it is often not advisable.

7.4.1.9 Ergasilosis

The predominance of the disease is witnessed in *L. parsia* cultured in low-saline sewage-fed bheries and less frequently in Indian major carps. Infestation occurs in gills, buccal cavity, operculum and gills. The parasitic copepods look like white bodies less than 2 mm long. Surfacing, lethargy and restlessness occur in affected fish. Infection increases with size of the fish causing damage to the gill tissue and retardation in growth. The causative agent is the species of genus *Ergasilus*. The parasites are controlled by pond treatment with potassium permanganate at 5 mg/l or bath treatment of affected fish with 2–3% sodium chloride. Bath treatment with 1:1000 glacial acetic acid for 5 min immediately followed by dip in 1% NaCl for 1 h is also effective.

Fig. 7.9 *Argulus* sp. in a fish raised in wastewater-fed system

7.4.2 Noninfectious Diseases

7.4.2.1 Hypoxia or Oxygen Deficiency

Sewage input, algal bloom, excess presence of organic matter, high stocking density, etc. often lead to serious oxygen depletion and surfacing, gasping and mortality of fish stock in wastewater bheries. The remedial measures are aeration of water by beating water surface, use of aerator or throwing water into waterbody from heights.

7.4.2.2 Gas Bubble Disease

The gas bubble disease is very common in wastewater bheries caused by excess nitrogen and oxygen. Small fry and fingerlings of *C. mrigala* and *L. rohita* are frequently affected by the disease. The abdomen is swollen. The balance of the fish is lost due to accumulation of large gas bubbles in the intestine. It indicates that the environmental factors act as a predisposing factor for disease outbreak.

7.4.2.3 Algal Toxicosis

There is clogging of the gills by the algae causing respiratory distress and mortality to fish in sewage-fed ponds. The causative agent is the bloom condition of blue-green algae, *Microcystis* and *Anabaena* spp. It is often encountered under eutrophic conditions. The dead and decomposing cells release enough breakdown products or toxins harmful for fish. The bloom condition can be controlled by (1) copper sulphate application at 0.5 mg/l and (2) sprinkling cow dung at 200 kg/ha over the surface of water or covering it with water hyacinth, thereby blocking sunlight.

7.5 Rapid Method for Evaluation of Fish Health in Sewage-Fed Fish Farms

The effect of stress and disease on the general health of fish population is evaluated by a variety of approaches. Each type has its own advantages and disadvantages, but most of them cannot be rapidly and inexpensively applied to field studies. The HAI (health assessment index) developed by Adams et al. (1993) allows a statistical comparison of fish population health. The method was applied by Das (2005) to

Table 7.6 Health assessment index (HAI) values for *L. rohita* from three waterbodies along with their water quality parameters

Environmental quality	Static freshwater pond (S1)	Freshwater wetland (S2)	Freshwater sewage-fed pond (S3)
Transparency(cm)	28	59	14.0
Alkalinity mg/l	200	170	194
Hardness mg/l	187	160	182
Dissolved oxygen mg/l	6.0	6.5	4.2
pH	8.2	8.0	8.2
Unionized ammonia mg/l	0.03	Nil	0.2
HAI	17.3	29.3	51
SD	20.8	25.3	31.4
CV	120.0	86.4	61.6

Source: Das (2005); the average HAI values for the sewage-fed bheri (S3) were high (51) indicating that the health of *L. rohita* population was in a relatively poor condition compared to S1 and S2

comparatively assess the health condition of fish population (*Labeo rohita*) in a wastewater bheri and found that conditions are suboptimal (Table 7.6).

7.6 Emerging and Persistent Issues Related to Fish Health Management in India

7.6.1 Environmental Aspects

Environmental deterioration as a result of pollution and other anthropogenic activities has been one of the major causes of fish kills, public health problems, limitations on aquaculture development and declining production. These problems and inevitable and future conflicts and competition for aquatic resources should be solved as a matter of urgency.

7.6.2 Public Health and Aquaculture Products

Public health issues very often get associated with aquaculture production especially in wastewater aquaculture and the treatment of disease in fish. The problems arise from contamination of products as a result of pollution or risks to consumers, farm workers and the environment posed by some of the chemicals present in wastewater or the chemotherapeutants used to control disease in fish farms.

7.6.3 Use of Drugs, Chemicals and Antibiotics

Use of antibiotics in aquatic environments poses serious threats to the consumer and to the sustainability of the aquaculture system. In natural environment bacteria rapidly develop resistance to the antibiotics. Many of the human pathogenic bacteria like *Aeromonas*, *E. coli*, *Samnonella*, *Vibrio* and *Listeria* are often present in aquatic environments, and these pathogens may develop resistance to antibiotics very fast. Development of resistant strains implies that newer and newer antibiotics need to be developed to control resistant bacteria, which is an expensive and never-ending process.

7.6.4 Impact of New Fish Culture Methods on Fish Health

The native aquatic habitat like river harbours many parasites of fishes in apparently harmless condition. These parasites very often convert into causative agent of serious epizootics to the same host when cultured in closed waterbodies. *L. parsia* extensively cultured in sewage-fed bheries (wetland) are attacked by the disease ergasilosis in epizootic proportion causing growth retardation and mortality. It is therefore essential that each new species of fish proposed for cultivation in a new culture system ought to be studied from the epizootical point of view and estimation of parasites infecting it in the natural waterbodies be done.

7.6.5 Introduction of Exotic Fishes

Introduction of exotic carps has enhanced fish production significantly, but serious attention needs to be given to the possibility of introduction of new pathogens. Introduction of various exotic fishes in wastewater-fed culture ponds needs to be taken care for avoiding unintended introduction of pathogens.

7.6.6 Development of Disease Surveillance Mechanism

Surveillance is an integral component of aquatic health management for early warning of risk factors and disease onset, emergency disease preparedness including health advice to farmers, monitoring of disease control measures, health certification for freedom from infection and reporting to national and international organizations on fish/animal health. Efforts have been taken to strengthen the aquatic animal disease surveillance mechanism through general and targeted surveillance in wastewater-fed system.

7.6.7 Quarantine and Certification of Fish

Quarantine and certification of fish stocks as a means of preventing the spread of pathogens are becoming important. The existing legislation and quarantine system are very weak and do not act as a deterrent against introduction of serious pathogens especially in wastewater-fed system. Legislation must be realistic and should be based on adequate diagnostic facilities in the country.

7.7 Conclusions

Wastewater use for agriculture and aquaculture is practised in many countries. The major limitations to its reuse in aquaculture are (1) accumulation of silt and high organic matter in pond bottom, (2) incidence of pathogen and fish diseases, (3) possibilities of pathogens being transmitted to human beings and (4) accumulation of heavy metals in the ecosystem. There is an urgent need for concerned government agencies to restrict unplanned wastewater reuse in aquaculture by putting in place adequate health safeguards and environmentally sound aquaculture practices. Wastewater-fed aquaculture in a scenario of imminent water crisis should be part of an integrated water resource management plan of the government.

References

Acharya S, Dutta T, Das MK (2005) Physiological and ultrastructural changes in *Labeo rohita* (Hamilton-Buchanan) fingerlings exposed to sublethal acidic and alkaline pH for long duration. Asian Fish Sci 18:297–307

Adams SM, Brown AM, Goede RW (1993) A quantitative health assessment index for rapid evaluation of fish condition in the field. Trans Am Fish Soc 122:63–73

Basu SP (1959) Active respiration of fish in relation to ambient concentration of oxygen and carbon dioxide. J Fish Res Bd Can 16:175–212

Bhowmick ML, Jena JK, Ayyappan S (2011) Wastewater aquaculture. In: Shashi VA, Kumar Aruna T, Obaidur R, Sudhir P (eds) Handbook of fsheries and aquaculture, 3rd edn. Director of Information & Publication of Agriculture, I CAR, New Delhi, pp 449–468

Boyd CE (1982) Water quality management for pond fish culture. Elsevier Scientific Publishing Company, Amsterdam

Das MK (2002) Social and economic impacts of disease in inland open water cultured based fisheries in India. In: Arthur JR, Philips MJ, Subasinghe RP, Reantaso MB, Rae IHM (eds) Primary aquatic animal health care in rural, small scale, aquaculture development, vol 406. FAO Fisheries Technical Paper, Rome, pp 333–344

Das MK (2005) Application of the health assessment index (HAI) for rapid evaluation of fish health. J Inland Fish Soc India 37(2):87–92

Das MK (2011) Fish and shrimp health management. In: Shashi VA, Kumar Aruna T, Obaidur R, Sudhir P (eds) Handbook of fisheries and aquaculture, 3rd edn. Director of Information and Publication of Agriculture, ICAR, New Delhi, pp 763–793

Das MK, Das RK, Ghosh SP, Bhowmick S (1994) Fish disease its relation with environmental factors in sewage fed wetland. J Inland Fish Soc India 26(1):100–105

Das MK, Das RK, Ghosh SP et al (1997) Urceolariid ciliates of fish as indicators of water quality. In: Vass KK, Sinha M (eds) Proceedings national seminar changing perspectives in inland fisheries. Inland Fisheries Society of India, Barrackpore

Das MK, Manna S, Bhowmick S, Ghosh SP (1999) Changes in the haematological profile of fish in response to some abiotic and biotic stressors. In: Sinha M, Kumar D, Katiha PK (eds) Eco-friendly management of resources for doubling fish production- strategies for 21st century. Proceedings of national seminar, December 1999, Inland Fisheries Society of India, pp 63–67

Das MK, Das RK, Mondal SK (2002) Measurements of some stress sensitive parameters of young major carp *Labeorohita* (Hamilton-Buchanan). Indian J Fish 49(1):73–78

Dutta T, Acharya S, Das MK (2002) Some changes in juvenile *L. rohita* (Ham.-Buch.) subjected to handling, crowding and transportation stress. In: Proceedings of national seminar on recent advances in molecular physiology. University of Kalyani, Kalyani, West Bengal, 4–6 February 2002

Dutta T, Acharya S, Das MK (2005) Impact of water quality on the stress physiology of cultured *L. rohita* (Ham.-Buch). J Environ Biol 26(3):585–592

Hattingh J (1976) Blood sugar as an indicator of stress in the freshwater fish *Labeo capensis* (smith). J Fish Biol 10:191–197

Jana BB (1998) Sewage-fed aquaculture: the Calcutta model. Ecol Eng 11:73–85

Klontz GW (1973) Syllabus of fish health management: fish culture methods. Texas A & M University/Sea Grant Program, Texas

Kramer DL (1987) Dissolved oxygen and fish behaviour. Environ Biol Fish 18:81–92

Lloyd R (1961) Effect of dissolved oxgen concentrations on the toxicity of several poisons to rainbow trout (*Salmo gairdneri*). J Exp Biol 38:447–455

Paria T, Konar SK (1999) Management of fish ponds and its relation to fish diseases in West Bengal, India. Environ Ecol 17:962–970

Pickering AD (1984) Cortisol induced lymphocytopenia in brown trout, *Salmo trutta* L. gen. Comp Endocrinol 53:252–259

Pickering AD, Pottinger TG (1987) Poor under quality suppresses the cortisol response of salmonid fish to handling and confinement. J Fish Biol 30:363–374

Pickering AD, Pottinger TG, Christie P (1982) Recovery of brown trout, *Salmo trutta* L., from acute handling stress: a time course study. J Fish Biol 20:229–244

Smart GR (1978) Investigations of the toxic mechanisms of ammonia to fish gas exchange in rainbow host (*Salmo gairdneri*) exposed to acutely lethal concentrations. J Fish Biol 12:93–104

Soivio A, Oikari A (1976) Haematological effects of stress on ateleosts, *Esoxlucius* L. J Fish Biol 8:397–411

Sousa RJ, Meade TL (1977) The influence of ammonia on the oxygen delivery system of coho salmon haemoglobin. Comp Biochem Physiol A Comp Physiol 58:23–58

Wedemeyer G, Mcleay DJ, Goodyear CP (1984) Assessing the tolerance of fish and fish populations to environmental stress: the problems and methods of monitoring. In: Cairns VW, Hudson PV, Nriagu JO (eds) Contaminant effect on fisheries. Wiley, Toronto, pp 163–195

WHO (2006) Guidelines for the safe use of wastewater, excreta and greywater, vol 2: wastewater use in agriculture. World Health Organization, Geneva

Part III
Strategies Toward Wastewater Reclamation Using Green and Sustainable Technologies

Chapter 8
Ecosystem Resilient Driven Remediation for Safe and Sustainable Reuse of Municipal Wastewater

B. B. Jana, Johannes Heeb, and Shamik Das

Abstract Municipal wastewater poses a win-win strategy toward environmental protection as well as for water conservation through its reuse in various economic-driven activities. Wastewater reuse reduces the demand for conventional freshwater resources and provide enormous nutrients for biological production. Sewage sludge is also well recognized for its special role in soil conservation and enhances soil fertility and helps soil loss through erosion. Safe reuse of wastewater has thus become inevitable. Sewage effluent and sludge must be treated and managed properly to avoid any adverse impacts on the environment and human health. Though conventional sewage treatment plants and recently developed bioreactors are used to treat municipal sewage for improvement of water quality for reuse, the waste stabilization pond (WSP) system has gained considerable importance as an integral tool for treating wastewater as well as for closing the loop between sanitation-driven nutrient source and culture of fish and vegetable crops in aquaponics. The concept of engineered resilient ecosystem is being applied to reclaim the partially treated municipal wastewater for ecosystem service. Macrophytes, microalgae, probiotics, annelids, mollusks, crustaceans, fishes, etc. have been rightly designated as living machines due to their immense beneficial biofilter potentials for reclamation of eutrophicated water bodies, heavy metal-contaminated perturbed aquatic systems, etc. Wise use of ecological principle, traditional knowledge, right selection of biodiversity, design of sustainable ecosystem, appropriate

B. B. Jana (✉)
International Centre for Ecological Engineering, University of Kalyani, Kalyani, West Bengal, India

Centre for Environmental Protection & Human Resource Development (Kalyani Shine India), Kalyani, West Bengal, India
e-mail: bbjana@gmail.com

J. Heeb (✉)
Seecon International GmbH and Cewas, Willsau, Switzerland
e-mail: johannes.heeb@seecon.com

S. Das
Directorate of Fisheries, Government of West Bengal, Meen Bhavan, Kolkata, West Bengal, India

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_8

eco-technology, and patience for development are required where all aspects of technological, economical, legal, social, environmental, public health, and institutional are considered. A successful wastewater management decision requires a comprehensive, impartial evaluation of centralized and decentralized treatment systems.

Keywords Ecosystem resilient · Remediation · Wastewater · Safe reuse · Sustainable

Contents

8.1 Introduction

Water is the matrix of life. There has been increasing demand of water due to rapid population growth, urbanization, rising standards of living, increasing economic activities, and expanding areas of irrigated agriculture and aquaculture activities. Because of the threat of environmental pollution imposed on natural ecosystem and human health, a conscience has been developed worldwide for protection of environment, conservation of water and aquatic resources, mitigation of global warming and climate change, rehabilitation of degraded habitats, and restoration of biodiversity from extinction. Safe reuse of wastewater has, therefore, become inevitable to meet the increasing demand of wastewater in the future.

Municipal wastewater poses a win-win strategy toward environmental protection as well as for conservation of water through its reuse in various activities. Due to its immense nutrient potentials that would otherwise cause eutrophication of open water and loss of biodiversity, it is an immense nutrient resource for biological production. Eutrophication syndrome resulting from excess nitrogen and phosphorus favors the selection of cyanobacterial bloom and other specialized organisms known as bioindicator which are well acclimatized and adaptive to perturbed habitats. Hence, management plays a critical role in utilizing the nutrient resources of household wastewater. In the planning and implementation process, the intended wastewater reuse applications often determine the extent of wastewater treatment required or vice versa. It is obvious that despite its enormous benefits, some precautions and remedial measures must be taken to avoid health risks of the users, groundwater pollution, and contamination of surface waters. Some studies (Abdel-Shafy et al. 2008) have cautioned that groundwater system used for drinking purposes should be protected from sewage contact. Also, there should be clear-cut distinction between potable and non-potable groundwater. Important distinction has also to be made between indirect (surface spreading) and direct (injection wells) recharge. In the context of regional planning for efficient management of water and wastewater, it is most important to consider the specific local condition of which cost-benefit analysis comprises an important component (Otterpohl 2008).

In general, water reuse projects are often underestimated because the reuse benefits have been not properly focused with respect to watershed protection, local economic development and public health improvement, etc. Information about the strategies for ecosystem resilient-based reclamation of municipal wastewater is extremely scarce particularly under Indian scenario. The present chapter attempts to highlight the reclamation of wastewater using the engineered sustainable ecosystem for reuse of wastewater in aquaculture and other allied economic activities and providing ecosystem service to the society.

8.2 Potentials of Wastewater

Potentials of municipal wastewater can be assessed in terms of its volume generated as well as nutrient load. India with its more than 130 million population is experiencing high risk of water pollution mostly due to discharge of untreated municipal wastewater directly into the inland waters, rivers, and lakes causing disastrous effects on ecosystem health and human being. In India, 38000 million litre of sewage is generated per day and out which nearly 31% of sewage is treated and the rest is released to the environment without treatment. Earlier studies have shown that Calcutta city with its urban areas having more than 11 million inhabitants discharges an average of 1100 million of municipal sewage every day through more than 14000 km of drains and canals (Jana 1998). The population has now reached over 14 million and would have more disastrous effects on water bodies.

8.3 Characteristics and Nutrient Potentials of Municipal Wastewater

Sewage is defined as a cloudy fluid containing mineral and organic matter either in solution or particles of solid materials floating or in suspension or in colloidal or in pseudocolloidal form in a dispersed state. Among its organic and inorganic constituents, sewage contains living matter, bacteria, and protozoa. Water content is more than 99.9%; the rest is dried solid matter and may be different kinds of minerals, pesticides, insecticides, and other toxic substances.

Though the composition varies from place to place, municipal wastewater in general contains 250–400 mg/l organic carbon, 80–120 mg/l nitrogen (C/N = 3:1), 300–1200 mg/l solid particle, 100–400 mg/l BOD, 20–96 mg/l CO_2, and pH ranging from 6.9 to 7.3. It is suitable for direct use in fish farming after proper treatment and suitable dilution. In most countries, the waste disposal practice is based on the philosophy that the *solution to pollution is dilution*. As a rule, organic and bacterial loads are substantially reduced in the sewage treatment systems for effective use of sewage. Often sewage and sullage are used synonymously, but sullage is the wastewater resulting from personal washing, laundry, food preparation, and washing of kitchen utensil but excluding human body wastes. Industrial sewage comes from industries and contains unhygienic water; obnoxious gases like H_2S, NH_3, and iron; and other minerals. Therefore, it is higher C/N ratio than ratio of domestic sewage and hence is generally not suitable for direct use in fish farming.

8.4 Potentials of Sewage Sludge

The nutrient potentials of sewage sludge are equally prudent. Experiences in China revealed that 1 ton of pond humus is equivalent to 6 kg of ammonium sulfate. Intensively cultured pond produces about 52.5 tons of humus and silt/ha/year which is equivalent to 225 kg of urea. Moreover, sewage sludge is extensively used in soil conservation and soil fertility enhancement.

8.5 Wastewater Recycling

Water is a renewable resource within the hydrological cycle that involves the pathway between evaporation and precipitation. In view of the present and future crisis of water predicted, both groundwater and surface water resources should be protected from pollution, and at the same time wastewater generated should be reused for water conservation. The water recycled by natural systems provides a clean and safe resource for use, but once used, it is deteriorated in quality creating environmental pollution depending on the type and extent of use. Hence,

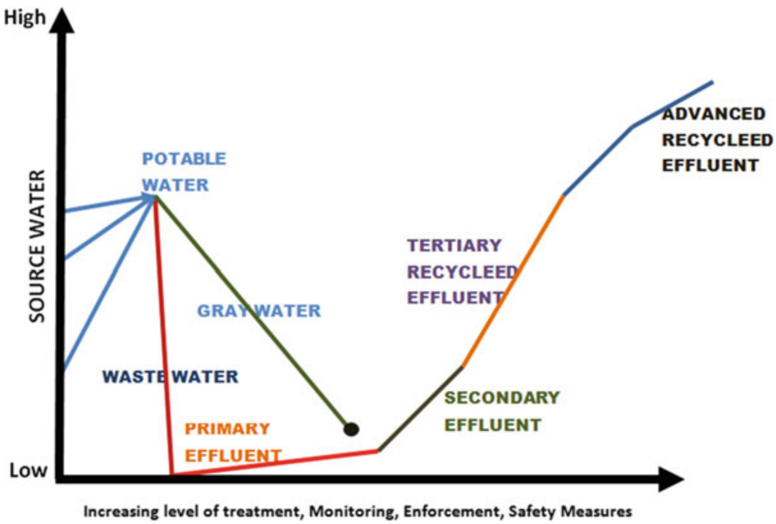


Fig. 8.1 Grading of wastewater in different stages of treatment

wastewater reuse plays an important role in water management as the domestic wastewater streams are available throughout the year. The reclaimed wastewater can be reused for the benefit of our society. There are also changes in micronutrients in water and wastewater as it undergoes use, reuse, treatment, and further treatment processes (Fig. 8.1). Effective management would enable to reduce the pollution load of water, thereby making it useful resource for use.

8.6 Rationale for Wastewater Reuse

It is right to conceive that wastewater is a resource out of place in the form of storehouse of fertilizers. The rationale for reuse of domestic wastewater in biological production has been on the fact that municipal wastewater contains immense nutrients such as nitrogen, phosphorus, potassium, carbon, and other elements. This is the foundation for realizing the concept of wastes into wealth. At a conservative and earlier estimate, 800 mg d of sewage can yield an annual outturn of 60,000 tons of NPK fertilizers. It is estimated that about 800×10^6 gallon day^{-1} of sewage and sullage can yield an annual outturn of 60,000 t of NPK and irrigation water equivalent to the performance of 1600 tube wells each having one cusec capacity (Roy et al. 2000). It is further projected that 90 t of nitrogen, 32 t of phosphorus, 55 t of potassium and 1340 t of organic matter valued at Rs. 61 million that could be recovered from country's domestic sewage daily (Ayyappan 2000). According to an earlier estimate, Calcutta sewage effluent with proper treatment could produce 5 tons of nitrogen, 1.5 tons of phosphorus, and 3 tons of potassium per day worth of

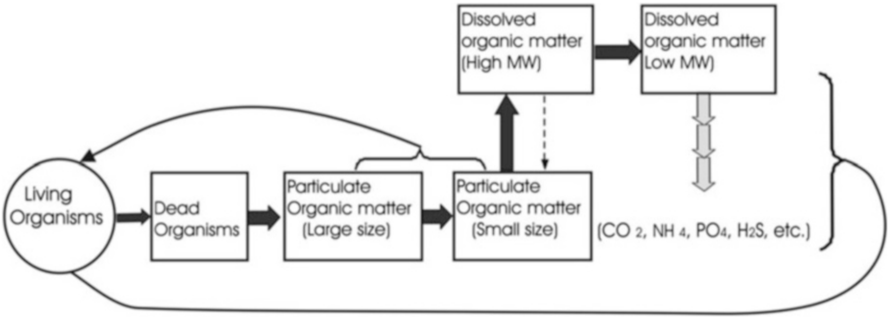


Fig. 8.2 Decomposition and mineralization process in pond environment

5 million rupees. This amount is still higher at present in view of increased population and wastewater treatment scenario. This huge sum of money could be recovered daily only from India's domestic sewage. Hence, it is a right approach to make use of sewage as an ideal source of liquid fertilizer for aquaculture and agriculture practices.

Basically, sewage containing dissolved organics undergoes decomposition process participated by microorganisms which participate in two ways: (a) hydrolytic breakdown of the organic high polymers which constitute the major parts of plants and animal tissues into compounds of low molecular weight and (b) nonhydrolytic breakdown of the resulting small organic molecules, generally accompanied by the consumption of oxygen. Through this mineralization process, organic molecules are converted into inorganic compounds (Fig. 8.2). In this process, excreta, night soil, or organic-rich wastewater is decomposed and mineralized into inorganic minerals and induces the production of natural food for fishes.

8.7 Technologies for Municipal Wastewater Treatment

8.7.1 Sewage Treatment Plants (STPs)

Conventional sewage treatment plants consisting of primary, secondary, and tertiary treatments are the common method for the treatment of municipal sewage. The basic function of primary treatment is mainly to remove solid materials, whereas the secondary treatment is meant for digestion of dissolved and suspended organic matter as well as for killing some pathogenic bacteria to some extent. The tertiary treatment processes are mainly for polishing methods used following sewage treatment sequence using microfiltration, synthetic membranes. However, lack of adequate infrastructure to treat municipal wastewater resulted in deterioration of existing water resources as well as pollution in inland waters, even in seas and oceans in many regions of the world.

8.7.2 Bioreactors

Several bioreactor-based techniques have recently been developed for enhancing the efficiency of treatment plants used to treat municipal wastewater. There has been a paradigm shift toward the implementation of latest technologies in the form of fluidized aerobic bioreactor (FAB) or moving bed bioreactor (MBBR), membrane bioreactor (MBR), SAFF-based treatment plants for sewage water, etc. Though these latest technologies are highly effective, these are highly expensive and are not affordable for the developing countries where maximum quantum of wastewater is generated due to increasingly high anthropogenic pressure and pollution.

8.7.3 Ecological Resilient Driven Reclamation

8.7.3.1 Waste Stabilization Ponds (WSPs)

Among different methods of wastewater treatment, waste stabilization pond (WSP) system has emerged as reliable, cost-effective alternative means to treat either raw domestic sewage or partially treated sewage. The performance of solar-driven, energy-saving, eco-friendly waste stabilization pond systems consisting of anaerobic, facultative, and maturation ponds are well recognized for the treatment of municipal sewage. It utilizes the principles of multidimensional ecological processes that create a benign environment required for farming of fish or other aquatic animals. Hence, they are equally effective in turning the so-called wastes present in the form of fertilizer storehouse into a useful resource conducive to biological production. In this process, the nutrients inherent in the domestic wastewater and animal wastes are recycled into economic resource of fish biomass mediated through food chain and food web. The philosophy of solution to pollution is dilution is used for turning the source of pollution into a resource. This is almost analogous to the second law of thermodynamics at the energy level, where highly concentrated state is toxic and transformed into more and more diluted form creating the benign environment for biological production (Jana 2011; Lahiri et al. 2015; Sarkar et al. 2017). Apart from substantial reduction in the cost of fish production, the wastewater aquaculture has a unique capacity for reclamation of wastewater and nutrient recovery through fish biomass. For this reason, WSP system has become very popular and is being extensively used in many countries of the world. However, fish farming has been incorporated as a beneficial input in the maturation ponds (Fig. 8.3) of WSP system in India and some other countries.

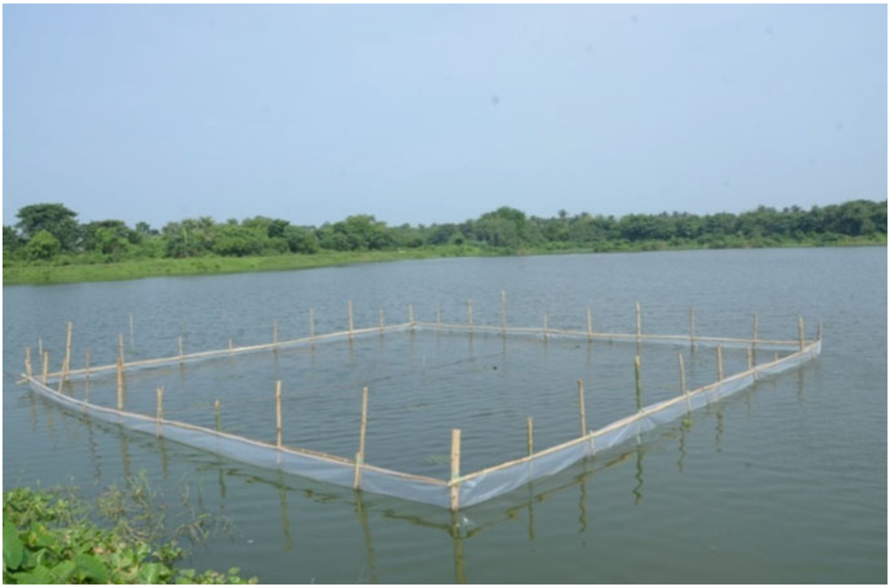


Fig. 8.3 A waste stabilization pond in Kalyani sewage-fed farm

The Structural Design

The structural design of the WSP has been to maximize production of microbiologically safe fish with minimal treatment of wastewater as the aerobic conditions prevailed throughout the system, and that promoted the rapid die-off of both fecal coliform and pathogens occurring in household sewage.

The oxygen required by the pond bacteria to oxidize the organic load of wastewater is provided by the microalgae that grow profusely in the facultative pond in response to nutrient enrichment of the system (Fig. 8.4). It is ensured that the partly reclaimed water in facultative ponds is further improved by the solar energy-driven algal-microbial mutualism in aquaculture ponds and achieves the standard water quality before being discharged into the inland waters. Hence, the degree of reclamation is function of the distance from the inflow of sewage (Lahiri et al. 2015).

Mara (2008) has suggested some modification in the structure of waste stabilization ponds wherein rock filters were used instead of maturation ponds and they can be aerated to remove ammonia for improving biochemical oxygen demand and suspended solid removals. Thus, the effluents of properly designed WSP system can be safely used for both restricted and unrestricted crop irrigation. Rana et al. (2011a) observed about 30% reduction of cadmium from the inflow to outflow point of the sewage effluent gradient in the wetlands of Kalyani waste stabilization pond system.

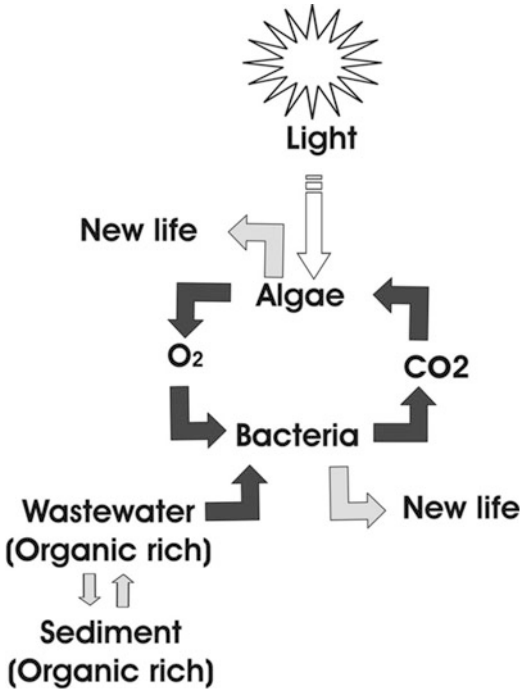


Fig. 8.4 Algal-bacterial mutualism in facultative and maturation ponds

8.7.4 *Constructed Wetlands*

Constructed wetlands have been frequently used for wastewater treatment in many countries of the world due to low maintenance and operation costs in comparison with conventional systems. The design criteria of constructed wetlands and their efficiency vary depending on the purpose and location and evidently their performance. The constructed wetlands have shown a high rate of efficiency in the removal of organic content (BOD, COD) nitrogen, total suspended solids and pathogens (Masi et al. 2008), pharmaceutical drugs, etc. The uses of constructed wetlands for the treatment of wastewater are in experimental stages in India. Recently, the performance of constructed wetlands for the treatment of municipal wastewater is being extensively evaluated in India through a DST-EU collaborative SWINGS (Safe Guarding Water Resources of India using Green and Sustainable Technologies) project (Álvarez et al. 2017).

The constructed wetlands were divided into free water surface system and subsurface flow system. All these systems are primarily based on the concept of either monoculture or polyculture of vascular plants in shallow eutrophic water bodies receiving wastewater with a long residence time. Constructed wetlands were also found highly effective in treating raw household wastewater, thus eliminating the need for septic tank (Chiarawatchai and Otterpohl 2008). In order to control the clogging in constructed wetlands, earthworms were incorporated into the system for enhanced efficiency (Chiarawatchai and Otterpohl 2008). Because of the benefits attributed to integrated anaerobic and aerobic wastewater treatment which reduces energy consumption, operation costs, and increased treatment efficiency, it has been recommended as a sustainable treatment option for the Middle East countries (Al Baz et al. 2008).

8.7.5 Engineered Ecosystem Conceptualized

In the developing countries, industrialization is promoted by replacing natural ecosystems with the main objective of production for a short-term and local-scale benefits. The mutual benefits of industries and environment can be achieved by employing ecological engineering approach which is of great use in developing nations where people have to focus more on environmental issues for their subsistence. It can speed up their economic and ecological development and march toward sustainable wealth, health, and faith.

Ecological engineering is the design of sustainable ecosystem that integrates society with natural environment for the benefit of both and thereby mutually symbiotic. The fundamental principles of ecological engineering are holism, harmony, self-resiliency and circulation, and multilayer and multiuse system. Self-resiliency includes self-regulation, self-reproduction, self-purification, etc. The ecosystem components are interconnected and interdependent causing multiple interactions among themselves. Ecosystems are rich in information networks comprising the physical and chemical communication flows that connect all parts and steer or regulate the system as a whole. Thus, ecosystems are considered cybernatics in nature, but control functions are internal and diffuse involving interaction between primary and secondary subsystems.

The nonteleological systems like ecosystems basically differ from mechanical systems in terms of self-resiliency which indicates the ability to recover when systems are disturbed by a perturbation from outside. Self-resiliency includes self-regulation, self-organization, self-regeneration, self-reproduction, self-purification, etc. This dynamic homeostasis can promote sustainable development and evolution of an ecosystem. This beautiful integration and excellent coordination among different subsystems of ecosystem through chemical messengers have led to develop sustainable ecosystem that may provide service to the society. The collective efforts are greater than the sum total of the components that comprised the ecosystem. This signifies the holistic effects of the ecosystem. The design of ecosystem is, therefore, primarily human engineered biotic component dependent. The fish biomass as an output provides the ecosystem service to the society.

In the wastewater pond, the design of sustainable ecosystem is the basic criteria for treating, cleaning, and utilizing the waste resources into wealth. The design criteria are most important because it relies on the structural composition and functional performance of the system in question. The ecosystem management is based on the premises of interdependence and symbiotic relationships among the component members of the ecosystem such as microalgae; probiotics; floating, rooted, and marginal weeds; herbivorous, carnivorous, and omnivorous fishes; mussels; benthic animals; etc. Due to relatively high toxic tolerance and rapid turnover of high organic loading, the so-called living machines develop self-design and regulation in functional process leading to system reclamation and provide ecosystem services.

The innovative approach in designing the sustainable ecosystem has been to consider the responsiveness of the local species in selecting the species for culture that would suit with the habitat in question. The resilient capacity, self-purification properties, and self-design character of the ecosystem have to be prioritized for choosing the specific economic-driven activities. In the aquaculture ponds, different species of fish that occupy the different ecological niche and graze upon different trophic niche of the pond ecosystem are of much importance in utilizing entire food spectrum of the pond in a balanced manner.

8.7.5.1 The Living Machines

Though heavy metal and other xenobiotic chemicals should not be a potential source of contamination under ideal domestic sewage systems, sometimes intermixing of domestic and industrial effluents in many developing countries results in a potential threat to the environment and human health. Aquatic macrophytes are often described as scavengers of contaminants in surface waters as they have the capacity to accumulate toxic metals and heavy metals like Zn, Pb, Cu, Mg, Mn, Ag, As, Cd, Co, Cr, Ni, Sn, etc. As a result, floating, emergent, and rooted macrophytes have been used as living machines for eutrophication control of wastewater system (Jana and Datta 1996; Saha and Jana 2002a; b). They are also effective in removing pollutants like pesticides, insecticides, phenols, petroleum hydrocarbons, fluoride, hydrogen sulfide, and volatile fatty acids. Macrophyte-based wastewater treatment system also indicated significant reduction in fecal coliform and other pathogens.

It is known that free-floating macrophytes remove nutrients from the water, whereas emergent macrophytes met up their P requirements exclusively from sediments. Rooted submersed macrophytes absorb most of the P from the interstitial water of the sediments and also from the surrounding water. In order to promote the cycling of substances in eutrophic and wastewater systems and to achieve environmentally sustainable low-cost technique, the potentials of different macrophytes have been examined using the application of eco-principle operating through integrated biosystem (Jana et al. 1996; Saha and Jana 2003). Likewise, freshwater bivalves have also been used and were demonstrated to be highly effective for the removal of cadmium from wastewater pond system (Das and Jana 1999, 2003, 2004) and herbivorous fishes for the control of algal bloom under experimental lake conditions (Datta and Jana 1998).

8.7.6 Wastewater-Fed Aquaculture System

Wastewater-fed aquaculture is a unique integrated biosystem having at least two subsystems in which the wastes generated by the first system are used by the next biological system to produce cash crops using the well-known 4R concepts of eco-principles. It provides an economically viable, environmentally sound, low-tech source of high protein through recycling of organic residues in the eco-friendly balanced system.

Wastewater-fed aquaculture offers means to treat wastewater with integrated material-flow recycling; concurrently, there are several benefits such as production of foodstuff, cash crops, animal feeds, raw materials, ornamental plants, and fish food organism; fishes are obtained on one side and converting the unsuitable form to a usable form on the other side. Therefore, it has a win-win strategy by serving as a natural means for converting wastes into wealth and conserving water resource.

Scientific and wise use of wastewater in aquaculture starts after tertiary treatment when organic-rich wastewater has been substantially decontaminated with drastic reduction of organic load, pathogens, etc. There appears a difference in the approach for utilization of this treated wastewater between the developing and economically less developed countries. While this is considered as a discarded waste in rich countries, it is considered as a resource in the economically poor countries. However, acute water crisis in recent years has forced some rich countries to consider wastewater as a possible source for drinking water. In economically less developed countries where there is dearth of protein with malnutrition, there has been a constant search for alternative source as if “hunger knows no boundary,” and many innovative ideas are applied in a traditional way to make use of vast array of the so-called discarded materials of the society. As a result, traditional reuse of sewage through agriculture, horticulture, irrigation, and aquaculture has in vogue in many Southeast Asian countries. Therefore, reuse of wastewater is most pertinent with a view to conserve water and to recover nutrients from wastewater. Logically, considerable efforts have been made toward the reuse of wastewater in different countries of the world especially in the developing world and focused on the positive impacts of wastewater and sludge reuse on soil and plant production. In India, West Bengal is a pioneering state to adopt the wastewater aquaculture in a large scale using the ecological principles and implementing through ecological engineering.

8.7.6.1 Microbiological Considerations

Usual load of bacteria in raw sewage ranges between $.10^8$ and $.10^9$ MPN/100 ml or above. There are also some nonpathogenic bacteria which contribute in the nutrient cycle of phosphorus, nitrogen, and carbon. The ponding system not only reduces the nutrient and organic loads to 50–90%, but the bacterial loads are also reduced by 2–3 log units at 100 kg COD ha/day. The fecal coliform concentrations were reduced by 4 log units within 24 h of retention. Research have shown that the values of fecal coliform were relatively less than total coliform, and a downward trend in the values of fecal coliform was noticed across the sewage effluent gradient (Patra et al. 2010). Cadmium tolerance and antibiotic resistance properties of *Pseudomonas* (Patra et al. 2010) and *E. coli* (Patra et al. 2012) were also investigated in waste stabilization pond. Computation of ecological signature using aerobic mineralization index for heterotrophic and ammonifying bacteria revealed steady increase across the sewage effluent gradient of the waste stabilization pond system in Kalyani used for batch culture of carps in maturation pond (Lahiri et al. 2015).

Direct use of municipal wastewater is mostly through fish culture for human consumption. Because of economic advantages, wastewater-fed aquaculture has been extensively developed in many Asian countries including India, China, Bangladesh, Thailand, and Vietnam and in many parts of Europe, Middle East, and Far East Asia (Jana et al. 2000) for the production of aquatic plants and live feed for fish and livestock. In India, wastewater-fed aquaculture dates back to 1940s when the world's single largest wastewater-fed aquaculture complex known as East Calcutta wetlands developed with fish culture facilities. There are 130 sewage-fed fish farms covering an area of 4000 ha and supply more than 8000 tons of fish per year to city consumers. A large number of people find their livelihood from this aquaculture using the principles of systems ecology and applying it through ecological engineering (Jana 1998). This practice has been well extended to semiarid and arid countries such as Egypt and Peru where there is increasing pressure to reuse wastewater for different activities (Edwards 2000).

Studies conducted at wastewater aquaculture substation in Rahara, 24 Parganas, for utilization of sewage and sludge for composite carp culture, vegetable and fruit cultivation with sewage irrigation, paddy cum fish culture with sewage irrigation, and mixed carp culture with sewage showed that fish production using municipal wastewater ranged from 1.95 to 8 t /ha/year under different treatment conditions, whereas the same from vegetable cultivation ranged from 85.9 to 120 t/ha/year (Roy et al. 2000). Comparative evaluation of sewage-fed and feed-based aquaculture further revealed that the fish yield (4862 kg/ha/year) was higher in the former than in the latter treatment (3371 kg/ha/year) (Datta et al. 2000).

A productive, attractive, and economical aquaculture-based sewage treatment system has been employed to treat and also to utilize domestic sewage by employing duckweed and fish. It has been demonstrated that disposal of sewage is carried out more effectively by integrating plant and fish in aquaculture through an ecologically balanced wastewater treatment system (Ayyappan 2000).

8.7.6.2 The Culture Practices

Raw sewage is harmful to fish life and hence should not be directly used in fish farming. After safe dilution with freshwater (1:1 to 1:4) or proper loading of sewage, city sewage provides congenial environment and aerobic condition necessary for fish culture. In practice, domestic sewage is carried by underground drains or sometimes by surface channels to the fish-growing ponds. In order to reduce the toxic effects of some heavy metals like cadmium, chromium, lead, and nickel, the fish farmers allow the growth of water hyacinth and other macrophytes in the canal or around the pond margins. In Kalyani sewage-fed fish farms, partially treated sewage effluents are also flown along a gradient through a series of anaerobic, facultative, and fish-growing ponds, and finally effluents are discharged into the river canal. The wastewater aquaculture system network at Cuttack comprises 18 duckweed culture ponds, two fish culture ponds, and two marketing reservoirs for the depuration before marketing of fish. An average retention time of 5 days was maintained throughout. It is suggested that a BOD_5 level of 10–20 mg/l of pond water should be continuously maintained for better fish growth.

8.7.6.3 Selection of Fish Species

Right selection of fish species and manipulation of their stocking ratios would create a sustainable ecosystem and utilize the food spectrum in a sustainable way in wastewater-fed aquaculture system. The bio-manipulation approach is mostly used in lake cleaning following the cascade effects. Omnivorous and bottom grazing fishes consume directly the organic detritus of sewage-fed ponds and thereby help to eliminate obnoxious gases from pond bottom and to keep the pond aerobic through bioturbation activity. As a result, dominance of herbivorous or carnivorous fish would direct the nature of food chain to be dominated, and the degree of reclamation would occur. For example, greater abundance of herbivorous fishes would result in greater utilization of microalgae and hence control algal bloom in natural ponds. In case of omnivorous or carnivorous fish, better use of detritus food chain would be noticed. Greater abundance of bottom grazers would have a bioturbation effect by the way of physical disturbance and oxygenation in the mud-water interface resulting in emission of obnoxious gases from the pond bottom. As a result, a more healthy condition develops in the ecosystem.

The species that are suitable for wastewater aquaculture are Indian carp, Israeli carp, silver carp, bighead carp, grass carp, common carp, hybrid buffalo, catfish, largemouth bass, tilapia, freshwater prawn, etc. Tilapia has been considered an ideal species for rearing because it can tolerate relatively low oxygen, wide range of salinity, high level of ammonia, and other adverse ecological factors. Likewise, air-breathing catfishes like *Clarias batrachus* are also considered suitable in most situations. Carps which are often more sensitive to low dissolved oxygen and high level of ammonia need larger water area and frequent water quality monitoring for growth. In some sewage-fed fishponds of West Bengal, freshwater giant prawn culture is quite successful.

8.7.6.4 Water Quality and Ecological Integrity

A favorable water quality should be achieved and maintained for successful aquaculture in sewage-fed ponds. The ecological resilience of waste stabilization pond accomplished by sedimentation and chelation, biological functional attributes mediated through redundancy of different subsystems, and self-purification capacity of system as a whole are responsible for the reclamation of wastewater resulting into benign environment for fish growth. As a result of interactive ecological processes, a distinct gradient in the values of pH, total alkalinity, and dissolved oxygen of water (5.03–12.05 mg/l) occurred across the sewage effluent gradient from the inlet of facultative pond to the last maturation pond. The concentrations of all the three species of nitrogen (ammonium-N, nitrite-N, and nitrate-N) were substantially higher in facultative ponds than in maturation ponds. The high values of BOD and COD, ammonia, and phosphorus have substantially reduced to favorable range required for fish growth. Ecological integrity focusing on the spatial and seasonal variability of the abundance and diversity of microalgae, biogeochemical cycling bacteria, and carbon sequestration potential of microalgae was assessed in relation to water quality across the six wetlands (waste stabilization ponds) used for treatment of domestic sewage cum fish culture. Mukherjee and Jana (2007) have shown the effect of water quality on the SDH activity, protein content of fish reared in waste stabilization pond system.

The gross and net primary productivity of phytoplankton ranged from 3.594 g C/m^2/day to 32.858 g C/m^2/day and 2.34 C/m^2/day to 15.227 C/m^2/day, respectively. The biogeochemical cycling bacteria (heterotrophic, ammonifying, and phosphate-solubilizing bacteria) occurring in surface water, in bottom water, as well as in surface sediment tended to reduce spatially from facultative to the last maturation pond. Comparison of the score values for optimal conditions of water quality parameters revealed that the sum total of the integrated ecological conditions were distinctly higher in maturation ponds compared to facultative ponds (Fig. 8.5). Thus there developed, a benign environment for fish growth mediated through microalgae-bacterial grazing and detrital food chain.

Reclamation efficiency of facultative pond has been assessed to be most dynamic registering 22–69% of the total reclamation. It is proposed that reclamation of sewage effluents occurred through functioning of different subsystems such as solar energy-driven autotrophic subsystem, heterotrophic animal community

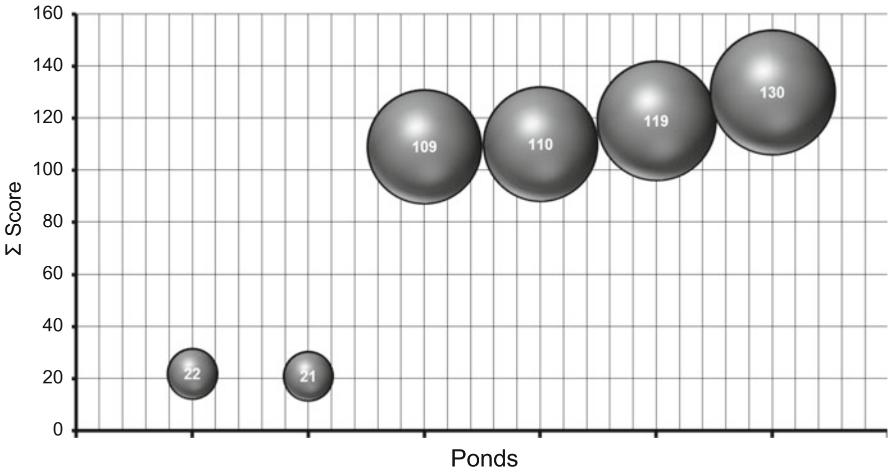


Fig. 8.5 Total scores of optimal values of different parameters (Σ pH + dissolved oxygen + phosphate + ammonium-N+ nitrate-N + fish yield) plotted against six ponds along the sewage effluent gradient

subsystem, microbial subsystem for decomposition and degradation, as well as sedimentation and chelation that lead to improvement in water quality mediated through feedback mechanisms (Lahiri et al. 2015).

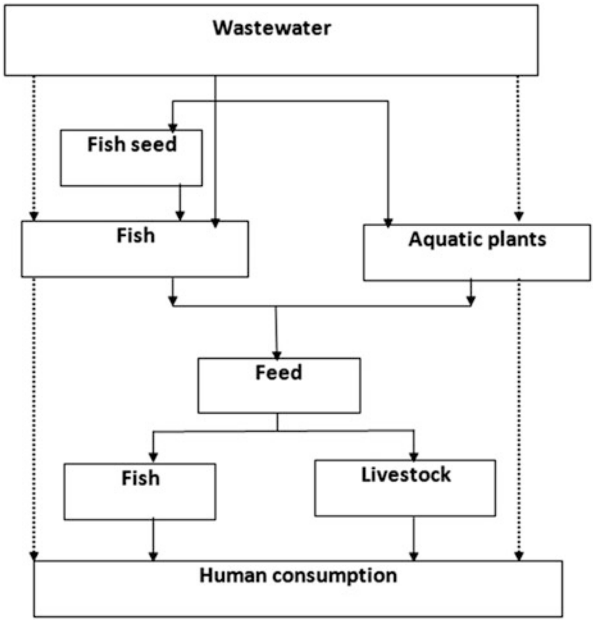
8.7.6.5 Fish Production

In general, fish yields from wastewater-fed ponds are two to four times higher than those from ordinary fish culture practices. The growth rates of different species of carp were as follows: big head carp > rohu > grass carp > mrigal. The mortality was maximal in mrigal and least in common carp, suggesting that the latter was more tolerant to sewage-fed aquaculture than the former. Recycling of domestic sewage in Calcutta wetlands yielded 7000 kg ha^{-1} $year^{-1}$ of carp and 9350 kg of tilapia. It is estimated that the return over investment is 28%, the profit to turnover is 22%, and return over fixed capital cost is 7%.

The annual fish catch in a sewage-fed fish farm in Calcutta over the last 10 years ranged from 2160 kg ha^{-1} to 5700 kg ha^{-1}. The sewage-fed fisheries practiced in the wetlands of Calcutta are known to provide substantial amount of fish in Calcutta market. At Cuttack city with duckweed-based wastewater aquaculture system, the percent survival of common carp was found to be less than other species reared.

Human urine is one of the components of household wastewater. Several studies have revealed that human urine can be effectively used for the production of phytoplankton (Jana et al. 2012), zooplankton, *Moina micrura* (Golder et al. 2007), as well as fish (Jana et al. 2016a) in experimental ponds. It was evident that total weight for all the species of fish and prawn at the time of harvest was

Fig. 8.6 Integration of fish farming with livestock and aquatic plants



significantly higher in stored urine-treated tanks (420.0 g) than fresh (356.0 g) or mixed urine (332.0 g)-treated tanks. The mean count of HB observed in stored urine-treated tanks was significantly higher (59–184%) than the remaining treatments employed. The mean count of *E. coli* did not differ from urine-treated tanks to control (Jana et al. 2016a). It is proposed that human urine preferably the stored ones with the counts of *E. Coli* within the permissible for wastewater would be an effective low-cost liquid fertilizer for carp and pawn culture in small holding tanks. Further, it was shown that stored urine stored for 6 months was microbiologically safe for use in biological production (Jana et al. 2016b).

The integration of fish farming (Fig. 8.6) has been based on the fact that nutrient resource of one system can be profitably used by the another system for sustainable production resulting in balanced and rational use of the resources. There are many examples of integration such as paddy cum fish culture, poultry cum fish culture, duck cum fish culture, pig cum fish culture, cattle cum fish culture, and many other combinations.

8.7.7 Aquaponics

Aquaponics is one of the common and popular methods for reclamation cum production of plant biomass in the wastewater system. Some creeping aquatic macrophytes are cultivated as vegetables for human consumption, and duckweeds are also cultivated, mainly for fish feed. Among the aquatic plants grown for use as vegetables are water spinach (*Ipomoea aquatica*), water mimosa (*Neptunia oleracea*), water cress (*Rorippa nasturtium-aquaticum*), and Chinese water chestnut (*Eleocharis dulcis*). The duckweeds *Lemna*, *Spirodela*, and *Wolffia* are cultivated in some parts of Asia in shallow ponds fertilized with excreta, mainly as feed for Chinese carps but also for chickens, ducks, and edible snails. Tomato plants were cultivated on the floating bed of pulp-free coconut fiber over four different concentrations of wastewater, and the results were found encouraging (Rana et al. 2011b). The subject of aquaponics has been discussed in more details in Chap. 10 of this volume.

8.8 Suggested Strategies for Safeguarding Public Health in Wastewater-Fed Aquaculture

Despite proper ecological functioning and ecosystem health of the WSP, the possibility of inadvertent contamination by some pathogens and contaminants cannot be ruled out. Hence, some mitigation strategies have to be adopted. Depuration was mentioned as a means to decontaminate fish grown in waste-fed aquaculture. It is generally believed that holding fish in clean-water ponds for several weeks at the end of the growing cycle will remove residual objectionable odors and pathogens and provide fish acceptable for market. Relatively short depuration periods of 1 to 2 weeks do not appear to remove all bacteria from the fish digestive tract. It is also suggested that the isolation pond may also be loaded with live water hyacinth in order to accelerate and complete the depuration process (Das and Jana 1999). However, further research is needed on this direction. Considering the lack of verification of the effectiveness of depuration as a health protective measure, it is desirable to monitor the health condition of fish using advanced protocol. It is recommended to follow some stringent protocol and safety measures for a better security of fish handlers. The fish farmers should use gloves and masks and other precautionary measures for preventing unintended health hazards (WHO 2006). Further, there should be provision for source separation of municipal and industrial wastes so that mixing of the wastes from two sources can be avoided.

8.9 Conclusions

Municipal wastewater is of immense importance as a source of nutrients as well as for water conservation. Sewage effluent and sludge must be treated and managed properly to avoid any adverse impacts on the environment and human health so that the resource value of these products can be realized safely. There should be a holistic approach for wastewater treatment using ecosystem resilient driven water reclamation that would reduce the cost of conventional wastewater treatment. Though the fishes are safe for consumption after proper cleaning and cooking, it is recommended to have some additional safety measures for human consumption. It is suggested to keep the harvested fishes in a separate tank for 2 weeks for decontamination before selling to the market. An integrated planning for source separation of domestic and industrial sewage should be done for proper use of municipal wastewater.

References

Abdel-Shafy HI, Guindi KA, Tawfik NS (2008) Groundwater contamination as affected by long term sewage irrigation in Egypt. In: Al Baz I, Otterpohl R, Wendland C (eds) Efficient management of wastewater-its treatment and reuse in water scarce countries. Springer, Berlin/Heidelberg, pp 53–64

Al Baz I, Otterpohl R, Wendland C (2008) Efficient management of wastewater-its treatment in water scarce countries. Springer, Berlin/Heidelberg, p 303

Álvarez JA, Ávila C, Otter P, Kilian R, Istenič D, Rolletschek M, Molle P, Khalil N, Ameršek I, Mishra VK, Jorgensen C, Garfi A, Carvalho P, Brix H, Arias CA (2017) Constructed wetlands and solar-driven disinfection technologies for sustainable wastewater treatment and reclamation in rural India: SWINGS project. Water Sci Technol 76(6):1474–1489. https://doi.org/10.2166/wst.2017.329

Ayyappan S (2000) Duckweed and fish based aquaculture sewage treatment system: status and prospects. In: Jana BB, Banerjee RD, Guterstam B, Heeb J (eds) Waste recycling and resource management in the developing world. University of Kalyani/International Ecological Engineering Society, Kalyani/Wolhusen, pp 59–64

Chiarawatchai N, Otterpohl R (2008) Options for improving the effectiveness and potentials for a sustainable resource recovery in constructed wetlands. In: Al Baz I, Otterpohl R, Wendland C (eds) Efficient management of wastewater-its treatment and reuse in water scarce countries. Springer, Berlin/Heidelberg, pp 163–176

Das S, Jana BB (1999) Dose-dependent uptake and *Eichhornia* induced elimination of cadmium in various organs of the freshwater mussel, *Lamellidens marginalis* (Linn.). Ecol Eng 12:207–229

Das S, Jana BB (2003) In situ cadmium reclamation by freshwater bivalve *Lamellidens marginalis* from an industrial pollutant fed river canal. Chemosphere 52:161–173

Das S, Jana BB (2004) Distribution pattern of ambient cadmium in wetland ponds distributed along an industrial complex. Chemosphere 55:175–185

Datta S, Jana BB (1998) Control of bloom in a tropical lake: grazing efficiency of some herbivorous fishes. J Fish Biol 53:12–24

Datta AK, Roy AK, Saha PK (2000) Comparative evaluation of sewage fed and feed based aquaculture. In: Jana BB, Banerjee RD, Guterstam B, Heeb J (eds) Waste recycling and resource management in the developing world. University of Kalyani/International Ecological Engineering Society, Kalyani/Wolhusen, pp 97–104

Edwards P (2000) Wastewater fed aquaculture: state-of-the-art. In: Jana BB, Banerjee RD, Guterstam B, Heeb J (eds) Waste recycling and resource management in the developing world. University of Kalyani/International Ecological Engineering Society, Kalyani/Wolhusen, pp 37–49

Golder D, Rana S, Sarkar (Paria) D, Jana BB (2007) Human urine as an excellent liquid waste for the culture of fish food organism, *Moina micrura*. Ecol Eng 30:326–332

Jana BB (1998) Wastewater fed aquaculture: the Calcutta model. Ecol Eng 11:73–85

Jana BB (2011) Managing the downstream pollution problems and poverty reduction in the tropical developing world: relying on the integration of nature's library, traditional knowledge and ecological sanitation. Procedia Environ Sci 9:201–208

Jana BB, Datta S (1996) Nutrient variability of six sewage-fed tropical fish ponds. Proceedings of the international conference on ecological engineering for wastewater treatment, Switzerland. Environ Res Forum 5–6:379–382

Jana BB, Datta S, Saha S (1996) Reclamation of eutrophic water: nutrient removal by water hyacinth in response to qualitative and quantitative variations of fertilizers. In: Proceedings of the international conference on ecological engineering for wastewater treatment, Switzerland. Environ Res Forum 5–6:331–336

Jana BB, Banerjee R, Guterstam B, Heeb J (2000) Waste recycling and resource management in the developing world. University of Kalyani/International Ecological Engineering Society, Kalyani/Wolhusen, pp 37–49

Jana BB, Rana S, Bag SK (2012) Use of human urine in phytoplankton production as a tool for ecological sanitation. Water Sci Technol 65:1350–1356

Jana BB, Lahiri S, Sarkar D, Rana R, Bhakta JN, Pal D (2016a) Storage induced changes in coliform, heterotrophic groups of bacteria and nutrient levels of human urine for its safe use in biological production. Indian J Exp Biol 54:544–548

Jana BB, Rana R, Lahiri S, Bag SK (2016b) Evaluation of fertilizer values of stored and fresh human urine in experimental mixed culture of fish and prawn. Russ Agric Sci 42:257–264

Lahiri S, Sarkar (Paria) D, Jana BB (2015) Evaluating the ecological resilient driven performance of a tropical waste stabilization pond system using ecological signature of biological integrity. J Ecol Eng 16:97–107

Mara D (2008) Waste stabilization ponds: a highly appropriate wastewater treatment technology for Mediterranean countries. In: Al Baz I, Otterpohl R, Wendland C (eds) Efficient management of wastewater-its treatment and reuse in water scarce countries. Springer, Berlin/Heidelberg, pp 113–124

Masi F, Conte G, Martinuzzi N (2008) Sustainable sanitation by constructed wetlands in the Mediterranean countries: experiences in small/medium-size communities and tourism facilities. In: Al Baz I, Otterpohl R, Wendland C (eds) Efficient management of wastewater-its treatment and reuse in water scarce countries. Springer, Berlin/Heidelberg, pp 125–138

Mukherjee S, Jana BB (2007) Water quality affects SDH activity, protein content and RNA: DNA ratios in fish (*Catla catla*, *Labeo rohita* and *Oreochromis mossambicus*) raised in ponds of a sewage fed fish farm. Aquaculture 262:105–119

Otterpohl R (2008) Cost efficiency in water management through demand side management and integrated planning. In: Al Baz I, Otterpohl R, Wendland C (eds) Efficient management of wastewater-its treatment and reuse in water scarce countries. Springer, Berlin/Heidelberg, pp 205–209

Patra S, Das TK, Ghosh SC, Sarkar D, Jana BB (2010) Cadmium tolerance and antibiotic resistance of *Pseudomonas* sp. isolated from water, sludge and fish raised in wastewater fed tropical ponds. Indian J Exp Biol 48:383–393

Patra S, Das TK, Avila C, Cabello V, Castillo F, Sarkar (Paria) D, Lahiri (Ganguly) S, Jana BB (2012) Cadmium tolerance and antibiotic resistance in *Escherichia coli* isolated from wastewater stabilization ponds. Indian J Exp Biol 50:300–307

Rana S, Jana J, Bag S, Mukherjee (Roy) S, Biswas JK, Ganguly (Lahiri) S, Sarkar (Paria) D, Jana BB (2011a) Performance of constructed wetlands in the reduction of cadmium in a sewage treatment cum fish farm at Kalyani, West Bengal, India. Ecol Eng 37:2096–2100

Rana S, Bag SK, Golder G, Mukherjee S, Pradhan C, Jana BB (2011b) Reclamation of municipal domestic wastewater by aquaponics of tomato plants. Ecol Eng 37(6):981–988

Roy AK, Rai SP, Datta AK (2000) Comparative evaluation of different resource recovery practices from sewage. In: Jana BB, Banerjee RD, Guterstam B, Heeb J (eds) Waste recycling and resource management in the developing world. University of Kalyani/International Ecological Engineering Society, Kalyani/Wolhusen, pp 91–96

Saha S, Jana BB (2002a) Nutrient removal potential of emergent (*Scirpus articulatus*) and floating (*Lemma major*) macrophytes. Int J Environ Stud 59(4):489–502

Saha S, Jana BB (2002b) Determination of biomass: water area ratio for effective reclamation in simulated models of wastewater at two nutrient levels. Int J Environ Stud 59(5):623–634

Saha S, Jana BB (2003) Fish macrophyte association as a low-cost strategy for wastewater reclamation. Ecol Eng 21:21–41

Sarkar (Paria) D, Lahiri (Ganguly) S, Jana BB (2017) Reponses of structure, function and C-sequestration potential of microalgae to nutrient enrichment across the sewage effluent of tropical waste stabilization pond system. Ecohydrology and Hydrobiology (in press)

WHO (2006) Guidelines for the safe use of wastewater, excreta and greywater, vol 2–4. Wastewater use in agriculture. WHO, Geneva

Chapter 9
Bioremediation of Perturbed Waterbodies Fed with Wastewater for Enhancing Finfish and Shellfish Production

Kishore K. Krishnani, Neeraj Kumar, K. K. Meena, and N. P. Singh

Abstract Inland waterbodies are environmentally impacted with the wastes generated through industries and domestic sewage resulting in pollution and complex ecosystem changes. Sustainable green technology has been emerging as an important tool for remediation of perturbed waterbodies as well as wastewater-fed aquaculture ponds. Various methods for bioremediation such as biostimulation, bioaugmentation, plant-based-assisted bioremediation, phytoremediation, biofilm-/periphyton-based bioremediation, biofloc technology, biodegradation, biotransformation, nano(bio)-remediation, enzymatic bioremediation/recombinant DNA technology, biosorption and nutriremediation for alleviation of the contamination in waterbodies have been discussed. In addition, improved technology interventions in terms of abiotic and biotic stress management, environmental enhancement, stock enhancement/replenishment, species enhancement/selection of the right species, environmentally sound enclosure culture technologies, management enhancement and integrated multi-trophic aquaculture have been explored.

Keywords Environmental management · Contamination · Bioremediation

Contents

K. K. Krishnani (✉) · N. Kumar · K. K. Meena · N. P. Singh
ICAR-National Institute of Abiotic Stress Management, Baramati/Pune, Maharashtra, India
e-mail: krishnanik@hotmail.com

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_9

9.1 Introduction

Water is the most beneficent available substance (> 70%) of the earth's surface. Mismanagement of natural resources may lead to freshwater crisis in the world. World Water Assessment Programme predicted that, in the next 20 years, the quantity of water availability per capita would be decreased by 30% (World Water Development Report 2003). The crisis would be more acute in Asian countries where availability of water per capita is the lowest.

Water is used for domestic purposes and carrying away wastes and in agriculture for irrigation, fisheries, aquaculture, power generation, industries, navigation, recreation and many other purposes. Wastewater generated from domestic and industrial sources of the country is enormous. This may become a source of pollution for the lack of proper management and planning. In order to cope with the problem of shortage in protein food supplies, wastewater aquaculture is one of the most important ventures which need to be promoted as economic viable option (Ponniah and Krishnani 2009) for water conservation. However, the discharge water quality should be strictly monitored to meet environmental standards.

9.2 Bioremediation of Perturbed Waterbodies

A vast array of discharged water from urban sewage, agricultural wastes, food processing wastes, distillery wastes, paper-pulp mill wastes, organic discharges from the chemical industry and oil spillages pose a threat to the environmental security and development of aquaculture in general. This can be attributed to both biotic and abiotic factors that adversely affect the fish yield of the waterbody. Chemical stressors such as nitrogenous contaminants, excessive nutrients, high organic load, heavy metals, pesticides, extreme climate events, pathogens and aquatic weeds also pose a threat for aquaculture.

9.2.1 Bioremediation in Inland Waters and Aquaculture

Improved technology interventions in terms of bioremediation of pollutants, abiotic and biotic stress management, environmental enhancement, selection of right species, integrated multi-trophic culture, environmentally sound enclosure culture technologies and harvest and postharvest management would help in achieving estimated production potential of inland waterbodies and aquaculture (Table 9.1). Using bagasse-assisted bioremediation in zero water exchange system, Krishnani et al. (2012, 2013) have demonstrated improved coastal shrimp aquaculture. This is an advantageous cost-effective biofilm-based biostimulation technology which may also be adopted in culture-based fisheries.

9.2.2 Stock Enhancements: A Bioremediation Strategy

Fish produces green slime which acts as bioaugmentor. Hence, stock enhancement can be used as a bioremediation strategy for aquaculture production. For example, bioaugmentation technology by integration of milkfish in pens in shrimp ponds has successfully been demonstrated by Krishnani et al. (2012) for controlling shrimp pathogenic bacteria resulting in enhanced shrimp production. Integrated culture of economically important fishes as bioaugmentors in zero water exchange system of coastal shrimp aquaculture has potential application for the removal of excess nutrients and improving water quality, due to the probiotic effect of fish slime.

9.2.3 Integrated Multi-trophic Aquaculture (IMTA) as Bioremediation Strategy

Intensive aquaculture system results in adverse environmental conditions with reduced oxygen level, high organic loading, metabolic loads and pathogens. This eventually reaches the environment through drained waste. Such abiotic and biotic stresses have an adverse impact on the finfish and shellfish production. Effective means for the treatment of culture and wastewater are still lacking. The concept of bio-mitigation can be achieved through integrated multi-trophic aquaculture (IMTA) comprising integration of different groups of commercially important species with varied feeding habits which have been described as a key development factor for aquaculture sustainability (Barrington et al. 2009). IMTA involves advantage of the mutualism between some detritivorous fish and phytoplankton. In IMTA, a number of complementary organisms are integrated at a farm site, optimizing nutrient utilization and reducing solid waste. A holistic integrated approach based on the more efficient reactor systems needs to be developed for waste treatment that would allow more environmentally balanced aquaculture practices (Zhang and Kitazawa 2016).

Selection of appropriate algal species, aquatic weeds and strains is required for bioremediation of dissolved nutrient loads in waterbodies. Lawton et al. (2013) have successfully demonstrated bioremediation activities at land-based aquaculture

Table 9.1 Actual and potential production from inland waterbodies in India

Reservoir	Total number of reservoirs	State with maximum numbers of reservoirs	Area (ha)	Present production (tonnes)	Average fish production (kg/ha)	Potential production (tonnes)	Expected production potential (kg/ha)
Small	19,134	Tamil Nadu (8895)	14,85,557	74,200	49.5	7,43,000	500
Medium	180	Andhra Pradesh (32)	5,27,541	6500	12.3	1,27,000	250
Large	56	Karnataka (12)	11,60,511	13,000	11.43	1,16,000	100
Total	19,370	–	31,73,609	13,700	24.41	9,86,000	

Fig. 9.1 Seaweed-based integrated multi-trophic aquaculture

facilities in Eastern Australia using the fast growth rates and broad geographical distribution of *Ulva ohnoi* as an ideal species. Phang et al. (1996) also demonstrated effective uptake of nutrients by seaweeds cultivated in ponds receiving shrimp effluent waters (Fig. 9.1). Biological approaches to remediate in shrimp culture systems have been promoted in the Philippines by integrating the culture of seaweeds and other economically important species with shrimp farming (Hurtado and Agbayani 2000).Skriptsova and Miroshnikova (2011) proposed that *Ulva pinnatifida* be introduced into IMTA systems during the winter season to remove nutrients from cultured animals. Silva et al. (2012) have assessed IMTA for Pacific oyster (*Crassostrea gigas*) aquaculture as a bioremediation strategy. Seaweeds such as *Kappaphycus* and *Ulva lactuca* apparently are popular among aquaculturist for their almost universally adoptable characteristics in wide range of aquatic environmental conditions.

Aquaculture effluents have been bioremediated using filter-feeding bivalves, microalgae and seaweeds (Jones et al. 2002; Muangkeow et al. 2007). Besides, low or zero water exchange system (Balasubramanian et al. 2005) and recirculation system (Lezama- Cervantes and Paniagua-Michel 2010) have also been applied in different places.

A cage experiment using the red alga *Gracilaria chouae* cocultured with the black sea bream *Sparus macrocephalus* in Xiangshan Bay, China, was proven to be an efficient bioremediation species in this system to measure the nutrient flux of the IMTA (Wu et al. 2015a). Gilles et al. (2013) created an artificial ecosystem by combining tilapia *Sarotherodon melanotheron heudelotii* and the unicellular alga (*Chlorella* sp. and *Brachionus plicatilis)*, wherein nutrients are recycled by consuming algae and providing the inorganic carbon to fuel the growth of live algae. Algae purify the water and generate the oxygen required by fishes. Seaweeds are an important and cheaper source for treatment/therapeutics in aquaculture with greater accuracy without causing toxicity (Madhuri et al. 2012). A variety of functions in the seaweeds can be attributed to the presence of various active compounds like alkaloids, flavonoids, pigments, phenolics, terpenoids, steroids and essential oils. Seaweeds have high nutraceutical potential because of their nutritional factors, such as vitamins, minerals, protein, polysaccharides, steroids, carotenoids, saturated and unsaturated fatty acid and dietary fibre. Researchers have intensified efforts to exploit seaweeds as dietary supplements that enhance growth performance and health and immune system of cultured fish instead of chemotherapeutic agents.

Some researchers (Manju et al. 2009) have successfully demonstrated integrated approach for bioremediation of nitrogenous toxicants, including ammonia in recirculation aquaculture systems, coastal shrimp aquaculture, coastal fish diversity and phytoplankton variation in coastal aquaculture. Using the seaweeds in the nutrient-rich outflow of a commercial fish farm, the studies of Azevedo et al. (2015) have demonstrated the yield potential of *Mastocarpus stellatus* for sustainable production of high-value polysaccharides. Molluscs have been used for bioremediation of aquaculture effluents (Ramos-Corella et al. 2014).The principles of integrated multi-trophic aquaculture may be applied in wastewater aquaculture for enhancement of bioremediation coupled with aquaculture production.

There is an urgent need of eco-friendly techniques for controlling or minimizing the pathogenic bacterial problem in wastewater-fed system. A laboratory estimation of the bacterial accumulation of *Mytilus galloprovincialis* in the presence or absence of another filter feeder, the demosponge *Hymeniacidon perlevis* on sewage flowing into the Northern Ionian Sea, has been done (Caterina et al. 2016).The bioremediation capability of the sponges cocultured with mussels has also been evaluated. The co-occurrence of the filter-feeder *H. perlevis* with *M. galloprovincialis* is a powerful tool in mitigating the health hazard related to the consumption of edible mussels by reducing the bacterial load in shellfish culture areas.

9.2.4 Bacterial Bioremediation

In bacterial bioremediation, naturally occurring microorganisms are used to break down hazardous substances into less toxic or nontoxic forms by acting as biostimulator.

9.2.4.1 Biostimulation

Biostimulation is a type of natural remediation through optimization of conditions such as aeration, addition of nutrients and electron acceptors or electron donors and pH and temperature control to increase the number or stimulate the activity of indigenous microorganisms capable of bioremediation of the waste materials in aquaculture system (Piehler et al. 1999; Rhykerd et al. 1999). According to Margesin and Scinner (2001), the primary advantage of biostimulation is that bioremediation is undertaken by already existing native microorganisms that are well-suited to the subsurface environment and are well distributed spatially within the subsurface.

One approach to improve sustainability has been the development of intensive zero water exchange system (Burford and Lorenzen 2004), which is an environmentally friendly alternative option to conventional aquaculture for producing high-density shrimp (Boopathy 2009). However, the system also generates toxic ammonia which often limits the water quality and adversely affects the shrimp yield (Krishnani et al. 2011). Bioremediation is necessary for the removal of toxic ammonia in aquaculture system. Such bioremediation approaches have received much more attention in recent years to remediate waste products in aquaculture systems.

9.2.4.2 Bagasse-Assisted Bioremediation

Certain plant-based products may be employed for stimulating microbial activity, which subsequently increases the detoxification potential in the process called as plant-assisted bioremediation. The use of lignocellulosic bagasse material as a biostimulator has successfully been demonstrated to maintain ammonia and nitrite in coastal shrimp aquaculture leading to increased shrimp production (Krishnani et al. 2013). Integration of bagasse biostimulation technology (at 10–20 kg biostimulator/hectare shrimp pond) in coastal aquaculture for 2–3 months led to 29–52% ammonia removal and 4–28% higher shrimp production in the aerated culture ponds (Fig. 9.2). This is due to a biofilm mode of growth of nitrifying consortia and periphytic growth onto bagasse (Fig. 9.3). Biostimulation technology is simple and economically viable without much technical sophistication and could be advantageous for water savings and reduced risk of contamination. Krishnani and Kathiravan (2010) have further demonstrated through field trials by employing various molecular tools to quantify ammonia-oxidizing bacteria (AOB) in bagasse biofilm. Ca^{++} ion exchange mechanisms combined with the biofilm mode of growth of nitrifying consortia onto bagasse have been substantiated by quantifying *ammonia monooxygenase* gene (*amo A*) by real-time PCR. Bagasse as biodegradable substrate has a significant role in nitrification and denitrification in zero water exchange aquaculture production system (ZWEAPS). The conventional denitrification has been restricted in anoxic condition, until the discovery of the phenomenon of aerobic denitrification mechanism. Molecular methods based on sequencing of clone libraries for the bacteria possessing both nitrification and aerobic denitrification capability have been used to provide sequence and the phylogenetic information, which has an application in bioremediation (Kathirvan and Krishnani 2013).

9.2.4.3 Bioaugmentation

Bioaugmentation is a promising technique/process of adding selected strains to wastewater treatment plants to improve the catabolism of specific compounds. Advantages of important advancement of microbial ecology, molecular biology, immobilization techniques and bioreactor design can be undertaken by enhancing the potential of microbial treatments. However, the ratio of resistant/sensitive microorganisms to the contaminant should be regarded important. In addition, the poor bioreactor performance may be attributed to the lack of a sufficient number of

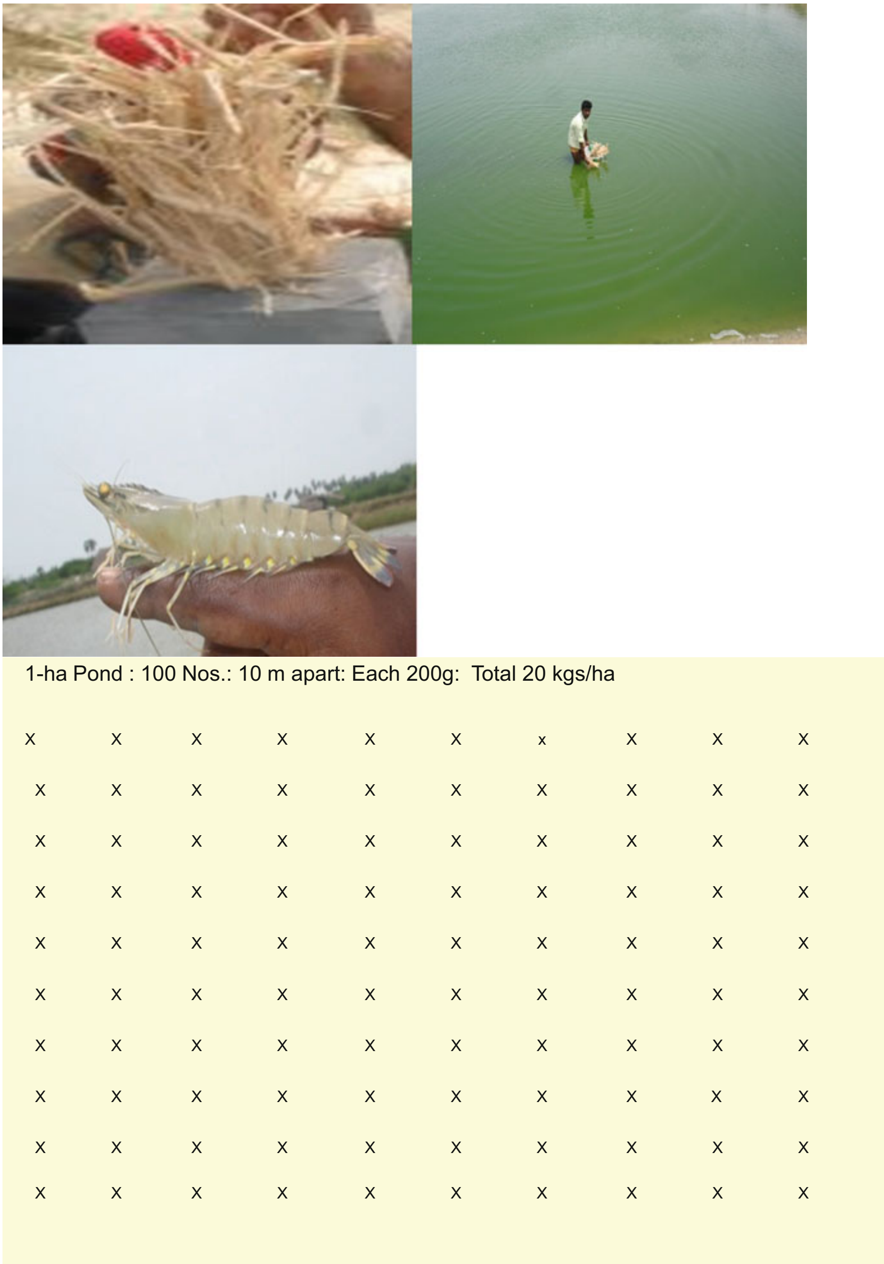


Fig. 9.2 Bagasse-assisted bioremediation in coastal shrimp aquaculture

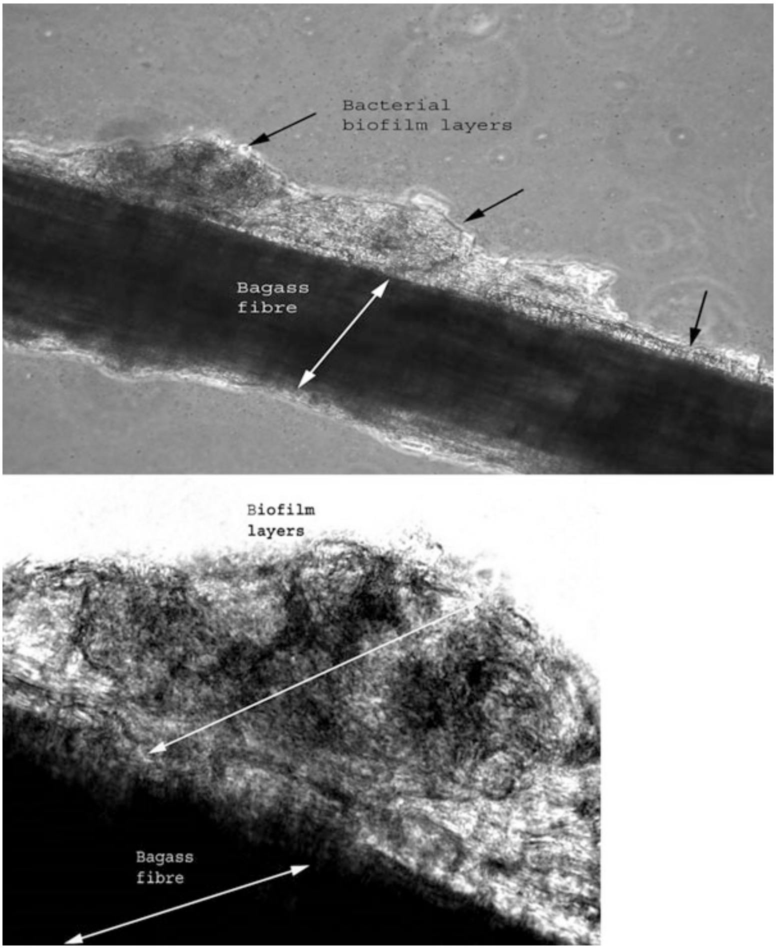


Fig. 9.3 Biofilm-based bioremediation

a specific microorganism implicated in transformation of the target contaminant into less harmful end products. To enhance bioaugmentation process, it is necessary to add a preadapted consortia, genetically engineered bacteria or biodegradation relevant genes that are packaged into a vector in order to be transferred by conjugation into microorganisms already present in the biosystem. According to Yu and Mohn (2002), three criteria are required: firstly they should catabolically be able to degrade the contaminant, even in the presence of other potentially inhibitory pollutants; secondly, they must persist and be competitive after their introduction into the biosystem; and thirdly, they should be compatible with the indigenous communities present; however, the choosing microorganism should not belong to or closely related to human pathogens (Singer et al. 2005).

In situations where indigenous degraders cannot rapidly degrade recalcitrant chemicals, the only means for successful bioremediation is bioaugmentation which involves the addition of indigenous laboratory-grown microorganisms implicated in biodegradation of the target contaminant or serving as donors of catabolic genes. Nakano et al. (2008) developed microbial consortium containing *Nitrosomonas* sp. for ammonia oxidation and *Pseudomonas* sp. and *Alcanivorax* spp. for denitrification for the removal of nitrogen from aquaculture. *Pseudomonas stutzeri* strains, isolated from catfish pond, were effective in lowering soluble N (NH_4, NO_2 and NO_3) levels in fish pond water from 10 mg/l to negligible amounts after 4 days (Diep et al. 2009). The aerobic nitrifying organisms need adequate oxygen for their growth; hence, in high-density ponds, the aerators served to stimulate bacterial growth and activity which consequently maintained the quality of the water to match that of low-density ponds (Fernandes et al. 2010). Biological aerated filter bioaugmented with heterotrophic nitrifying bacterium *Lutimonas* sp. H10 has been set up by Fu et al. (2009) for ammonia removal in the circulating marine aquaculture water, where due to the poor biofilm forming ability of the inoculated strain, the ammonia removal was not significant.

9.2.4.4 Green Water Technology

A common problem in Indian aquaculture is vibriosis due to *Vibrio harveyi*, which is a luminous gram-negative bacterium that causes mortalities among *P. monodon* larvae, post larvae and cultured shrimp (Le Groumellec et al. 1996), creating significant economic losses (Karunasagar et al. 1996). The green water culture system is a bioaugmentation technique in which herbivore finfish such as grey mullet (*Mugil cephalus*) and milkfish (*Chanos chanos*) are propagated in fish cages placed in shrimp-growing ponds (Krishnani et al. 2012) (Fig. 9.4). Finfish, stocked in net cages in shrimp culture ponds, serve as biomanipulators/bioremediators by feeding on the uneaten feed and algae. The secretions of protein-rich slime from the fish enhance the production of green water suitable for abundant growth of beneficial indigenous bacteria, antagonistic against pathogenic bacteria *Vibrio harveyi*, leading to higher production of shrimp. In addition, green slime helps nitrifying and oxygen-tolerant denitrifying bacteria to grow and colonize. Pathogenic bacteria are controlled through a variety of mechanisms such as competitive exclusion, improvement of water quality, enhancement of immune response of host species and enhancement of nutrition of host species. Krishnani et al. (2012) have successfully demonstrated bioaugmentation green water technology in zero water exchange systems of coastal shrimp aquaculture for environmental and disease management leading to higher shrimp production in the treatment ponds (2.4–3.2 t/ha) as compared to the control ponds (1.9–2.4 t/ha). The *Streptomyces* species are the most widely studied microbial species from the coastal waters as a source of antibiotics (Blunt et al. 2007). Advancement in molecular biology-based techniques has led to rapid and accurate strategies for monitoring, discovery and identification of novel bacteria

Fig. 9.4 Integration of green water bioaugmentation technology in shrimp aquaculture

(Krishnani 2010; Krishnani and Kathiravan 2010) implicated in bioremediation of wastewater and improvement of fish yield and vegetables in wastewater-fed system.

9.2.4.5 Biofilm-/Periphyton-Based Bioremediation

Sites provided by substrates facilitate epiphytic microbial production serving as food for fish, which easily exploit the sessile forms of bacteria colonized on the surface of substrates as compared to free planktonic forms. The use of artificial substrates is advantageous for shrimp growth (Ballester et al. 2007). However, its mechanism for wastewater aquaculture has not been examined properly.

Microbial biofilm based on agrowaste periphyton in freshwater aquaculture system may be adopted to increase the productivity by conversion of nutrients into harvestable products (Mridula et al. 2003). Biofilm is an assemblage of microorganisms comprising of microbial species attached to a biological or inert surface and encased in a self-synthesized matrix comprising of water, proteins, carbohydrates and extracellular DNA (Costerton et al. 1987). Different microbial species present in biofilm consortia each with different metabolic degradation pathway are capable of degrading several pollutants either individually or collectively (Gieg et al. 2014). Biofilm-forming bacteria compete with nutrients and oxygen and are adapted to survive and suited for harsh environment found way in the process of bioremediation.

Biofilm-mediated remediation is an environmentally and economically viable option for cleaning up environmental pollutants/bioremediation. Bacterial biofilms exist within indigenous populations near the heavily contaminated sites to better persist, survive and manage the harsh environment. Expressions of genes vary within the biofilms and are distinctive relative to free-floating planktonic cells. Differential gene expressions within biofilms are owing to variable local concentration of nutrients and oxygen within biofilm matrix and division of labour among microbes. Such variable gene expression may be important for degradation of various pollutants by numerous metabolic pathways. An important consideration for biofilm formation in microorganisms is chemotaxis and flagellar-dependent motility (Pratt and Kolter 1999). Responses such as swimming, swarming, twitching motility, chemotaxis and quorum sensing in presence of xenobiotics commonly present in soil and water assist microbes to coordinate movement towards pollutant and improved biodegradation (Lacal et al. 2013).

Polluted surface water can be remediated using biofilm techniques (Fechner et al. 2012), the carrier of which directly influences treatment efficiency, energy consumption in waste recycling and water treatment (Cao et al. 2012). The remediation of recalcitrant compounds by conventional methods is often difficult due to their complex structure and persistent properties. To solve this problem, alternative biofilm-based treatment processes have been developed suitable for their remediation because of their high microbial biomass and immobilization ability. Rhizoremediation exploits the elevated microbial activity in the rhizosphere of plants for the degradation and removal of pollutants, which has gained much attention in recent years. The root exudates of *Phragmites* serve as a source of carbon and energy for cell growth, facilitating the degradation activity. Additionally, the roots provide a large surface area for bacterial colonization.

Several disadvantages of single species microbial aggregates can be overcome by the use of periphyton biofilm, which are microbial communities consisting of heterotrophic and photoautotrophic microorganisms capable of remediating surface waters that suffered from pollution due to a variety of contaminants. Algae, zoogloea, filamentous bacteria growing on aquatic macrophytes and other submerged substrates serve as fish food and also play a key role in the production of enzymes, degradation of organic matter and environmental toxicants and improve production and water quality as well (Azim et al. 2001).

Bagasse is a complex native cellulosic fibrous waste left after extraction of juice from cane sugar. In bagasse-treated ponds, biofilm acts as a biofilter with the result of significant increase in biological production (Krishnani et al. 2013). However, further research is needed to employ this as a bioremediation tool in wastewater-fed ponds.

9.2.4.6 Biofloc Technology

Biofloc technology has recently gained attention as a sustainable method to control water quality through balancing carbon and nitrogen in the aquaculture system. The technology is considered as a resourceful alternative system since nutrients could be continuously recycled and reused, with the added value of producing proteinaceous feed in situ (Crab et al. 2012). Biofloc not only maintains water quality, by the uptake of nitrogen compounds generating in situ microbial protein, but also provides nutrition, increases culture feasibility by reducing feed conversion ratio and decreases feed costs. Numerous benefits such as improvement of growth rate and a decrease of FCR and associated costs in feed have been demonstrated using the consumption of biofloc by shrimp or fish (Burford et al. 2004). The current focus of intensive research in nutrition fields is biofloc meal (also called single-celled protein), added to compounded feed (Kuhn et al. 2009). More information on biofloc technology has been dealt in Chap. 4 of this volume.

9.2.5 Biosorption of Heavy Metals

Heavy metals have potential adverse impacts on the public health as well as on aquatic species. The use of lignocellulosic agrowastes is environmentally viable for effective removal of heavy metals. Krishnani et al. (2009) have successfully demonstrated the use of plant biomass residues and lignocellulosic agrowastes for the development of novel cation exchangers/biosorbents for bioremediation of waters contaminated with heavy metals. Biosorption and ion exchange technology have potentials in the treatment of industrial effluents at the point source.

9.2.6 Phytoremediation (in Aquatic Environment)

Phytoremediation is a common method of bioremediation under terrestrial conditions, which involves the use of green plants to remove, contain or render harmless environmental contaminants. However, the information is less for aquatic habitats. In phytoremediation, selected or genetically engineered plants capable of direct uptake of pollutants from the environment are used. This process usually involves the following steps: uptake, translocation, transformation, compartmentalization and sometimes mineralization.

Recycling of water employing aquatic plants can reduce the volume of water required in fish pond to remove the nutrients prior to discharge to natural waterways. This will allow legislative compliance and can lead to greater profitability. Three mangrove species (i.e. *Avicennia germinans*, *Laguncularia racemosa* and *Rhizophora mangle*) were used for the biological removal of ammonium, nitrite, nitrate and phosphate in a closed fishery system (De-Leon-Herrera et al. 2015). The development of phytoremediation with continuous bio-harvesting through the performance of *Chlorella* sp. in removing nutrient in aquaculture wastewater has been successfully demonstrated by Ahmad et al. (2016). Wu et al.

(2015b) have successfully demonstrated large-scale cultivation of *P. yezoensis* with selection of *Gracilaria lemaneiformis* and *Laminaria japonica* as coculture seaweeds in open sea to efficiently alleviate eutrophication by removing dissolved nutrients and control harmful algae blooms.

Reeta et al. (2004) have successfully demonstrated nutrient removal by floating aquatic macrophytes cultured in anaerobically digested flushed dairy manure wastewater, where growth of water hyacinth (*Eichhornia crassipes*) was inhibited and both pennywort (*Hydrocotyle umbellata*) and water lettuce (*Pistia stratiotes*) failed to grow successfully in a 1:1 dilution of anaerobically digested flushed dairy manure wastewater. Saha and Jana (2002a) have conducted studies on nutrient removal capacity of *Lemna major* (floating macrophyte) and compared with *Scirpus articulatus* (emergent macrophyte) in hypertrophic mesocosms held in situ. Studies showed the removal of orthophosphate mainly from water phase by *Lemna*, whereas *Scirpus* removed their phosphorus exclusively from the sediment. Plant recovery of both nitrogen and phosphorus was higher in emergent macrophyte than in floating macrophyte. There was decline of denitrifying bacteria and the increase in heterotrophic bacterial populations with the introduction of macrophyte. Counts of the heterotrophic bacterial population were significantly higher in the case of *Lemna* than in *Scirpus*. Phytoplankton number declined in case of *Lemna* due to its shading effect compared to *Scirpus*. Saha and Jana (2002a) concluded that the reclamation ability of floating *Lemna* was short-lived because of nutrient removal mainly from the water phase, whereas the nutrient removal mechanism in emergent *Scirpus* was primarily through the root system from the sediment. In the studies conducted by Saha and Jana (2002b) on three different densities of water hyacinth biomass for adequate nutrient depletion in simulated models of wastewater, it is indicated that there is greater preference of N over P when space and nutrients were limitless, whereas preferential uptake of P over N occurred at high density of both nutrient levels. Saha and Jana (2002b) concluded that the required level of orthophosphate of water was achieved at high density of low nutrient enrichment after 12 days of water hyacinth introduction, suggesting their immense potentials for reclamation of eutrophic water and induction of grazing food chain.

9.2.7 Aquaponic-Based Bioremediation

Nutrients including nitrogen and phosphorus, as well as pathogens, are being discharged into waterbodies potentially leading to eutrophication. Wu et al. (2012) have developed in situ remediation processes using ecological floating bed techniques for bioremediation of polluted surface waters. *Aquaponics* is a combination of raising fish and growing plants without soil. This is a system of aquaculture in which the wastes produced by farmed fish or other aquatic creatures are broken down by nitrifying bacteria into nutrients such as nitrite and nitrates, supplied for plants grown hydroponicallys, which in turn purify the water. Local hydrophytic plants were used to set up ecological floating bed along the riverbank at different locations for enhancing the purification (Shan et al. 2011; Jia et al. 2011).

A study conducted by Rana et al. (2011) in search of low-cost eco-tech for the reclamation of municipal, domestic wastewater, tomato plants (*Lycopersicum esculentum*) were cultivated on the floating bed of pulp-free coconut fibre over four different concentrations of wastewater (25%, 50%, 75% and 100%) and groundwater as control, in 10 l plastic bucket for 2 months. The study revealed that PO_4-P was removed by 58.14–74.83% with maximum removal at 50% wastewater. More than 75% removal of NO_3-N was observed in all treatments. Both COD and BOD were reclaimed highest at 100% wastewater by 61.38% and 72.03%, respectively. The population of coliform bacteria (*Escherichia coli*) was reduced to 91.10–92.18% with maximum efficiency at 100% wastewater. The aquaponically reclaimed water can be reused in agriculture, aquaculture and industries. The subject has been discussed in length in Chap. 10 of this volume.

9.2.8 Nutriremediation/Nutribioremediation for Alleviation of Multiple Stresses

In the last decade, there has been much focus on nutritional remediation on environmental contaminant especially pesticide. Among all forms of pesticide, the organochlorine is the most dangerous in terms of persistence. The endosulfan is more persistent in aquaculture soil, with an average field half-life of 50 days; however, it persists for many years in soil and water, when it adheres to clay particles. Neeraj et al. (2016a, b, c) have developed a nutritional remediation system which protects the fish, *Chanos chanos*, at cellular and physiological levels as well as immunity against the pesticide endosulfan, heavy metals and temperature. The nutritional components such as methyl donors (Muthappa et al. 2014), pyridoxine (Akhtar et al. 2010), yeast RNA, omega-3 fatty acid (Jha et al. 2007) and microbial load are very important which have immense role in remediation against environmental contamination (Gupta et al. 2014).

9.2.9 Nanoremediation/Nanobioremediation

Healthy and resilient inland open waters with abundant fish stocks provide sustainable economic returns. Byproducts from cheaply and abundantly available sources and fishery wastes may be used for the development of nanostructured materials against bacterial and viral contaminants. Nanomaterials coating as antimicrobial agent can be used for fishing nets, boats and FRP tanks. The use of selenium and zinc nanoparticles in the feed may be explored for stress resilience in finfish and shellfish. Krishnani et al. (2012) have synthesized silver ion-exchanged zeolite, which has successfully been demonstrated for nanobioremediation of ammonia and shrimp pathogenic bacteria. The use of conducting nanopolymers and polyethylene glycol (PEG)-based amphiphilic nanopolymers has also been successfully demonstrated for detoxification of Cr (VI) and bactericidal activity (Krishnani et al. 2014). Zeolites have increasingly been used in water treatment due to their three-dimensional, microporous and crystalline solid nature and their ion exchange properties and thermal stability. Zeolites have cation exchange capacity for various applications in industries, agriculture and aquaculture because of its cagelike structure consisting of SiO_4 and AlO_4 tetrahedra joined by shared oxygen atoms. Nanoremediation/nanobioremediation to detoxify these contaminants could be an efficient, economical approach.

Recent studies have shown that abiotic and biotic stresses lead to oxidative stress in plants. It develops as a result of overproduction and accumulation of reactive oxygen species (ROS), which inactivate enzymes and damage important cellular components. ROS production inhibits cell growth and induces lipid peroxidation and cell death. Ameliorating conditions of oxidative stress in agriculture may lead to increased levels of food production and profitability. However, investigations are limited in aquatic plants facing multiple stresses. Biologically synthesized nanoselenium has potential application as antioxidant and antimicrobial materials in agriculture and aquaculture. There is a need to better understand Si-mediated tolerance and/or resistance to edaphic stresses at the molecular level.

9.2.10 Remediation in Wastewater-Fed System

Wastewater-fed aquaculture has emerged as an important remediation cum economic driven activities in most of the developing countries. This is very important for utilizing wastewater in view of the enormous volume of wastewater generated in different cities of India and lack of adequate infrastructural facilities for the treatment of wastewater. Because of high nutrient load and high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) resulting in almost anaerobic state, such water cannot be directly used for aquaculture. Hence there is a need of following remedial measures for reducing the BOD: regulation of sewage intake into the ponds, providing freshwater for dilution and use of prophylactics and depuration of fish in freshwater before marketing. Considerable efforts have been made towards utilization of sewage through aquaculture in terms of source, chemical nature, diversity pattern, recycling practices, production potential of aquaculture, environmental issues and safety measures for eco-friendly sustainable environmental management strategies (Jana 1998; Stuart et al. 2010; Kumar et al. 2015). Further details of the subject have been dealt in different chapters of this volume.

9.3 Multiomic Approaches for Predictability and Reliability of Bioremediation

Multiomic techniques are very useful in making rapid and accurate strategies for identification and characterization of novel bacteria and their functional genes implicated in detoxification processes. A better understanding of genetic diversity of these extremophiles is of keen interest because of its relevance to bioremediation of priority pollutants.

The recent developments necessitate a combination of frontier science tools collectively like genomics, proteomics, metabolomics, metagenomics, bioinformatics and nanobiotechnology, benefitting all sectors of aquaculture and fisheries. Adoption of molecular techniques greatly improves the efficiency of bioremediation and its predictability and reliability. System biology approach may be applied for abiotic and biotic stress management in inland open water fisheries. Metagenomics may be utilized for examining microbial population and exploring novel microbial genes for their application in culture-based reservoir fisheries (Fig. 9.5). Chemolithoautotrophic bacterial diversity implicated in nitrification, denitrification, sulphur oxidation and nitrogen fixation in coastal shrimp aquaculture has been examined by Krishnani et al. (2010) by employing metagenomics novel heterotrophic nitrifying and aerobic denitrifying bacteria isolated from green water system of coastal aquaculture (Kathiravan and Krishnani 2014) which have been identified as *Pseudomonas aeruginosa* and *Achromobacter* sp. based on the 16S rRNA gene, FAME analysis and biochemical test. These have been named as *P. aeruginosa* strain DBT1BNH3 and *Achromobacter* sp. strain DBTN3. Molecular techniques based on the functional gene revealed the presence of denitrifying functional genes such as nitrite reductase (nirS), nitric oxide reductase (qnorB) and nitrous oxide reductase (nosZ) indicating that these strains are aerobic denitrifies and have an oxygen-tolerant denitrification system. These strains were found to have a 27 kb plasmid coding for nirS and nosZ. The possibility of horizontal transfer of plasmid among *Pseudomonadaceae* and *Alcaligenaceae* families in coastal aquaculture has been explored. Combined nitrification and oxygen-tolerant denitrification potential in the same isolates has been studied. Multiomic approaches have huge potential for predictability and reliability of bioremediation in wastewater system.

9.4 Conclusions

Bioremediation is one of the most prominent areas of environmental biotechnology representing a potential solution to clean up contaminants from open waterbodies fed with wastewater. Microbial bioremediation could be advantageous with the

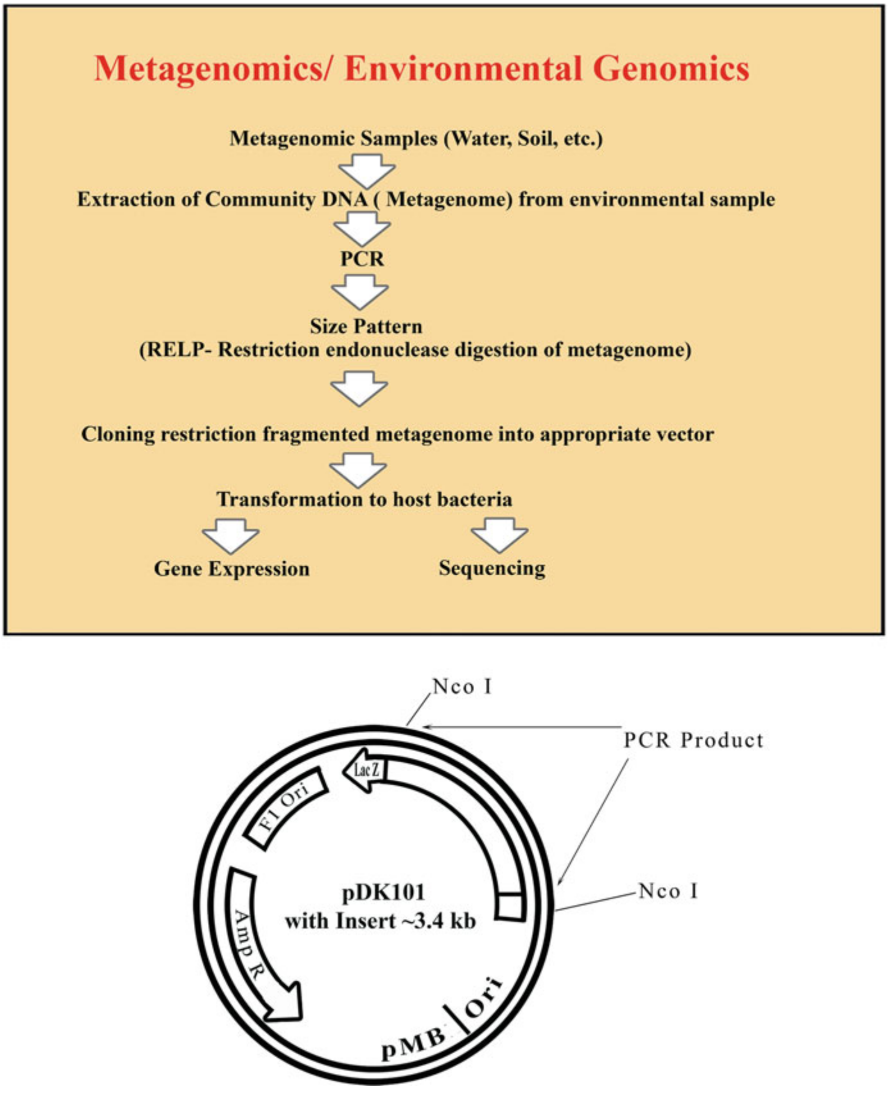


Fig. 9.5 Metagenomics for examining microbial diversity

result of formation of completely nontoxic end products. Biofilm-based bioremediation, biostimulation, bioaugmentation, biofloc-based bioremediation, biodegradation, biotransformation, biosorption and nanobioremediation are promising remediation technologies. Adoption of biofilm-based biostimulation and integrated culture-based bioaugmentation in small reservoirs not only will have the capacity to convert nutrients into harvestable products but also have great potential in environmental management with the result of increase in the productivity. Conclusively, bioremediation has tremendous potential to alleviate the existing pollution, toxicity and abiotic and biotic stresses in perturbed waterbodies. Suitable and proper bioremediation strategies can bring noticeable advantages of minimizing chemical and microbial pollution in reservoirs, wetlands and rivers in a sustainable and eco-friendly manner.

References

Ahmad A, Hadi F, Ali N, Jan AU (2016) Enhanced phytoremediation of cadmium polluted water through two aquatic plants Veronica anagallis-aquatica and Epilobium laxum. Environ Sci Pollut Res Int 23(17):17715–17729

Akhtar MS, Pal AK, Sahu NP, Alexander C, Kumar N (2010) Effects of dietary pyridoxine on haematoimmunological responses of Labeo rohita fingerlings reared at higher water temperature. J Anim Physiol Anim Nutr 96:581–590

Azevedo G, Domingues B, Abreu H, Sousa-Pinto I, Feio G, Hilliou L (2015) Impact of cultivation of *Mastocarpus stellatus* in IMTA on the seaweeds chemistry and hybrid carrageenan properties. Carbohydr Polym 116:140–148

Azim ME, Wahab MA, van Dam AA, Beveridge MCM, Verdegem MCJ (2001) The potential of periphyton-based culture of two Indian major carps, rohu Labeo rohita (Hamilton) and gonia, Labeo gonius (Linnaeus). Aquac Res 32:209–216

Balasubramanian CP et al (2005) Zero-water exchange shrimp farming systems (extensive) in the periphery of Chilika lagoon, Orissa, India. Aquac Int 12:555–572

Ballester ELC, Waisielesky WJ, Cavalli RO, Abreu PC (2007) Nursery of the pink shrimp *Farfantepenaeus paulensis* in cages with artificial substrates: Biofilm composition and shrimp performance. Aquaculture 269:355–362

Barrington K, Chopin T, Robinson S (2009) Integrated multi-trophic aquaculture (IMTA) in marine temperature waters. In: Soto D (ed) Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper. No. 529. FAO, Rome, pp 7–46

Blunt JW, Copp BR, Keyzers RA, Munro MH, Prinsep MR (2007) Marine natural products. Nat Prod Rep 24:31–86

Boopathy R (2009) Biological treatment of shrimp production wastewater. J Ind Microbiol Biotechnol 36:989–992

Burford MA, Lorenzen K (2004) Modeling nitrogen dynamics in intensive shrimp ponds: the role of sediment remineralization. Aquaculture 229:129–145

Burford MA, Thompson PJ, McIntosh RP, Bauman RH, Pearson DC (2004) The contribution of flocculated material to shrimp (Litopenaeus vannamei) nutrition in a high intensity, zero-exchange system. Aquaculture 232:525–537

Cao W, Zhang H, Wang Y, Pan J (2012) Bioremediation of polluted surface water by using biofilms on filamentous bamboo. Ecol Eng 42:146–149

Caterina L, Cardone F, Corriero G, Licciano M, Pierri C, Stabili L (2016) The co-occurrence of the demosponge *hymeniacidon perlevis* and the edible mussel *Mytilus galloprovincialis* as a new tool for bacterial load mitigation in aquaculture. Environ Sci Pollut Res Int 23(4):3736–3746

Costerton JW, Cheng KJ, Geesey GG, Ladd TI, Nickel JC, Dasgupta M, Marrie TJ (1987) Bacterial biofilms in nature and disease. Annu Rev Microbiol 41:435–464

Crab R, Defoirdt T, Bossier P, Verstraete W (2012) Biofloc technology in aquaculture: Beneficial effects and future challenges. Aquaculture 356(357):351–356

De-Leon-Herrera R, Flores-Verdugo F, Flores-de-Santiago F, González-Farías F (2015) Nutrient removal in a closed silvofishery system using three mangrove species (*Avicennia germinans*, *Laguncularia racemosa*, and *Rhizophora mangle*). Mar Pollut Bull 15: 91(1):243–248

Diep CN, Cam PM, Vung NH, Lai TT, My NT (2009) Isolation of *Pseudomonas stutzeri* in wastewater of catfish fish-ponds in the Mekong Delta and its application for wastewater treatment. Bioresour Technol 100(16):3787–3791

Fechner LC, Versace F, Gourlay-Francé C, Vuillemin MT (2012) Adaptation of copper community tolerance levels after biofilm transplantation in an urban river. Aquat Toxicol 106–107:32–41

Fernandes SO, Kulkarni SS, Shirodkar RR, Karekar SV, Kumar RP, Sreepada RA, Vogelsang C, Loka Bharathi PA (2010) Water quality and bacteriology in an aquaculture facility equipped with a new aeration system. Environ Monit Asssess 164:81–92

Fu S, Fan H, Liu S, Liu Y, Liu ZA (2009) Bioaugmentation failure caused by phage infection and weak biofilm formation ability. J Environ Sci (China) 21(8):1153–1161

Gieg LM, Fowler SJ, Berdugo-Clavijo C (2014) Syntrophic biodegradation of hydrocarbon contaminants. Curr Opin Biotechnol 27:21–29

Gilles S, Fargier L, Lazzaro X, Baras E, De Wilde N, Drakidès C, Amiel C, Rispal B, Blancheton JP (2013) An integrated fish-plankton aquaculture system in brackish water. Animal 7 (2):322–329

Gupta SK, Pal AK, Sahu NP, Saharan N, Mandal SC, Chandraprakash AMS, Prusty AK (2014) Dietary microbial levan ameliorates stress and augments immunity in Cyprinus carpio fry (Linnaeus,1758) exposed to sub-lethal toxicity of fipronil. Aquat Res 45:893–906

Hurtado AQ, Agbayani RF (2000) The farming of the seaweed *Kappaphycus* Extension Manual No. 32 SEAFDEC, Philippines

Jana BB, 1998. Sustainable aquaculture towards protein crop and cash production in India. In: Moser A (ed) The green book of ecotech. Sustain, Austria, pp 151–159

Jha AK, Pal AK, Sahu NP, Kumar S, Mukherjee SC (2007) Haemato-immunological responses to dietary yeast RNA, omega-3 fatty acid and beta-carotene in Catla catla juveniles. Fish Shellfish Immunol 23(5):917–927

Jia W, Zhang J, Li P, Xie H, Wu J, Wang J (2011) Nitrous oxide emissions from surface flow and subsurface flow constructed wetland microcosms: effect of feeding strategies. Ecol Eng 37:1815–1821

Jones AB, Preston NP, Dennison WC (2002) The efficiency and condition of oysters and macroalgae used as biological filters of shrimp pond effluent. Aquac Res 33:1–19

Karunasagar I, Otta SK, Karunasagar I (1996) Effect of chlorination on shrimp pathogenic *Vibrio harveyi*, World aquaculture '96, book of abstracts. The World Aquaculture Society, Baton Rouge, p 193

Kathiravan V, Krishnani KK (2013) Heterotrophic nitrifying and oxygen tolerant denitrifying bacteria from greenwater system of coastal aquaculture. Appl Biochem Biotechnol 169 (6):1978–1992

Kathiravan V, Krishnani KK (2014) Aerobic heterotrophic nitrifying and denitrifying bacterium *Achromobacter* sp DBTN3 and *Pseudomonas aeruginosa* DBT1BNH3 have plasmid coding for nitrous oxide reductase and nitrite reductase gene. World J Microbiol Biotechnol 30 (4):1187–1198

Krishnani KK (2010) Detection and diversity of nitrifying and denitrifying bacteria in coastal aquaculture. Aquaculture 302:57–70

Krishnani KK, Kathiravan V (2010) A quantitative method for detecting ammonia-oxidizing bacteria in coastal aquaculture systems. Aquac Res 41(11):1648–1657

Krishnani KK, Shekhar MS, Gupta BP, Gopikrishna G (2009) Sequence similarity based identification of nitrifying bacteria in coastal aquaculture for bioremediation predictability. Asian Fish Sci 22:41–49

Krishnani KK, Gopikrishna G, Pillai SM, Gupta BP (2010) Abundance of sulfur oxidizing bacteria in coastal aquaculture using *soxB* gene analyses. Aquac Res 41(9):1290–1301

Krishnani KK, Gupta BP, Muralidhar M, Sarswathy R, Pillai SM, Ponnusamy K, Nagavel A (2011) Soil and water characteristics of traditional paddy and shrimp fields of Kerala. Indian J Fish 58(4):71–77

Krishnani KK, Yu Z, Yan Y, Xiong L, Boopathy R, Mulchandani A (2012) Bactericidal and ammonia removal activity of silver ion exchanged zeolite. Bioresour Technol 117C:86–91

Krishnani KK, Srinives S, Mohapatra BC, Boddu VM, Hao J, Meng X, Mulchandani A (2013) Removal of hexavalent chromium using conducting polymers. J Hazard Mater 252–253C:99–106

Krishnani KK, Hao J, Meng X, Mulchandani A (2014) Bactericidal activity of elastin-like polypeptide biopolymer with polyhistidine domain and silver. Colloids Surf B: Biointerfaces 119:66–70

Kuhn DD, Boardman GD, Lawrence AL, Marsh L, Flick GJ (2009) Microbial floc meals as a replacement ingredient for fish meal and soybean protein in shrimp feed. Aquaculture 296:51–57

Kumar D, Chaturvedi KMM, Sharma SK, Asolekar SR (2015) Sewage-fed aquaculture: a sustainable approach for wastewater treatment and reuse. Environ Monit Assess 187:656

Lacal J, Reyes-Darias JA, Fontana CG, Krell L (2013) Tactic responses to pollutants and its potential to increase biodegradation efficiency. J Appl Microbiol 114(4):923–933. https://doi.org/10.1111/jam.12076

Lawton JR, Mata L, de Nys R, Paul NA (2013) Lawton Algal bioremediation of wastewaters from land-based aquaculture using *Ulva*: selecting target species and strains. PLoS One 8(10): e77344. https://doi.org/10.1371/journal.pone.0077344

Le Groumellec M, Goarant C, Haffner P, Berthe F, Costa R, Mermoud I (1996) Syndrome 93 in New Caledonia: investigation of the bacterial hypothesis by experimental infections, with reference to stress-induced mortality, SICCPPS book of abstracts, SEAFDEC, Iloilo City, Philippines, p 46

Lezama-Cervantes C, Paniagua-Michel J (2010) Effects of constructed microbial mats on water quality and performance of Litopenaeus vannamei post-larvae. Aquacult Eng 42(2):75–81

Madhuri S et al (2012) Antimicrobial activity of some medicinal plants against fish pathogens. Int Res J Pharm 3:28–30

Manju NJ, Deepesh V, Achuthan CRP, Singh ISB (2009) Immobilization of nitrifying bacterial consortia on wood particles for bioaugmenting nitrification in shrimp culture systems. Aquaculture 294:65–75

Margesin R, Schinner F (2001) Bioremediation (natural attenuation and biostimulation) of diesel-oil-contaminated soil in an alpine glacier skiing area. Appl Environ Microbiol 67:3127–3133

Mridula RM, Manissery JK, Keshavanath P, Shankar KM, Nandeesha MC, Rajesh KM (2003) Water quality, biofilm production and growth of fringe-lipped carp (*Labeo fimbriatus*) in tanks provided with two solid substrates. Bioresour Technol 87:263–267

Muangkeow B, Ikejima K, Powtongsook S, Yi Y (2007) Effects of white shrimp, *Litopenaeus vannamei* (Boone), and Nile tilapia, *Oreochromis niloticus* L., stocking density on growth, nutrient conversion rate and economic return in integrated closed recirculation system. Aquaculture 269:363–376

Muthappa NA, Gupta S, Yengkokpam S, Debnath D, Kumar N, Pal AK, Jadhao SB (2014) Lipotropes promote immunobiochemical plasticity and protect fish against low-dose pesticide-induced oxidative stress. Cell Stress Chaperones 19(1):61–81

Nakano M, Shimizu Y, Okumura H, Sugahara I, Maeda H (2008) Construction of a consortium comprising ammonia-oxidizing bacteria and denitrifying bacteria isolated from marine sediment. Biocontrol Sci 13(3):73–89

Neeraj K, Ambasankar K, Krishnani KK, Gupta SK, Bhushan S, Minhas PS (2016a) Acute toxicity, biochemical and histopathological responses of endosulfan in *Chanos chanos*. Ecotoxicol Environ Saf 131:79–88

Neeraj K, Ambasankar K, Krishnani KK, Gupta SK, Minhas PS (2016b) Dietary pyridoxine promotes growth and cellular metabolic plasticity of *Chanos chanos* fingerlings exposed to endosulfan induced stress. Aquac Res 48(5):2074–2087. https://doi.org/10.1111/are.13042

Neeraj K, Ambasankar K, Krishnani KK, Kumar P, Akhtar MS, Bhushan S, Minhas PS (2016c) Dietary pyridoxine potentiates thermal tolerance, heat shock protein and protect against cellular stress of milk fish (*Chanos chanos*) under endosulfan-induced stress. Fish Shellfish Immunol 55:407–414

Phang S-M, Shaharuddin S, Noraishah H, Sasekumar A (1996) Studies on *Gracilaria changii* (Gracilariales, Rhodophyta) from Malaysian mangroves. Hydrobiologia 326/327:347–352

Piehler MF, Swistak JG, Pinckney JL, Paerl HW (1999) Stimulation of diesel fuel biodegradation by indigenous nitrogen fixing bacterial consortia. Microb Ecol 38:69–78

Ponniah AG, Krishnani KK (2009) Environment friendly technologies to address food safety and environmental concerns in brackishwater aquaculture. In: Goswami UC, Dilip Kumar (eds) Proceedings of 96th Indian Science Congress Special Publication, Narendra Publishing House. pp 115–128

Pratt LA, Kolter R (1999) Genetic analyses of bacterial biofilm formation. Curr Opin Microbiol 2 (6):598–603

Ramos-Corella K, Martínez-Córdova LR, Enríquez-Ocaña LF, Miranda-Baeza A, López-Elías JA (2014) Bio-filtration capacity, oxygen consumption and ammonium excretion of Dosinia ponderosa and Chione gnidia (Veneroida: Veneridae) from areas impacted and non-impacted by shrimp aquaculture effluents. Rev Biol Trop 62(3):969–976

Rana S, Bag SK, Golder D, Mukherjee (Roy) S, Pradhan SC, Jana BB (2011) Reclamation of municipal domestic wastewater by aquaponics of tomato plants. Ecol Eng 37(6):981–988

Reeta D, Sooknah A, Wilkie C (2004) Nutrient removal by floating aquatic macrophytes cultured in anaerobically digested flushed dairy manure wastewater. Ecol Eng 22:27–42

Rhykerd RL, Crews B, McInnes KJ, Weaver RW (1999) Impact of bulking agents, forced aeration and tillage on remediation of oil-contaminated soil. Bioresour Technol 67:279–285

Saha S, Jana BB (2002) Determination of biomass: water area ratio for effective reclamation in simulated models of wastewater at two nutrient levels. Int J Environ Stud 59(5):623–634

Shan B, Ao L, Hu C, Song J (2011) Effectiveness of vegetation on phosphorus removal from reclaimed water bya subsurface flow wetland in a coastal area. J Environ Sci 23:1594–1599

Silva C et al (2012) Assessing a bioremediation strategy in a shallow coastal system affected by a fish farm culture – application of GIS and shellfish dynamic models in the Rio San Pedro, SW Spain. Mar Pollut Bull 64:751–765

Singer AC, van der Gast CJ, Thompson IP (2005) Perspectives and vision for strain selection in bioaugmentation. Trends Biotechnol 23:74–77

Skriptsova AV, Miroshnikova NV (2011) Laboratory experiment to determine the potential of two macroalgae from the Russian Far-East as biofilters for integrated multi-trophic aquaculture (IMTA). Bioresour Technol 102(3):3149–3154

Stuart W, Bunting JP, Edwards P (2010) Wastewater fed aquaculture in the East Kolkata wetlands, India: anachronism or archetype for resilient eco cultures? Rev Aquac 2(3):138–153

World Water Development Report (2003) The United Nations, The water for people water for life. UNESCO/World Water Assessment Program, Paris, pp 1–23

Wu S, Kuschk P, Wiessner A, Muller J, Saad RA, Dong R (2012) Sulphur transformations in constructed wetlands for wastewater treatment: a review. Ecol Eng 52:278–289

Wu H, Huo Y, Han F, Liu Y, He P (2015a) Bioremediation using *Gracilaria chouae* co-cultured with *Sparus macrocephalus* to manage the nitrogen and phosphorous balance in an IMTA system in Xiangshan Bay, China. Mar Pollut Bull 91(1):272–279

Wu C, Xiong W, Dai J, Wu Q (2015b) Genome-based metabolic mapping and 13c flux analysis reveal systematic properties of an oleaginous microalga *Chlorella protothecoides*. Plant Physiol 167:586–599

Yu Z, Mohn WW (2002) Bioaugmentation with the resin acid degrading bacterium *Zoogloea resiniphila* DhA-35 to counteract pH stress in an aerated lagoon treated pulp and paper mill effluent. Water Res 36(11):2793–2801

Zhang J, Kitazawa D (2016) Assessing the bio-mitigation effect of integrated multi-trophic aquaculture on marine environment through a numerical approach. Mar Pollut Bull 110 (1):484–492

Chapter 10
Aquaponics: A Green and Sustainable Eco-tech for Environmental Cum Economic Benefits Through Integration of Fish and Edible Crop Cultivation

S. Datta, B. K. Mahapatra, J. N. Bhakta, S. K. Bag, S. Lahiri, R. N. Mandal, and B. B. Jana

Abstract Municipal wastewater generated by household activities is a storehouse of fertilizers often causing eutrophication of aquatic systems and environmental degradation if not properly managed. Aquaponics is a green and sustainable eco-technological approach integrating aquaculture in hydroponic system and can play a pivotal role in harnessing nutrient from wastewater resources. Consequently, the nutrient-rich wastewater may be reclaimed with concurrent production of fish crops and economically important aquatic plants that can fetch high income from wastewater. The present chapter deals with the potentials of aquaponics in turning wastewater into suitable water for producing fish and different crops for food and nutritional security as well as environmental sustainability.

Keywords Aquaponics · Hydroponics · Eutrophication · Nutrients recovery · Fish · Edible crops

S. Datta (✉) · B. K. Mahapatra
ICAR-Central Institute of Fisheries Education, Salt Lake, Kolkata, India
e-mail: subhdatta@gmail.com

J. N. Bhakta · S. K. Bag · S. Lahiri
International Centre for Ecological Engineering, University of Kalyani, Kalyani, West Bengal, India

R. N. Mandal
Regional Research Centre, ICAR-Central Institute of Freshwater Aquaculture, Kolkata, India

B. B. Jana (✉)
International Centre for Ecological Engineering, University of Kalyani, Kalyani, West Bengal, India

Centre for Environmental Protection & Human Resource Development (Kalyani Shine India), Kalyani, West Bengal, India
e-mail: bbjana@gmail.com

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_10

Contents

10.1 Introduction

Food security and environmental sustainability are the prime global concerns to day in view of the ever-rising increased population and global climate change. Enhancement of food production utilizing waste resources coupled with sequestration of carbon is a win-win approach towards food security, environmental protection, conservation and mitigation to climate change. One of the crucial issues of the present day is the effective management of municipal wastewater which is potentially rich in nutrients and poses a threat to the environment with respect to its pollution potential. Reuse of municipal wastewater in different economy-driven activities has been conceptualized as an environmental mitigation strategy to make use of excessive nutrient load from wastewater through biological production, and thereby municipal wastewater has been extensively used for fish farming (Jana 1998; Edwards 2000; Jana and Jana 2002) and allied activities such as vegetable or horticultural crops. However, the information about the application of aquaponics in harnessing the nutrients from wastewater is extremely scarce.

Aquaponics is a green and sustainable eco-technology integrating aquaculture in hydroponic system and can play pivotal role in harnessing nutrients from the wastewater resources. Though different methods have been employed for utilizing wastewater for biological production either through land vegetation or direct aquatic system, the principles remain almost the same in both the systems used. More specifically, aquaponics is a mutually beneficial integrated system of hydroponics (e.g. soilless systems for crop production) and aquaculture (e.g. aquatic animal farming) for sustainable production of plant and animal products (Love et al. 2014). A large number of vegetables and crops such as beets, radishes, carrots, potatoes, cereal crops, fruits, ornamentals and seasonal flowers are grown in supporting medium such as gravel, sand, peat, rock wool, vermiculite, coconut fibre, sawdust, crushed rock or bricks, shards of cinder blocks and even Styrofoam instead of soil wetted with nutrient media prepared by mixing all essential elements and water (Jensen and Collins 1985; Runia 1995). Many commercially important vegetables and flowering plants can utilize the major nutrients (NO_3-N, NH_4-N and H2PO_4/HPO_4 - P) for their growth from the nutrient-rich wastewater if proper management or suitable amendments are made. Apart from nutrient recovery, this arrangement plays an important role in water conservation. Reducing land use would make a further contribution to sustainability. In this system, the crops not only will reduce the cost of wastewater treatment process but also yield some revenues in the form of agricultural crops. The beauty of this approach is due to the fact that wastewater provides all the essential elements required for plant growth and the wastewater, in turn, is reclaimed by the removal of excess nutrients through the bioprocess of crop production. The net outcome of this modified system is the reduction of fertilizer cost for crop production as well as the cost of wastewater treatment. However, it requires the ability to concurrently manage the production and marketing of two different agricultural products. There are different strategies for the cultivation of commercial vegetables on wastewater. The present chapter has attempted to focus on the role of aquaponics in recycling of municipal wastewater in an integrated manner with the farming of fish and horticulture crops as a green and eco-technology tool.

10.2 Aquaponics Conceptualized

Several technologies have been developed with the primary objectives of conserving water and reusing wastewater by growing economically important plants, vegetables and crops coupled with aquaculture. For example, hydroponics is a subset of hydroculture and is a method of growing plants using mineral nutrient solutions in water without soil. Terrestrial plants may be grown with their roots in the mineral nutrient solution only or in an inert medium, such as perlite, gravel, biochar, mineral wool, expanded clay pebbles or coconut husk (Douglas 1975). As plants utilize nutrients, they help purify the water the fish are living in. This creates a sustainable ecosystem where both plants and fish can coexist, using less water and space, producing no wastewater and pollutants compared to conventional methods (Mukherjee 2011). Aeroponics is the process of growing plants in an air or moist environment without the use of soil or an aggregate medium (known as geoponics). Aeroponic culture differs from conventional hydroponics, aquaponics and in vitro plant tissue culture. Unlike hydroponics or aquaponics, aeroponics is conducted without a growing medium. Because water is used in aeroponics to transmit nutrients, it is sometimes considered a type of hydroponics (Stoner and Clawson 1997–1998). The approaches of such integration are based on the principle of organic farming using green compost and biopesticides. A natural microbial process keeps both the fish and plants healthy. This creates a sustainable ecosystem where both plants and fish can thrive, using less water and space, producing no wastewater and pollutants compared to conventional methods.

10.3 Components

Aquaponics consists of two main parts: the aquaculture part for raising aquatic animals and the hydroponics part for growing plants. Although consisting primarily of these two parts, aquaponic systems usually may have several components or subsystems responsible for the effective removal of nutrients from wastewater, for adding bases to neutralize acids or for maintaining water oxygenation. The following are the typical components of aquaponic system:

- *Rearing tank*: the tanks for raising and feeding the fish
- Settling basin: a unit for catching uneaten food and detached biofilm and for settling out fine particulates
- Biofilter: a place where the nitrifying bacteria can grow and convert through nitrification ammonia into nitrates which are used by the plants
- *Hydroponic subsystem*: the portion of the system where plants are grown by absorbing excess nutrients from the water
- Sump: the lowest point in the system where the water flows to and from which it is pumped back to the rearing tanks

One of the key to the success of aquaponic system is the beneficial bacteria which convert the fish wastes into nutrients that the plant used (Rakocy et al. 2006). All of the tanks and various aquaponic components are connected by pipes. Water flows from the fish tank to mechanical filter where solid wastes are removed. The water then flow into a biological filter that converts ammonia to nitrate. Some system use special tank that are designed to promote eco-friendly bacteria act as biofilter.

10.4 A Brief History of Aquaponics

Aquaponics, principally an application part of hydroponic methods, was first initiated at the University of California in 1929 (Gericke 1940). However, aquaculture researchers first started the experiment in the early 1970s for raising fish in land-based tanks with continuously recycled water. Collins et al. (1975) and Bohl (1977) conducted some experiments with aquatic recirculating system for aquaculture and soilless plant systems as a means of treating fish wastes and removing nitrogen compounds (Sneed et al. 1975; Lewis et al. 1978; Naegel 1977; Sutton and Lewis 1982). Until the 1980s, integrated hydroponics and aquaculture witnessed limited success. However, innovative researches have transformed aquaponic technology into a viable system of food production. Modern aquaponic systems can be highly successful, but they require intensive management. Todd (1980) introduced permaculture at the New Alchemy Institute and experimented with linking hydroponics and aquaculture. In order to make it popular, a training course was conducted at the University of the Virgin Islands for its propagation (Rakocy 1984, 2012; Watten and Busch 1984; Diver 2002; Rakocy et al. 2006). Subsequently, aquaponics have been greatly developed and designed as a modern model and spread and practiced worldwide (Shultz and Saviday 2014).

Different systems of aquaponics have been developed from time to time, for example, the North Carolina State University system developed by McMurthy and Dong Sanders in 1980, which integrates aqua-vegeculture system and tilapia fish tanks which were sunk below the greenhouse floor. After draining from the beds, the water recirculated back into the fish tanks.

The North Carolina State University method was modified by Tom and Paula Speraneo in the early 1990s by raising tilapia in a 500 gallon tank. This system is known as the Speraneo system in which fish effluent is linked to gravel-cultured hydroponic vegetable beds inside an attached solar greenhouse. It was practical, productive and highly successful.

The University of Virgin Island system: James Rakocy and his associates developed a commercial aquaponic system in which Nile and red tilapia were raised in fish rearing tanks, and the aquacultural effluent is linked to floating raft hydroponics. Basil, lettuce, okra and other crops have been grown successfully with outstanding quality and yields.

The Cabbage Hill Farm system: Cabbage Hill Farm has designed and continues to operate a simple recirculating aquaponic system. Tilapia fish and leaf lettuce are the main products of the Cabbage Hill Farm system, though basil and watercress are also grown in smaller quantities (Diver 2006).

10.5 Functional Mechanism

The functional mechanism of aquaponics is a dynamic and complex process principally involving the nutrients recycling in different subsystems. The functional mechanism of aquaponics is based on the principle of the hydroponics in which the chemical salts dissolved in water are the source of nutrients for the soilless plants grown above water. In aquaponic system, organic-enriched wastewater of aquaculture is the source of nutrients released and available to the plants by a number of processes carried out by large number of microorganisms. The complex form of nutrients is transformed into a simple form by microbial decomposition process, which helps to grow the microalgae and zooplankton as feed required for fish growth as well as to grow soilless plants for producing crop products. Consequently, the aquaponic systems improved water quality and produced a second profit centre, in the form of edible plants. All of the tanks and various aquaponic components are connected by pipes. Water flows from the fish tank to mechanical filter where solid waste is removed. The water then flow into a biological filter that converts ammonia to nitrate by nitrifying bacteria. Some systems have special tanks that are designed to promote the growth of microorganisms that act as filter. After being treated in the mechanical and biofiltration component, the water flows back to the fish tank (Mukherjee 2011).

10.6 Aquaponics in Wastewater Reclamation

Several commercially important vegetables and flowering plants are known to utilize the major nutrients such as NO_3-N, NH_4-N, H_2PO_4 and HPO_4-P for their growth from the nutrient-rich wastewater under proper management or suitable amendments. The municipal wastewater is the storehouse of fertilizers but poses a serious threat to the aquatic system in the form of eutrophication unless it is managed properly for biological production. The significance of aquaponics is that it can remove the required nutrients from the municipal wastewater by the roots of vegetables and plants that can grow over the surface of wastewater in a soilless cultivation system. The nutrients flow from wastewater into plant biomass, crop, leaf and flower resulting in the production of cash crop for human consumption. The nutrient-less wastewater is now ready for different activities of the society. Therefore, it is apparent that aquaponics is one of the important eco-technological tool for treating the wastewater. It can also be used in intensive fish farming where the aquatic effluents, resulting from uneaten feed of raising fish, accumulate in water due to the closed-system aquaculture. However, studies are extremely less under wastewater-fed system in the field.

Rana et al. (2011) performed an experiment using different concentrations of municipal wastewater (25%, 50%, 75% and 100%) in plastic buckets, and 10-day-old young healthy tomato plants were implanted in the matrix of pulp-free coconut fibre (3 in. $\times$ 3 in. $\times$ 1 in.) as per one plant in one bed and three plants in one bucket. The plants were allowed to grow on the mat for 2 months (December–January) under natural conditions. Water loss due to sampling and evaporation was replenished with the addition of distilled water. The growth performance and yield of the tomato plant were investigated by measuring biomass, number of leaves, chlorophyll content in index leaf, number of twig, stem length, shoot/root ratio, nitrate reductase (NR) activity in root, crop number and crop mass. After 2 months, the tomatoes were harvested from the plants. Nutrient removal capacity of tomato plants was determined by monitoring PO_4-P, NH_4-N, NO_2-N and NO_3-N of bucket water before and after tomato plantation. The possibility of faecal coliform transmission from wastewater to human has been investigated through the quantification of population size of *E. coli* in wastewater as it is the major species in the faecal coliform group and is the best indicator of faecal pollution and possible presence of pathogens.

The results revealed that the reclamation efficiency of wastewater was the direct function of the growth performance of tomato plants. There were significant differences in average dry biomass among the treatments (Table 10.1). The root mass tended to grow bigger up to 50% dilution but then declined with the highest

Table 10.1 pH, CF and ppm requirement level of different plants

Plants	pH	CF (CF/10 = EC)	PPM	Groups (L, M, H) nutrition requirement
Veggies				
Broccoli	6.0–6.8	28–35	1960–2450	H grow
Cauliflower	6.5–7.0	5–20	1050–1400	M
Common bean	6.0	20–40	1400–2800	M grow and bloom, support stick
Cucumbers	5.5	17–25	1190–1750	M grow, bloom, flowering booster, support
Eggplant	6.0	25–35	1750–2450	H
Okra	6.5	20–24	1400–1680	H grow and bloom
Peppers (*Capsicum*)	6.0–6.5	18–22	1260–1540	M grow, bloom, flowering booster, support
Peas	6.0–7.0	8–18	980–1260	L
Pumpkin	5.5–7.5	18–24	1260–1680	M
Sweet corn	6.0	16–24	840–1680	M
Tomatoes	6.0–6.5	20–50	1400–3500	H grow, bloom, flowering booster, support
Leafy greens				
Cabbage	6.5–7.0	25–30	1750–2100	H grow
Lettuce	6.0–7.0	8–12	560–840	L grow
Spinach	6.0–7.0	18–23	1260–1610	M grow
Fruits				
Banana	5.5–6.5	14–18	1260–1540	M grow, bloom, flowering booster
Melon	5.5–6.0	20–25	1400–1750	H
Pineapple	5.5–6.0	20–24	1400–1680	H
Strawberries	6.0	18–22	1260–1540	M grow, bloom, flowering booster
Watermelon	5.8	15–24	1260–1680	M
Root plants				
Asparagus	6.0–6.8	14–18	980–1260	L grow and bloom
Carrots	6.3	16–20	1120–1400	M
Garlic	6.0	14–18	980–1260	L
Onions	6.0–6.7	14–18	980–1260	L
Potatoes	5.0–6.0	20–25	1400–1750	H
Radish	6.0–7.0	16–22	840–1540	M
Sweet potato	5.5–6.0	20–25	1400–1750	H
Turnip	6.0–6.5	18–24	1260–1680	M

Sources: www.gthydro.com; http://cherylsnotebook.blogspot.com/2010/01/growing-blackberrys-raspberrys-and.html; http://growcontrol.co.uk/cf_ph_nutrient_chart.pdf; http://our.windowfarms.org/2012/01/20/photoperiodism concentration. By contrast, the shoot dry mass increased with the strength of wastewater, and the highest shoot mass (5.921 g) was obtained in 100% wastewater.

The crop yield in all treatments varied from 32 ± 2.0 g (in 25% wastewater) to 125 ± 7.21 g (in 100% wastewater) that was statistically distinct. The crop yield was increased with the rise of the strength of wastewater, and crop was yielded in control. It is evident from the experimental study that tomato plant in an aquaponic system removed as high as 58–75% phosphate, 75% nitrate and reduced chemical oxygen demand by 72% from domestic wastewater within 2 months period. It was concluded that tomato plants grew better in 100% domestic wastewater. The N, P, BOD, coliform bacteria and heavy metal load of 100% domestic wastewater were reclaimed significantly through aquaponic cultivation of tomato plant. The tomato crop yielded in the study was safe for human consumption, and possibility of colitis disease transmission from wastewater to human was very low in this approach.

10.7 Diversity of Aquaponics

There are five primary aquaponic methods emerging in aquaponic system.

10.7.1 Nutrient Film Technique (NFT)

In this system, a film of water with nutrients is allowed to flow through the horizontal pipelines. Generally leafy vegetable plants (e.g. lettuce and other larger plants) are grown above the water. Roots of plants are submerged inside the water and nutrient film and take up nutrients and water required for their growth (Fig. 10.1).

Fig. 10.1 NFT system of aquaponics

In most NFT systems, PVC pipes are used to carry the flow of water-nutrient mixture from fish tank. A series of holes are drilled over the whole length of PVC pipes. Types of plants that are desired to grow in the NFT system will decide the diameter of holes. The advantages and some disadvantages of this system have been discussed (https://sites.google.com/site/aquapanaponics/4-project-updates/advantagesanddisadvantagesofaquaponics).

10.7.2 Vertical System

This is mainly a multi-tier system. A large fish tank is placed on the first lower tier. Then vegetables are grown in multi-tier vertical columns without soil above the fish tank (Fig. 10.2). Nutrient-rich water from fish tank is drawn to the top tier with the help of a pump. Water is allowed to trickle down through the roots of the plants. In the process, it releases nutrients for plants and gathers oxygen from the air as it back into the fish tank. As the system is mostly enclosed, little or no waste is generated, and also there is no need for fertilizer or pesticides. It is a water-efficient and space-saving way to garden and raise fish. In this system, tilapia and trout are cultured with leafy vegetables, tomatoes and herbs (www.Instructables.com).

10.7.3 Media-Based System

This system is also known as gravel bed system. It uses containers filled with rock medium of expanded clay, which are porous to absorb water and air, and then seedlings are planted directly into the system. Water from fish tank is circulated through the container to allow the plants to access the nutrients. In this system,

Fig. 10.2 Vertical system of aquaponics

Fig. 10.3 Gravel media-based small aquaponic model in operation at Central Institute of Fisheries Education, Kolkata Centre

rocks act as biological filter as well as solids filter. This scale (www.backyardaquaponics.com)

Gravel media-based flood and drain aquaponic model was used in the Central Institute of Fisheries Education, Kolkata Centre, since June 2014 (Fig. 10.3). The growth of tilapia, koi carp and leafy vegetables (pumpkin, Malabar spinach, bitter gourd) is satisfactory (Figs. 10.4a, b) (Datta 2015).

10.7.4 Deep Water Culture System

Deep water culture system (Fig. 10.5) works on the idea of floating plants on top of the water allowing the roots hanging down into the water. This system is constructed with long channels which hold water at a depth of around 30–40 cm. Boards can be made from Styrofoam, plastic, etc. Holes are made into the boards. Plants are either sown directly into the net pots or transplanted from other growing area. The plants grown with their roots always immersed in the long channel of water below the boards. This is one of the more commercial methods (Blom 2013).

10.8 Wicking Bed System

In wicking bed aquaponic system, the water from fish tank is fed once a week in summer through a slotted pipe that allows the water to flow down and slowly 'wick' its way up by capillary action and feed the plant roots from the bottom up (Fig. 10.6). One of the advantages of this system is that the wicking beds only

Fig. 10.4 (**a**) Growth of pumpkin and Malabar spinach on the aquaponics. (**b**) Koi carp grown in aquaponic roof of wet laboratory arising out of vegetable beds of aquaponic system

Fig. 10.5 Deep water culture system of aquaponics

Fig. 10.6 Wicking bed system of aquaponics

need watering once a week in high summer and once a month in winter. Wicking beds are suitable for growing carrots, beets, potatoes, etc. (Smith 2012).

10.9 Factors Influencing Performance of Aquaponics

As a general rule, plants will have higher nutrient requirement during winter and a lower requirement during summer when plants take up and transpire more water than nutrients. In a well-designed and balanced aquaponic system, the ratio between fish and plants is based on the feeding rate ratio. For a raft hydroponic system, the optimum ratio varies from 60 to 100 g/m^2/day. For example, if the fish are being fed 1000 g/day on average, the area devoted to hydroponic production should be 16.7 m^2 for a feeding rate ratio of 60 g/m^2/day. The optimum feeding rate ratio depends on many factors such as type of hydroponic system, plants being cultivated, chemical composition of source of water and percentage of system water lost during solids removal. The optimum feeding rate ratio for a nutrient film technique hydroponic system is roughly 25% of the ratio used for a raft system (Rakocy 2007).

One of the factors that can be used as indicator for the performance of aquaponics is electrical conductivity, which is directly proportional to the dissolved mineral salt content of water, i.e. the more the electrical conductivity, the more is the salt content of water and vice versa. Pure water does not conduct electricity, so the conductivity factor (CF) is 0 (EC 0.0), but it increases with increase in dissolved mineral salt. This is used as indicator of mineral content of water.

CF is important to plants because a solution that is too strong can burn the roots and causes reverse osmosis. Reverse osmosis occurs when the minerals are drawn out of the plant because the solution on the outside of the plant is stronger than on the inside; this can lead to plant death. When the CF level is too low, it will cause weak, thin and leggy plants, and the plant will not produce its potential yield. It will also be more susceptible to disease.

The required CF levels are different for many crops; even it varies at different stages of growth of the same plant. Lettuces grow at a CF range of 6–16. Levels are generally at the higher end under cool, low and light conditions and lower in the tropical conditions. Tomatoes are normally grown at CF levels of 26–46, depending on variety and stage of crop. They start at levels as low as 18 at planting and build up the CF level until full fruiting occurs at the higher levels. Home growers with hobby systems will grow good tomatoes at CF levels of 18–30, harvesting the fruit vine ripe, while the commercial grower will grow his commercial varieties of tomatoes at the higher CF levels to get better quality into the fruit, as they are often picked before being fully ripe (http://www.nftgully.com/).

According to conductivity factor, plants are divided into three types (Savidov 2005).

1. High CF (20–40): tomato, eggplant
2. Medium CF (10–20): lettuce, basil, spinach, cucumber, chives
3. Low CF (2–10): watercress

Plant EC or CF may vary according to the stage of growth. For example, cucumber prefers CF 20 when establishing and CF 25 after the first harvest. However, the optimum CF is 17 within 7 weeks after the first harvest (http://our.windowfarms.org/tag/pumpkin/). The pH and electroconductivity values (Table 10.2) revealed a wide range of variability among the plants and that specific plant requirements will vary according to regional climatic conditions from season to season in a particular region. In this case 1 CF = 100 μS and 1 mS = 10 CF = 700 ppm (http://www.homehydrosystems.com/index.html).

10.10 Global Scenario of Aquaponics

India

There are as many as ten private aquaponic farms which are working to produce crops particularly organic vegetable at commercial level. Vigyan Ashram in India is exploring aquaponic agriculture in Indian conditions mainly to increase productivity of agriculture per unit area of land with less water. An experimental study conducted to study the ‘Effect of Aquaponics on Polyhouse Cucumber Cultivation’ during February to May 2013 in Vigyan Ashram, Pabal, Pune, Maharashtra, showed that aquaponic treatment produced 18.25%, more yield over control treatment; the average number of fruits per plant was much higher compared to control plot. Fish growth in this system was satisfactory with 25 g weight gain per month (Shanbhag 2013).

USA

Dr. James Rakocy at the University of Virgin Islands developed an aquaponic system that relies on rainwater catchment, rotating mechanical biofilters and floating polystyrene panels that hold the plants. This differs dramatically from the

Table 10.2 Water quality in different strengths of domestic wastewater in the tomato aquaponic experiment

Parameter	Treatment									
	Control		25% wastewater		50% wastewater		75% wastewater		100% wastewater	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Temperature (°C)	$22.5^{a} \pm 0$	21.5 ± 0	$22.5^{a} \pm 0$	21.5 ± 0	$22.5^{a} \pm 0$	21.5 ± 0	$22.5^{a} \pm 0$	21.5 ± 0	$22.5^{a} \pm 0$	21.5 ± 0
Concentration of hydrogen ion (pH)	8.14^{a}	8.3	7.82^{b}	8.47	7.74^{b}	8.4	7.71^{b}	8.32	7.49^{c}	8.26
Total alkalinity (mg $CaCO_3$/l)	$178.0^{a} \pm 8.67$	211.64 ± 10.32	$158.98^{b} \pm 9.23$	306.0 ± 13.27	128.99c ± 7.54	287.0 ± 13.29	$124.32^{c} \pm 7.77$	220.14 ± 12.31	$62.1^{d} \pm 3.37$	198.23 ± 9.87
Dissolved oxygen (DO) (mg/l)	$4.01^{a} \pm 0.17$	12.67 ± 0.75	$3.97^{a} \pm 0.18$	14.67 ± 0.89	$3.74^{a} \pm 0.18$	12.01 ± 0.56	$3.11^{a} \pm 0.19$	11.74 ± 0.86	1.32b ± 0.061	9.54 ± 0.29
Inorganic phosphate-phosphorus (PO_4-P) (mg/l)	$0.043^{e} \pm 0.005$	0.018 ± 0.002	$0.094^{d} \pm 0.011$	0.035 ± 0.002	$0.147^{c} \pm 0.042$	0.037 ± 0.001	$0.182^{b} \pm 0.027$	0.055 ± 0.008	$0.209^{a} \pm 0.018$	0.058 ± 0.006
Nitrate nitrogen (NO_3-N) (mg/l)	$0.001^{e} \pm 0.000$	0	$0.842^{d} \pm 0.091$	0.213 ± 0.019	$7.14^{c} \pm 0.084$	1.78 ± 0.152	$8.13^{b} \pm 0.761$	2.01 ± 0.213	$8.83^{a} \pm 0.875$	1.94 ± 0.213
Ammonium ion (NH^{4+}) (mg/l)	$0.01^{e} \pm 0.001$	0.087 ± 0.093	$0.72^{d} \pm 0.084$	0.41 ± 0.052	$1.81^{c} \pm 0.201$	0.53 ± 0.067	$4.0^{b} \pm 0.53$	0.61 ± 0.078	$5.91^{a} \pm 0.641$	0.76 ± 0.112
Nitrite nitrogen (NO_2-N) (mg/l)	$0.001^{d} \pm 0.000$	0.006 ± 0.001	$0.005^{c} \pm 0.001$	0.013 ± 0.006	$0.008^{c} \pm 0.001$	0.043 ± 0.007	$0.015^{b} \pm 0.003$	0.052 ± 0.008	$0.034^{a} \pm 0.005$	0.087 ± 0.014
Chemical oxygen demand (COD) (mgO_2/l)	0	20 ± 3.12	$100^{d} \pm 11$	80 ± 9.5	$212^{c} \pm 17.28$	140 ± 11.23	$307^{b} \pm 23.51$	160 ± 13.28	$518^{a} \pm 27.89$	200 ± 17.78

Biological oxygen demand (BOD_5 at 20 °C) (mgO_2/l)	0	4 ± 0.81	60.7^{d} ± 6.17	23.3 ± 1.89	90.1^{c} ± 8.41	34.2 ± 3.11	147.3^{b} ± 11.32	48.7 ± 4.17	211.4^{a} ± 22.37	59.12 ± 6.31
E. coli population (cfu × 10^7/ml)	0	0	87^{d} ± 7	7 ± 2	153^{c} ± 15	12 ± 3	192^{b} ± 18	17 ± 3	243^{a} ± 21	19 ± 3
Total dissolved solid (TDS) (mg/l)	0	4 ± 0.78	269^{d} ± 23.56	9^{a} ± 1.23	779^{c} ± 62.38	9 ± 2.14	1983^{b} ± 153.7	10 ± 1.03	3749^{a} ± 271.31	12 ± 0.97
Total suspended solid (TSS) (mg/l)	0	16 ± 1.21	547^{d} ± 43.28	17 ± 1.18	1581^{c} ± 129.37	19 ± 2.11	3375^{b} ± 311.27	21 ± 1.97	4971^{a} ± 437.28	28 ± 2.31
Total solid (TS) (mg/l)	0	20 ± 1.88	816^{d} ± 47.66	26 ± 2.13	2360^{c} ± 211.37	28 ± 2.13	5358^{b} ± 521.52	31 ± 2.74	8720^{a} ± 633.28	40 ± 8.17

Data represented as arithmetic mean of three samples ($n = 3$) with standard error of mean (±SE). Unlike superscripts (a–e) denote significant differences between treatment means at 5% level ($P < 0.05$) and vice versa (*Source*: Rana et al. 2011)

Speraneo and NC state models in which vegetable beds themselves serve as biofilter for cleaning effluent water. Rakocy raises tomatoes and leafy vegetables. Mark McMurtry and Dr. Rakocy used integrated water reuse systems as viable solution to self-sufficient food production in developing countries and other locations where freshwater is scarce (Diver 2000). Research conducted at University of Florida showed that cucumber crop can be successfully adopted with aquaponic system. This is reported that 45.3 kg (100 pound) of fish will produce sufficient nitrogen for 4050 lettuce or 540 tomato plants when they are fed with 3 % of their body weight.

Japan
It is stated that all fishes are not suitable for culture in aquaponic system. Tilapia is the main fish that can be used because these fishes are hardy and can tolerate high levels of ammonia and nitrate. Researches have shown that a right selection of qualitatively different fish feed (low protein and low fat and high protein and high fat) along with type of leafy green vegetables (lettuce and *Brassica juncea*) was important for superior growth of the fish (Paul 2013).

Australia
Gravel beds were used as hydroponic component. Gravel beds are very useful for small systems as they act as both solids and biological filter components and therefore may replace traditional aquaculture filtering components. One of the important considerations in aquaponics is that reciprocal flows (flood and drain flows – the pump is on for a number of minutes in every hour) are to be used for gravel beds, which will add aeration of the gravel beds, increase oxygen availability to the plant roots and aid in more uniform nutrient supply. It has been claimed that NFT system may be as much as 20% less efficient than gravel beds/floating rafts. This was probably because in gravel bed and raft systems, the plant roots are 100% in contact with water column, whereas, in NFT, only up to 50% of the root mass is in contact with water (Lennard 2004).

Canada
Aquaponics is considered as a potentially important industry with two major components: fish and plants, each locally grown as high-value products and can be produced and marketed year-round. Fish waste could be an adequate source of nutrients for intensive crop production. The yield under the conditions of standard greenhouse technology plant density was about 40 kg of tomatoes/m^2/y, 100 cucumber/m^2/y. These yields far exceeded the average yields of greenhouse vegetables produced by organic soil-based technologies in Canada (Savidov 2005).

10.11 Conclusions

Water and soil are two important natural resources, the scarcity of which has been projected to be acute in the coming years. In view of projected water crisis, reduced cultivable land and population rise, aquaponics can provide a suitable complementary high-density culture method both for fish and vegetables. It can also reduce land crisis by utilizing wastewater resources for biological production. Also the production of crops and fish in India is highly dependent on rainfall. When the rainfall is low, the production of food as well as fish is affected adversely. Production of fish and plants is not dependent on rainfall in the aquaponics.

In ornamental fishery, the water used for culture is generally exchanged routinely with freshwater. This nutrient-rich water with some innovative aquaponic intervention could be utilized to grow some vegetables which are grown in home/kitchen garden and cut some expenditure of ornamental fishermen to run the household. In the absence of suitable reuse mechanism, the consumption of freshwater is more in aquaria due to routine water exchange. Gravel media-based aquaponic system has been used successfully to rear the ornamental fish koi carp and to grow a variety of vegetables (pumpkin, Malabar spinach, bitter gourd, ash gourd, tomato) without routine water exchange and aeration in Central Institute of Fisheries Education, Kolkata Centre (Datta 2015). However, more field studies are necessary to evaluate the potentials of aquaponics for ornamental fishery.

References

Blom J (2013) Deep water culture grow bed. Aquaponics.info http://aquapons.info/resource/grow-beds/deep-water-culture-grow-bed/

Bohl M (1977) Some initial aquaculture experiments in recirculating water systems. Aquaculture 3:323–328

Collins M, Gratzek J, Shotts E Jr, Dawe D, Campbell L et al (1975) Nitrification in an aquatic recirculating system. J Fish Res Board Can 32:2025–2031

Datta S (2015) Aquaponics – its present status and potential. Fishing Chimes 34(11):44–48

Diver S (2000) Aquaponics-integration of hydroponics with aquaculture. www.attra.ncat.org

Diver S (2002) Work linking integrated farming with permaculture. http://attra.ncat.org/attra-pub/perma.html

Diver S (2006) Aquaponics-integration of hydroponics with aquaculture. www.attra.ncat.org

Douglas JS (1975) Hydroponics, 5th edn. Oxford University Press, Bombay, pp 1–3

Edwards P (2000) Wastewater fed aquaculture: state of the art. In: Jana BB, Banerjee RD, Guterstam B, Heeb J (eds) Waste recycling and resource management in the developing world: ecological engineering approach. International Centre of Ecological Engineering Society/University of Kalyani, Wolhusen/Kalyani, pp 37–50

Gericke WF (1940) The complete guide to soilless gardening. Prentice-Hall Inc., New York

Jana BB (1998) Sewage-fed aquaculture: the Calcutta model. Ecol Eng 11:73–85

Jana BB, Jana S (2002) The wastewater resources for aquaculture: the need for sustainable development. Verh Int Verein Limnol 28:1771–1774

Jensen MH, Collins WL (1985) Hydroponic vegetable production. Hortic Rev 7:483–558

Lennard WA (2004) Aquaponics research at RAMIT University, Melbourne Australia. Aquaponics J 35:18–24

Lewis WM, Yopp JH, Schramm JHL (1978) Use of hydroponics to maintain quality of recirculated water in a fish culture system. Trans Am Fish Soc 107:92–99

Love DC, Fry JP, Genello L, Hill ES, Frederick JA, Li X, Semmens K (2014) An international survey of aquaponics practitioners. PLoS One 9(7):e102662. https://doi.org/10.1371/journal.pone.0102662

Mukherjee S (2011) Aquaponic system and technology. http://www.sankalpacmfs.org/src/wp/Concept.Note_Aquaponic.Systems.pdf

Naegel LCA (1977) Combined production of fish and plants in recirculating water. Aquaculture 10:17–24

Paul BC (2013) Reproduced from practical hydroponics and greenhouses, *PHG May 2013* – Issue *131.* http://hydroponics.com.au/free-articles/aloha-aquaponics

Rakocy JE (1984) A recirculating system for tilapia culture and vegetable hydroponics. In: Smitherman RO, Tave D, (ed). Auburn, pp 103–114

Rakocy J (2007) Ten guidelines for aquaponic systems. Aquaponics J 46:14–17

Rakocy JE (2012) Aquaponics-integrating fish and plant culture. Wiley-Blackwell, Oxford, pp 344–386

Rakocy JE, Masser MP, Losordo TM (2006) Recirculating aquaculture tank production systems: aquaponics – integrating fish and plant culture (454). Southern Regional Aquaculture Center. Retrieved April 24, 2013

Rana S, Bag SK, Golder D, Mukherjee (Roy) S, Pradhan C, Jana BB (2011) Reclamation of municipal domestic wastewater by aquaponics of tomato plants. Ecol Eng 37: 981–988

Runia WT (1995) A review of possibilities for disinfections of recirculation water from soilless cultures, glasshouse crops. Res. Sta. (Naaldwijk, Holland), 9

Savidov N (2005) Evaluation of aquaponics technology in Alberta, Canada. Aquaponics J 37:20–25

Shanbhag R (2013) Effect of aquaponic system on yield of polyhouse cucumber. http://vigyanashram.files.wordpress.com/2013/09/aquaponics-farming-techniquc.pdf

Shultz RC, Saviday NA (2014) Evolution of Aquaponics in Alberta, Canada; Seattle

Smith C (2012) Integrating wicking beds into an aquaponic system. http://community.theaquaponicsource.com/groups/group/show?groupUrl=wicking-bed-growers&id=4778851%3AGroup%3A329626&page=5

Sneed K, Allen K, Ellis J (1975) Fish farming and hydroponics. Aquac Fish Farmer 2:18–20

Stoner RJ, Clawson JM (1997–1998) A high performance, gravity insensitive, enclosed aeroponic system for food production in space. Principal Investigator, NASA SBIR NAS10-98030

Sutton RJ, Lewis WM (1982) Further observations on a fish production system that incorporates hydroponically grown plants. Prog Fish Cult 44:55–59

Todd J (1980) Dreaming in my own backyard. J New Alchemists 6:108–111

Watten BJ, Busch RL (1984) Tropical production of tilapia (*Sarotherodon aurea*) and tomatoes (*Lycopersicon esculentum*) in a small-scale recirculating water system. Aquaculture 41:271–283

Chapter 11
Recent Technologies for Wastewater Treatment: A Brief Review

S. P. Shukla, Saurav Kumar, S. Gita, V. S. Bharti, Kundan Kumar, and G. Rathi Bhuvaneswari

Abstract There is an unprecedented increase in per capita use of, especially water, during the past few decades. In view of the vital significance of water resources, unsustainable use of water resources would cause serious impediment to the growth of economy and standard of living worldwide. Therefore, new approaches for a sustainable utilization of water resources are of utmost importance for a secure future. In recent past, a number of new wastewater treatment technologies have been developed which paved the way for achieving the sustainability through judicious water resource utilization and management. The new wastewater treatment technology, especially the integration of urban water and waste management systems, is a promising approach for the improvement of sustainability of global water resources.

Keywords Wastewater treatment · Nanotechnology · Microbial fuel cells

Contents

S. P. Shukla (✉) · S. Kumar · S. Gita · V. S. Bharti · K. Kumar · G. Rathi Bhuvaneswari
Aquatic Environmental Management Section, Aquatic Environment & Health Management Division, Central Institute of Fisheries Education, Versova, Mumbai, India
e-mail: spshukla@cife.edu.in

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_11

11.1 Introduction

There is an unprecedented increase in per capita use of, especially water, during the past few decades. In view of the vital significance of water resources, unsustainable use of water resources would cause serious impediment to the growth of economy and standard of living worldwide. Therefore, new approaches for a sustainable utilization of water resources are of utmost importance for a secure future. In recent past, a number of new wastewater treatment technologies have been developed which paved the way for achieving the sustainability through judicious water resource utilization and management. The new wastewater treatment technology, especially the integration of urban water and waste management systems, is a promising approach for the improvement of sustainability of global water resources (Peter-Varbanets et al. 2009).

The natural mechanism and processes of hydrologic cycle involve continuous recycle of water, making it inherently renewable. However, an increasing rate of use of water prior to its return to the environment can impact the sustainability of water resources negatively. Wastewater treatment has gained immense importance in recent years due to increasing demand of clean water, and its scarcity has created limited water resources. The total water demand for all the uses is likely to be 1180 BCM (billion cubic meters) by 2050 (Fig. 11.1) as per NCIWRD (National Commission on Integrated Water Resources Development) report (Kumar 2013). Depending on their origin, wastewaters can be classified as sanitary, commercial, industrial, or surface runoff.

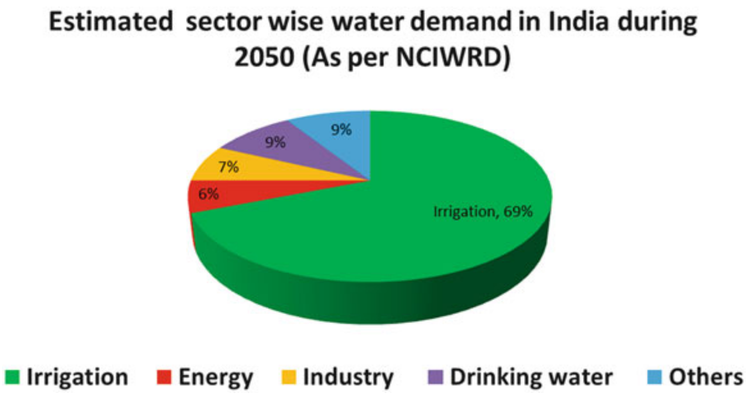


Fig. 11.1 Estimated sector-wise demand in India during 2050 (As per NCIWRD)

Though the recycling technologies can significantly reduce net water abstraction from the environment, the application of these technologies for water recycling can facilitate the sustainability of water resources.

11.2 Recent Techniques

Some of the advanced and modern techniques which are used as components of the wastewater treatment are as follows.

11.2.1 Cavitation

Cavitation of water results in the generation, growth, and subsequent collapse of gas-filled cavities (bubbles) due to pressure pulses inside a liquid bulk. The bubbles generated through a mechanical device grow in size until the external pressure over the liquid decreases to a threshold value, usually around the vapor pressure of the liquid. After reaching this threshold, bubbles collapse and implode. When bubbles implode, the compression effects upon its internal gases might cause temperature increase up to 103–104°K and pressure peaks of 102–103 bar. Due to the extreme pressure – temperature conditions inside the bubbles – water dissociates into H^+ and OH^- radicals. The hydroxyl radical due to its strong oxidation tendency readily oxidizes the chemicals and affects the microbes (Dular et al. 2016).

In spite of higher operation costs, cavitation offers two important advantages over conventional advanced oxidation processes (AOPs) due to the fact that neither reactants nor UV light are used: first, it requires significantly lower operation costs than the rest of the advanced oxidation processes (AOPs); and second, the by-products are limited to those expected from the oxidation of the contaminants, avoiding the presence of other dangerous oxidants such as chlorine.

11.2.1.1 Hydrodynamic vs. Ultrasonic Cavitation

Cavitation is classified into two, (1) ultrasonic cavitation and (2) hydrodynamic cavitation, depending upon the type of device used for generating the bubbles in aqueous phase. The first one consists of pressure waves generated in an ultrasonic bath or through an ultrasonic horn inside a liquid bulk, while the latter is based on the pressure variations due to acceleration/deceleration of a liquid flow.

Ultrasound cavitation has proven to efficiently remove a wide variety of contaminants in water. Ultrasonic equipment (horns and baths) are probably the best way to effectively study the phenomenon of cavitation. Most commercial equipment are prepared to work at lab scale. The parameters of the pressure pulse, such as amplitude or frequency, are easy to control and reproduce. Moreover, the whole process takes place inside a static liquid with no change in the ambient conditions, and therefore observations and measurements are easy to perform. Due to these advantages, ultrasonic cavitation has been the main object of study for most groups interested on cavitation. Nevertheless, some technical problems have been found up-scaling the equipment. Large bulk liquids cushion ultrasound waves, and the liquid only cavitates in the proximity of the ultrasonic horns, what causes significant decreases in the efficiency of the process. It is generally agreed that hydrodynamic cavitation implies a number of practical problems in both operation control and direct measurements. Cavitation loops are usually designed for medium- and large-scale operations (tanks from10 to 1000 l). In contrast with ultrasonic cavitation, the process takes place in a high velocity flow inside a closed pipe. This is the source of additional complexity and limitations regarding the control over the pressure pulse. It is unclear whether turbulence, boundary layer separation, and other hydrodynamic factors are positive or negative in terms of final effects of the technique, but they have certainly prevented an exploratory research on potential applications of hydrodynamic cavitation.

Benito et al. (2005) designed a plant to produce hydrodynamic cavitation. The cavitation loop consists of a tank (containing the contaminated water), a discharge pipe with a pump, and a cavitation chamber after which liquid flows back to the tank. High-speed loop circulation of the contaminated water creates cavitation. In the first stage, the liquid first accelerates in the convergent section; as a result, pressure decreases; and therefore bubbles generate and grow. In the second stage – the liquid decelerates after entering a diverging section, giving rise to pressure recovery and bubble explosion. The liquid is circulated and cavitated during a period of time that varies from case to case (15 and 90 min).

11.2.1.2 Advantages of Hydrodynamic Cavitation

Ultrasonic cavitation has been extensively studied during the last decade. Its capability to oxidize organic substances is comparable to that of other AOPs, but due to the difficulties to perform at industrial scale, the technique has been studied from a scientific point of view rather than an engineering one. Operational cost based on energy efficiency is also lower for hydrodynamic cavitation processes. Although experimental procedures are less flexible and optimization is harder to achieve, the technique offers some important advantages over ultrasonic cavitation. Hydrodynamic loops, which essentially consist of a pump, a tank, a Venturi tube, and pipes, are cheaper than ultrasonic equipment for a given scale (especially for industrial scale). Operation costs, based on energy efficiency, are also lower for hydrodynamic cavitation.

11.3 High Rate Algal Pond System (HRAPs)

HRAPs are shallow, open raceway ponds that have depths of 0.2–1 m and have been used for treatment of municipal, industrial, and agricultural wastewaters. Mixing is normally provided by a paddle wheel to given mean horizontal water velocity of approximately 0.15–0.3 m/s. The pond bottom may be either lined or unlined depending on soil conditions and local regulations, and CO_2 can be added into a countercurrent gas sparging sump (1.5 m depth) creating turbulent flow within the pond (Montgomery 1985). Algae growing in wastewater treatment HRAPs assimilate nutrients, and thus subsequent harvest of the algal biomass recovers the nutrients from the wastewater.

Wastewater treatment HRAPs are normally part of an advanced pond system which typically comprises advanced facultative ponds which incorporate anaerobic digestion pits, HRAP, algal settling ponds, and maturation ponds in series. Based on the design for BOD removal, advanced pond systems require approximately 50 times more land area than activated sludge systems (one of the most common wastewater treatment technologies), although this does not account for the land area needed to dispose off waste activated sludge.

Merits of HRAPs

Algae produced in HRAP can be simply and cost-effectively converted into biofuel through anaerobic digestion in an ambient temperature in covered digester pond or heated and mixed anaerobic digesters could also be used. The biomass produced in HRAPs can be used as a tertiary treatment.

Demerits

HRAPs require large area for the construction. Screening of suitable species of algae according to type of wastewater is a tedious process. Control of grazers and parasites needed, algae harvest and density control are necessary.

11.4 Biotechnological Interventions in Wastewater Treatment

Biotechnology offers the opportunity to create artificial combination of genes that do not exist together in nature. Methods based on biotechnology in wastewater treatment are activated sludge, trickling filters, oxidation ponds, biofilters, and anaerobic treatment.

The genetic engineering of bacteria for bioremediation mainly involves the transfer of genes for the enzymes specific to the degradation of a contaminant, genes coding for metal-binding proteins and heavy metal transporter and uptake genes, etc. (Buyukgungor and Gurel 2009).

11.5 Application of Nanomaterials for Water and Wastewater Treatment

11.5.1 Adsorption

Adsorption is a process of removal of organic and inorganic contaminants from water and wastewater through binding of the contaminants on active sites on the surface of the adsorbents. Nanoadsorbents are superior to than conventional adsorbents due to their extremely higher specific surface area and associated sorption sites, short intra-particle diffusion distance and tunable pore size, and surface chemistry.

11.5.2 Carbon-Based Nanoadsorbents

Carbon nanotubes – Carbon nanotubes (CNT) have shown higher efficiency than activated carbon for the removal of various organic chemicals through adsorption (Pan and Xing 2008).

11.5.3 Metal-Based Nanoadsorbents

The nanoscale oxides of iron, titanium, and alumina are effective low-cost adsorbents for heavy metals and radionuclides. The metal oxide nanoadsorbents exhibit a higher adsorption capacity and faster kinetics because of the higher specific area, shorter intra-particle diffusion distance, and larger number of surface reaction sites.

Nanomaterials have shown great potential for the removal of metals such as arsenic, lead, mercury, copper, cadmium, chromium, and nickel. They have been found to outcompete the conventional adsorbents such as activated carbon.

11.5.4 Polymeric Nanoadsorbents

Polymeric nanoadsorbents (dendrimers) are tailored adsorbents with a capacity to remove both organic contaminants and heavy metals (Fig. 11.2). The interior of polymeric nanoadsorbents can be hydrophobic for sorption of organic compounds, while the exterior branches can be tailored by incorporating hydroxyl or amine groups. The tailored dendrimers facilitate adsorption of heavy metals through complexation, electrostatic interactions, hydrophobic effect, and hydrogen bond.

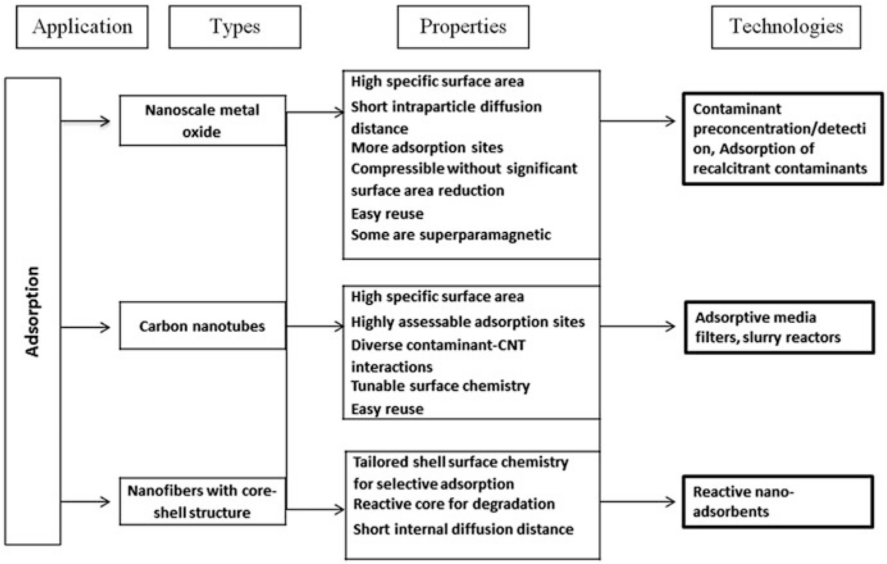


Fig. 11.2 Application of nanomaterials for the improved adsorbents for the removal of contaminants from wastewater

11.5.5 Nanomaterial-Based Membranes

The performance of membrane systems used in wastewater treatment processes depends upon the characteristics such as low energy requirement, maintenance of membrane selectivity and permeability, and non-susceptibility to biofouling (Fig. 11.3) (Mohmood et al. 2013). If the membrane lacks above attributes, the lifetime of membranes and membrane modules is reduced considerably. Incorporation of functional nanomaterial into membranes is a promising approach to improve the membrane permeability, fouling resistance, and mechanical and thermal stability.

11.5.6 Nanofiber Membranes

Nanofiber membrane has high specific surface area and porosity in comparison to traditional membrane. An advantage associated with nanofiber membranes is the easy manipulation of diameter, morphology, composition, secondary structure, and alignment of nanofibers in the membrane (Li and Xia 2004). Nanofiber membranes have a potential for removal of micron-sized particle from aqueous phase at a high rejection rate with least fouling of membrane. By virtue of the tunable properties, the electrospun nanofibers provide a feasible solution for wastewater treatment

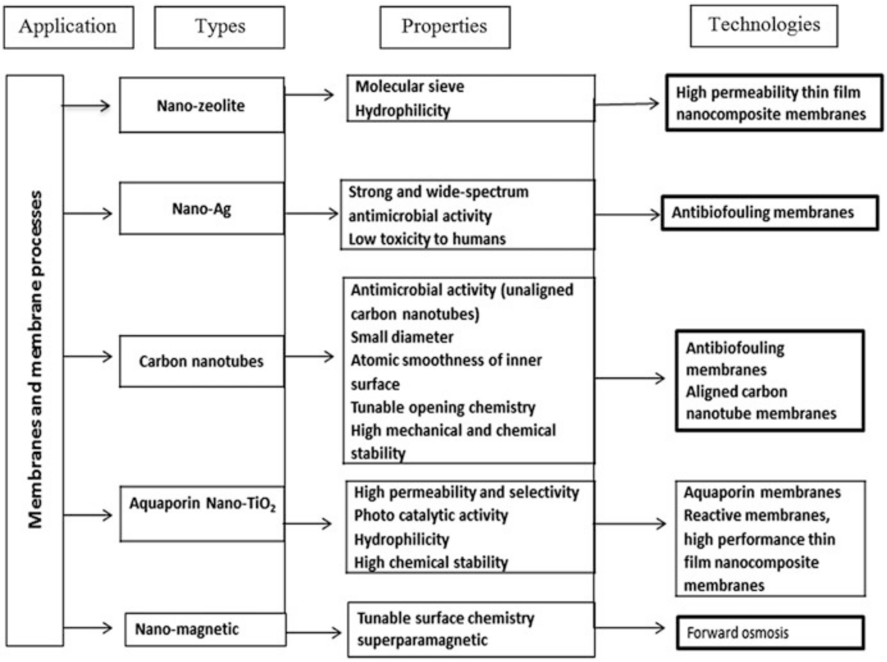


Fig. 11.3 Nanomaterials applied for the enhanced efficiency of membrane processes employed for wastewater treatment

either by directly using intrinsically multifunctional materials, e.g., TiO_2, or by incorporating specific capture agents on the nanofiber scaffold.

Nanocomposite membrane – The nanocomposite membranes show a lesser extent of biofouling than the traditional membranes. An introduction of hydrophobic metal oxide nanoparticle, e.g., Al_2O_3, TiO_2, and zeolite, increases the fouling resistance of the membrane. These metal oxides of nanosize also help in enhancing the mechanical and thermal stability of polymeric membranes.

Thin film nanocomposite (TFN) membranes – TFN membranes are developed by incorporating nanomaterials into the active layer of thin film composite (TFC) membranes via doping in the casting solutions. Nanomaterials that have been found suitable for such applications include nano-zeolite, nano-Ag, nano-TiO_2, and CNTs. Nano-zeolites are the most frequently used dopants in TFN and have shown potential in enhancing membrane permeability. TFN membrane doped with 200 nm nano-zeolite at 0.2 wt % showed moderately higher permeability and better rejection (>99.4%) than commercial RO membranes (Lind et al. 2010).

Application of nanomaterials for water and wastewater treatment is gaining popularity globally. The unique properties of nanomaterials and their convergence with the traditional water treatment technologies offer great opportunities for bringing a revolutionary change in water and wastewater treatment.

11.6 Microbial Fuel Cell (MFCs) and Wastewater Treatment

MFCs are low-cost and low energy solution for conventional aerobic treatment processes used for wastewater such as domestic wastewater.The traditional wastewater treatment processes consume higher energy and produce large amount of excess sludge which requires further expenses on appropriate treatment and disposal. Microbial fuel cells enable the recovery of energy out of the wastewater, therefore reducing both the energy input and the excess sludge production. Initially, MFCs were not gaining adequate attention; however, due to increase in power outputs by integration of both microbial and electrochemical aspects, MFCs have emerged as a promising solution for wastewater treatment (Aelterman et al. 2006).

MFC technology is a new approach for generating renewable energy via wastewater. In spite of its infancy, MFC technology is thought to offer a true alternative to traditional energy generation processes based on fossil fuels.

11.6.1 Concept of MFCs

MFCs are based on the concept of bacteria-led oxidation and reduction processes using the electrolytes present in water as substrate. The MFCs consist of two chambers (anode and cathode) filled with wastewater in one and seawater (as electrolyte) in other chamber along with two electrodes, a proton-exchange membrane and an external circuit. Wastewater is degraded by the bacteria in the anodic chamber, and seawater is diluted to brine in the cathodic chamber. This whole process generates bioelectricity. Typical reactions within MFC are:

$$CH_3COO^- + 2H_2O \rightarrow 2CO_2 \text{(Anode Reaction)}$$
$$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O \text{ (Cathode Reaction)}$$

11.6.2 Mechanism of MFCs

Electron and protons are continuously generated in a MFC due to oxidation of substrates such as acetate, in the anodic chamber. Carbon dioxide is produced as an oxidation by-product. The electron(e-) is absorbed by the anode and transferred to the cathode through an extended circuit. Once the proton crosses the proton-exchange membrane (PEM) or a salt bridge, the proton enters the cathodic chamber where they combine with oxygen to form water.

11.7 Conclusions

Wastewater treatment is closely related to the standards and/or expectations set for the effluent quality. Wastewater treatment processes are designed to achieve improvements in the quality of the wastewater. So, different factors like quality and quantity of wastewater, land availability, financial flexibility, etc. should be taken under consideration to choose the best suited technique for a particular plant.

Besides various scientific developments, treatments of 100% wastewater are yet to be achieved to ensure better environmental health. Wastewater treatment process is one of the most important environmental conservation processes that should be encouraged worldwide especially in developing countries.

References

Aelterman P, Rabaey K, Clauwaert P et al (2006) Microbial fuel cells for wastewater treatment. Water Sci Technol 54(8):9–15

Benito Y, Arrojo S, Hauke G, Vidal P (2005) Hydrodynamic cavitation as a low-cost AOP for wastewater treatment: preliminary results and a new design approach. WIT Trans Ecol Environ 80:495–503

Buyukgungor H, Gurel L (2009) The role of biotechnology on the treatment of wastes. Afr J Biotechnol 8(25):7253–7262

Dular M, Griessler-Bulk T, Gutienez-Aguire I et al (2016) Use of hydrodynamic cavitation in (waste) water treatment. Ultrasonics Sonochem 29:577–580

Kumar S (2013) India's national security: annual review 2010. Routledge, Taylor & Francis Group, New Delhi, p 540

Li D, Xia YN (2004) Electro-spinning of nanofibers: reinventing the wheel? Adv Mater 16 (14):1151–1170

Lind ML, Suk DE, Nguyen TV, Hoek EMV (2010) Tailoring the structure of thin film nanocompositememebranes to achieve seawater RD membrane performance. Environ Sci Technol 44(21):8230–8235

Mohmood I, Batista Lopes C, Lopes I, Ahmad I, Duarte AC, Pereira E (2013) Nanoscale materials and their use in water contaminants removal-a review. Environ Sci Pollut Res 20:1239–1260

Montgomery JM (1985) Water treatment principles and design. Wiley, New York

Pan B, Xing BS (2008) Adsorption mechanisms of organic chemicals on carbon nanotubes. Environ Sci Technol 42(24):9005–9013

Peter-Varbanets M, Zurbrugg C, Swartz C, Pronk W (2009) Decentralized systems for potable water and the potential of membrane technology. Water Res 43(2):245–265. https://doi.org/10.1016/j.watres.2008.10.030. Epub 2008 Nov 1

Chapter 12
Adsorption Technique for Removal of Heavy Metals from Water and Possible Application in Wastewater-Fed Aquaculture

Subhas Sarkar and S. Adhikari

Abstract The presence of various inorganic and organic pollutants in aquatic streams has readily increased as a result of industrialization and urbanization. Among the technologies available, adsorption has widely been used for the removal of various contaminants from aqueous media, and accordingly different adsorbents have already been prepared over the years. The choice of adsorbent for purification of a specific type of wastewater containing specific pollutants is mainly determined by the concentration and type of the pollutant(s) present in the wastewater, the efficiency/ cost ratio of the adsorbents and the adsorption capacity of the adsorbent for the specific pollutant(s) of interest. In recent years, researchers have focused their efforts on the use of various low-cost biosorbents and also some synthesized polymer-based adsorbents for removal of heavy metal ions from wastewater. The purpose of this article is to provide comprehensive, up-to-date and critical information on the adsorption of different heavy metal pollutants by various types of biosorbents and polymer-based synthetic adsorbents. Further, the article describes the possible application of adsorption-based water remediation technology for wastewater-fed aquaculture.

Keywords Wastewater · Heavy metal · Adsorption · Biosorption · Polymer · Nanocomposites · Aquaculture

Contents

S. Sarkar (✉) · S. Adhikari
ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar, Odisha, India
e-mail: subhas.cifa@gmail.com

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_12

12.1 Introduction

Water is the most limited natural resource for aquaculture production in future. As a result, availability of freshwater for expansion of aquaculture will be limited. This warrants the necessity for the reuse of wastewater. Currently, various agricultural operations consume 70% of water resources in India, while groundwater supplies 80% of domestic water demand. This leads to rapid depletion of groundwater level in different states of India. Therefore, there is a necessity to explore the utilization of various types of wastewater resources for agriculture and more specifically in aquaculture. But it is well established that human activity has continuously disturbed the natural environment, particularly the aquatic ecosystems. Freshwater pollution due to heavy metal contamination becomes a hazard due to discharge of untreated industrial effluents. Even the essential metals are beyond the optimum threshold levels and may become hazardous and toxic to aquatic flora, fauna and other organisms. Therefore, it is pertinent to determine the characteristics of various types of wastewater and identify the specific pollutants, and corrective measures be taken prior to utilizing wastewater in aquaculture. In this regard, adsorption-based technologies can be applied for remediation of various types of toxic metal ions from wastewater, and then the water can be used in aquaculture or other agricultural activities.

Up to now, there are several techniques developed for removing micro pollutants from wastewater, including chemical precipitation, filtration, surface complexation, ion exchange, adsorption, reverse osmosis and electrolysis. Some recent reviews are available that deal with various techniques of removal of toxic chemical (Barakat 2011). However, each technique has its own advantages and disadvantages for practical applicability. Due to cost-effectiveness, adsorption is being applied widely to remediate toxic pollutants laden wastewater. The selection of adsorbent for purification of a particular type of pollutant is mainly determined by the chemical nature and concentration of the pollutant(s) present, the cost-effectiveness of the adsorbents and the adsorption affinity of the adsorbent. So far, various types of adsorbents have already been used for water treatment that include activated zeolites (Inglezakis et al. 2003), clays (Unuabonah et al. 2008a, b; Nishikiori et al. 2009; Zhang et al. 2010), activated carbons (Mirmohseni et al. 2012; Nethaji et al. 2013), agricultural waste peel (Bhatnagar et al. 2015), biochar (Mohan et al. 2014) and polymeric resins (Rivas and Munoz 2009). Other low-cost ecosystem approaches have also been dealt in the book.

The present chapter is an attempt to provide comprehensive, up-to-date and critical information on adsorption of different heavy metal pollutants by various types of biosorbents and polymer-based synthetic adsorbents. Further, the article describes the possible application of adsorption-based water remediation technology for wastewater-fed aquaculture. This chapter also critically analyses the effectiveness of these adsorbents under different physico-chemical process parameters.

12.2 Different Treatment Techniques for Heavy Metal Removal

A wide range of techniques are available for removal of toxic metal ions. These methods are chemical precipitation, ion exchange, adsorption, membrane filtration, electrochemical treatment technologies, etc. A brief introduction of these techniques as well as their advantages and limitations has been provided in this chapter.

12.2.1 Chemical Precipitation

Chemical precipitation is the most practical and effective technique adopted by the industries widely (Ku and Jung 2001). This process is relatively inexpensive and easy to operate. In this technique, heavy metals form insoluble precipitates by reacting with added chemicals. Then the precipitates can be easily removed from the liquid medium either by sedimentation or by screen filters. The treated water is then drained and discharged safely or reused for other purposes. In general, hydroxide and sulphide are being used for precipitation reaction in conventional water treatment process. However, its application in wastewater treatment is limited.

12.2.2 Ion Exchange

Ion-exchange techniques have been widely employed for removal of metals from wastewater owing to their many advantages, such as high removal efficiency, high scalability and rapid kinetics (Kang et al. 2004). Various types of synthetic and natural resins containing sulphonic acid groups ($^{-}SO_3H$) and carboxylic acid groups ($^{-}COOH$) are used for commercial purpose. Hydrogen ions of the ion-exchanging functional groups (sulphonic or carboxylic) of the resin undergo following ion-exchange process (Eqs. 12.1 and 12.2) for removing the metal ions from water:

$$nR\text{-}SO_3H + M^{n+} \rightarrow (R\text{-}SO_3^-)_n M^{n+} + nH^+ \tag{12.1}$$

$$nR\text{-}COOH + M^{n+} \rightarrow (R\text{-}COO^-)_n M^{n+} + nH^+ \tag{12.2}$$

12.2.3 Membrane Filtration

The highly efficient membrane filtration technologies with a wide range of membranes have immense potentials to remove toxic metal ions from water. The technique requires less space and is easy to operate. Different processes including electrodialysis, reverse osmosis, ultrafiltration and nanofiltration have been applied for removal of heavy metals from contaminated water. Ultrafiltration (UF) process employed low transmembrane pressures to remove contaminant ion and other suspended materials. In reverse osmosis, a semipermeable membrane is used to allow the liquid to be purified to pass through and rejecting the metal ions. Electrodialysis (ED) is a process where a charged membrane is used to separate the contaminants by an electric field as the driving force. Ion-exchange membranes are widely used for most ED techniques. However, application of these techniques is a new approach and requires experimentation for wastewater treatment.

12.2.4 Coagulation and Flocculation

Coagulation and flocculation followed by filtration are also used for remediation of metal ions from contaminated effluent. The process involves the destabilization of suspended particles by neutralizing the electrical repulsive forces that causes dispersion of particles. In general, different types of polyvalent cations are widely used in the conventional wastewater treatment. Salts of polyvalent cations, mainly aluminium, ferrous sulphate and ferric chloride, are used for charge neutralization of suspended particles and formation of amorphous metal hydroxide precipitates. Finally, precipitates are removed by sedimentation and followed by filtration process. The treated wastewater may then be reused in various activities.

12.2.5 Electrochemical Treatment

In electrochemical methods, metal ions are plating out on a charged surface (cathode), and contaminant ions are recovered in the elemental state. This process is not so popular and has limited applications for practical purpose due to high cost.

12.2.6 Adsorption

Adsorption process is considered as the most effective technique for remediation of contaminated water owing to its technical feasibility and cost-effectiveness. It offers great workability in design and operation, and the treated water is acceptable in terms of its good quality. Moreover, the adsorbents can be reused after regeneration by using suitable desorption process. So far, a wide range of adsorbents such as clays, modified clays, activated carbon, activated zeolites, agricultural waste peel (biosorbent), biochar and polymeric resins have been applied for heavy metal adsorption.

12.3 Use of Biosorbents for Removal of Heavy Metal

12.3.1 Definition of Biosorption

The term 'biosorption' has been used in a wide range of processes including bioabsorption, bioadsorption and biosorption by living or dead biomass and bioaccumulation of diverse array of substances including radionuclides, metals and organics. This is multidimensional and has been developed and being applied in a large scale over the past few decades.

Sorption is a process where one substance binds to other materials and governed by combination of physical and chemical process. Biosorption is a physico-chemical process involves in the removal of substances from contaminated solution by biological material (Gadd 2009). Bioadsorption and bioabsorption are the two similar terms (Gadd 2009); sorption is a process that is used for both absorption and adsorption. In absorption process a substance in one state is incorporated into another substance of a different state. Adsorption is a physical attachment of ions and molecules onto the functional molecules of other substances. Biosorption is a process where contaminants bind to the biological materials and is considered as a subcategory of adsorption (Michalak et al. 2013). Traditional clean-up technologies most commonly involved adsorption process, but sorption is the most preferred term for the process such as adsorption or absorption (Borda and Sparks 2008). A wide range of systems clearly exist in the continuum from adsorption to precipitation (Gadd 2009). Therefore, biosorption process involves a solid phase of biosorbent and a pollutant (sorbate)-laden liquid phase (mainly water). Any type of biological material having affinity for inorganic and organic pollutants indicates its biosorption potential within countless types of biomaterials (Gadd 2009; Dhankhar and Hooda 2011). There has been a wide range of research for wastewater purification such as metal recovery and recycling, all types of microbial, animal and plant biomass and derived products, etc. (Volesky 1990, 2003). The kinds of substrates of biological origin that are widely used for biosorbent preparation include various types of microbial biomass (bacteria, cyanobacteria, microalgae, filamentous fungi and yeasts), sea weeds (macroalgae), agricultural wastes (fruit/vegetable wastes, grain straw, grain bran, pulp, soybean hulls, etc.), industrial wastes (fermentation and food wastes, activated and anaerobic sludges, etc.), natural residues (tree barks, plant residues, weeds, sawdust, sphagnum peat moss) and other materials (chitosan, cellulose, etc.) (Park et al. 2010; Dhankhar and Hooda 2011). The potentials of many more synthetic and natural materials are in the attention of current research.

12.3.2 Mechanism of Biosorption

Various mechanisms including adsorption, ion exchange and complexation/coordination are involved in biosorption process. The process is rapid and reversible when sorbent properties are similar to synthesized ion-exchange resins (Gadd 2009). However, biological substances are complex and composed of various structural compounds present in biomass substances. That means many functional groups such as carboxyl, hydroxyl, amino, thiol, etc. are able to interact with metal species and governed by various physico-chemical factors. Precipitations followed by crystallization are other possible mechanisms that may occur and complicate sorption and/or desorption. This may lead to very high uptake capacities but inhibit desorption. However, different mechanisms are likely to operate simultaneously in biosorption process. Ligand bonding mechanism is very important in metal-sorbent complex formation and relevant for understanding biosorption. Various cations like Cu^{2+} may participate in surface complexation reaction by forming coordination bond of metal ions with oxygen donor atoms and proton release resulting bidentate surface complexes (Gadd 2009). A cation can attach with the surface of biosorbent either as an inner-sphere or outer-sphere complex. Covalent bonding of metal ions with the electron-donating ions of adsorbent forms inner-sphere complex. Whereas, for outer-sphere complex, a metal cation reaches the surface negative sites to a critical distance and gets attached.

12.3.3 Different Types of Biosorbents for Heavy Metal Removal

The removal of dissolved elements requires the employment of more advanced techniques than primary and secondary treatments. This may include the use of ion-exchange resins that will scrub the toxic elements from the water. But, treating large volume of wastewater for aquaculture purpose also demands for cost-effective technologies. Therefore, to fulfil the requirement, low-cost biosorbents can be used as an alternative to ion-exchange resin, though research on application of biosorbent-based wastewater treatment for aquaculture is scarce. However, considering its potentials for removal of heavy metals, some research findings (Table 12.1) are presented as follows.

12.3.3.1 Rice Husk

Rice husk is a crop residue derived from rice processing industries. Major proportion (70–85%) of dry rice husk consists of organic matter such as cellulose, lignin, carbohydrates, etc. Silica is also a major component present in the cellular membrane. Recently, possibilities of using rice husk as an adsorbent for the removal of contaminants has been explored. It has been reported that pretreatment of rice husks would reduce crystallinity of cellulose due to removal of lignin and hemicelluloses with increase in surface area. In general, metal ion adsorption capacity of chemically modified or treated rice husk is higher than that of unmodified rice husk. For example, sodium hydroxide, sodium carbonate and epichlorohydrin treatment of rice husk increased cadmium adsorption capacity (Kumar and Bandyopadhyay 2006). The adsorption capacity of raw rice husk can

Table 12.1 The capacities of various biosorbents for removal of different metal ions

SL no.	Biosorbent	Heavy metal removal efficiency (%)					References
		Cr (IV)	Ni (II)	Cu (II)	Zn (II)	Pb (II)	
1.	Soybean hulls	98.1	95.6	99.7	96.4	–	Marshall and Champagne (1995)
2.	Cotton seed hulls	97.6	96.7	98.8	96.6	–	Marshall and Champagne (1995)
3.	NaOH-washed soybean hulls	–	55.8	61.0	71.4	–	Marshall and Champagne (1995)
4.	Coconut husk	>80	–	–	–	–	Tan et al. (1993)
5.	Palm-pressed fibre	>80	–	–	–	–	Tan et al. (1993)
6.	Sago waste	–	–	>75	–	>95	Quek et al. (1998)
7.	Rice hull biomass	98.93	–	–	–	99.43	Roy et al. (1993)

be improved by alkali (NaOH) treatment due to removal of base soluble materials that might musk the adsorption site on the husk surface. For example, study of Tarley et al. (2004) revealed that Cd adsorption capacity was doubled when rice husk was treated with NaOH. The reported Cd adsorption capacities were 7 and 4 mg/g for NaOH-treated and NaOH-untreated husk, respectively. Effect of various types of carboxylic acids on rice husk modification and its use for removal of copper (Cu) and lead (Pb) has been studied. It was revealed that tartaric acid modified rice husk removed highest amount of pollutants (Wong et al. 2003). The adsorption capacities of lead (Pb) and copper (Cu) were reported up to 108 and 29 mg/g, respectively.

12.3.3.2 Sawdust

Sawdust is a by-product generated from wood industry which has been used as a cheap biosorbent. It contains metal-binding polyphenolic functional groups along with other molecules such as lignin, cellulose and hemicellulose. Rehman et al. (2006) investigated the adsorption of Ni^{2+} ions on sawdust of *Dalbergia sissoo* treated with alkali (NaOH). The adsorption kinetics study showed that extracellular binding favoured the fast adsorption of ion in the first 20 min. The maximum capacity of Ni^{2+} adsorption was reported as 10.47 mg/g at 50 °C. Further, the study revealed that high temperature is favourable for adsorption and followed both Langmuir and Freundlich isotherm models. In another study, phosphate-treated sawdust (PSD) recovered 100% of Cr (VI) from Cr (VI) laden (50 ppm) synthetic and electroplating wastewater (Ajmal et al. 1996).

12.3.3.3 Sugarcane Bagasse

Sugar industry produces sugarcane bagasse as a by-product. Bagasse pitch is composed largely of various organic compounds such as cellulose, hemicelluloses and lignin. Junior et al. (2006) studied the effectiveness of succinic anhydride-modified sugarcane bagasse for adsorption of Cd, Cu and Pb from wastewater. Similarly, the adsorption performance of hydrogen peroxide-treated bagasse fly ash, for removal of Pb and Cr, was tested by Gupta and Ali (2004). Hydrogen peroxide with high oxidizing power was applied to remove the organic matter on the adsorbent and improving the adsorption capacity.

12.3.3.4 Fruit/Vegetable Waste

Acid (HNO_3)- and alkali (NaOH)-treated fruit (banana and orange) peels were tested by Annadurai et al. (2002) to examine the binding ability for various divalent metals such as zinc (Zn^{2+}), copper (Cu^{2+}), cobalt (Co^{2+}), nickel (Ni^{2+}) and lead (Pb^{2+}). The study revealed that the adsorption affinity for both adsorbents decreases in the order:

$Pb^{2+} > Ni^{2+} > Zn^{2+} > Cu^{2+} > Co^{2+}$. Banana peel (for Pb^{2+}, Ni^{2+}, Zn^{2+}, Cu^{2+} and Co^{2+} were 7.97, 6.88, 5.80, 4.75 and 2.55 mg/g, respectively) exhibited higher maximum adsorption capacity for metal compared to orange peel (for Pb^{2+}, Ni^{2+}, Zn^{2+}, Cu^{2+} and Co^{2+} were 7.75, 6.01, 5.25, 3.65 and 1.82 mg/g, respectively). However, their application in wastewater reclamation has received less attention.

12.4 Use of Polymer-Based Adsorbents

Recently, various types of polymer-based adsorbents have been utilized for removal of toxic pollutants from wastewater, among which (1) polymer-clay nanocomposites and (2) superabsorbent polymers (hydrogels) are most widely being used.

12.4.1 Polymer-Clay Nanocomposites (PNCs)

Application of various types of polymers is widespread in various industries. Recently, incorporation of nanosized particles into the polymer matrix further widens its applicability. Polymer nanocomposites (PNCs) are synthesized by reinforcing nanosized particles having high aspect ratios (L/h > 300) into the polymers (thermoplastics, thermosets or elastomers) matrix (Denault and Labrecque 2004). Incorporation of very low amount of filler (1–5 vol%) provides toughness of the resin without changing the inherent character of the polymers (Table 12.2).

12.4.1.1 Application of PNCs for Heavy Metal Removal

Polymer nanocomposites (PNCs) materials have successfully been used to purify the heavy metal-contaminated wastewater. Clay-polymethoxyethylacrylamide (PMEA) nanocomposite synthesized by Sölener et al. (2008) is applied successfully for absorption of Pb^{2+}ions with a maximum adsorption capacity of 81.02 mg/g. The binding ability of PNC for Pb^{2+} was explained by physisorption process which was endothermic in nature. The material performed well within the pH range of 4.0–6.0 without altering its sorption capacity, and even at low pH of about 3.0, the adsorbent showed a high removal efficiency of Pb^{2+}. A new adsorbent, organo-bentonite ammoxidated polyacrylonitrile (OBent-PAN) nanocomposite, was prepared by Anirudhan and Ramachandran (2008), using in situ intercalation polymerization reaction. The synthesized composite with pH_{PZC} of 6.3 showed very good adsorption capacity for Zn (II), Cu (II) and Cd (II) to the tune of 77.43, 65.4 and 52.61 mg/g, respectively. Maximum removal efficiency of Zn^{2+}, Cu^{2+} and Cd^{2+} was stated to be 98.9%, 99.8% and 97.4%, respectively. The reaction was

Table 12.2 The adsorption capacities of PNCs for various metal ions from water

Adsorbent	Adsorbate	Adsorption capacity (mg/g)	pH	Temp. (∘C)	Kinetic model	Isotherm	References
Polyacrylic acid/bentonite	Pb(II), Ni(II), Cd(II) and Cu (II)	1666.67, 270.27, 416.67 and 222.22, respectively	–	–	Pseudo-second-order	Langmuir	Bulut et al. (2009)
Poly(methacrylic acid)-grafted chitosan/ bentonite	Th(IV)	110.5	5.0	30	Pseudo-second-order	Langmuir	Thayyath et al. (2010)
Chitosan/clinoptilolite	Ni(II)	247.03	5.0	25	Pseudo-second-order	Langmuir	Dinu and Dragan (2010)
Humic acid-immobilized amine modified polyacrylamide/bentonite nanocomposite	Cu(II)	106.2	5.0	–	Pseudo-second-order	Langmuir	Anirudhan and Suchithra (2010)
Alginate–montmorillonite nanocomposite	Pb(II)	244.6	6.0	–	–	–	Shawky (2011)
Na-montmorillonite/cellulose	Cr(VI)	22.2	3.8-5.5	–	Second-order	Langmuir	Kumar et al. (2011)
Attapulgite/poly(acrylic acid)	Pb(II)	37	5.0		Pseudo-second-order	Freundlich	Liu et al. (2014)
Cellulose-graft-polyacrylamide/ hydroxyapatite	Cu(II)	175.0	7.0	–	Pseudo-second-order	–	Saber-Samandari et al. (2013)
Poly(acrylic acid-co-acrylamide)/ attapulgite	Cu(II)	69.75	6.0	–	–	–	Liu et al. (2015)

carried out with an initial ion content of 25 mg/l, initial pH of 6.0 and 2 g/l of the adsorbent dose. Ion exchange followed by chelation reaction has been claimed to explain the metal ions removal process.

Unuabonah et al. (2008a) prepared a novel nano-clay adsorbents by modifying kaolinite clay with polyvinyl alcohol (PVA) and showed that the adsorbent with pH_{zpc} value of 4.25 can adsorb Pb^{2+} (56.18 mg/g) and Cd^{2+} (41.67 mg/g) ions. It has been suggested that an inner-sphere surface complexation reaction governed the Pb^{2+} and Cd^{2+} adsorption process (Unuabonah et al. 2008b). Experiment conducted by fixed bed technique with the same adsorbent revealed that 20 g of the adsorbent is needed to treat 1180 ml of Cd^{2+} containing water (300 ppm) and 1243 ml of Pb^{2+} containing water (300 ppm). After treatment the water volume was reduced to 927 ml and 1020 ml, respectively, on regeneration of the adsorbent (Unuabonah et al. 2010, 2012). Modelling study by a two-stage batch experiment for predicting optimum Pb^{2+} removal by the adsorbent suggested that 4 kg (2 kg for each stage) of the PNC is needed to be used to remove 95% of Pb^{2+} from a 2.5 m^3 volume of aqueous solution containing 300 mg/l Pb^{2+}, in approximately 30 min (Unuabonah et al. 2009).

12.4.2 Superabsorbent Polymer (Hydrogels)

Over the years, researchers have given attention to the superabsorbent polymers commonly known as hydrogels. Typically, hydrogels are three-dimensional (3D) matrix composed of cross-linked polymeric network synthesized by the reaction of one or more monomers with the ability to absorb and retain large quantities of water or biological fluids (Ahmed 2015; Sarkar et al. 2014). Moreover, hydrogels will not dissolve in water and keep their network structure stable in their swollen state (Ahmed 2015). Such properties are attributed to the cross-linked structure of the polymer matrix that provides hydrogel stability in various media and environment (Sarkar et al. 2013, 2015).

12.4.2.1 Application of Hydrogels for Heavy Metal Removal

Recently, it has realized that hydrogels containing various active sites mainly carboxylic acid, amine, hydroxyl and sulphonic acid group could be utilized as trapping agents for the adsorption of various ionic species from wastewater. Compared with other adsorbents like ion-exchange resins, the use of hydrogel materials is advantageous mainly due to its excellent water permeability and expansibility for easy access of target ions. For example, chitosan (CTS)-based hydrogels containing hydroxyl and amino groups have been utilized as an attractive adsorbent for removing heavy metal ions. Zhang et al. (2007) prepared for the first time a composite hydrogel based on CTS-*g*-poly (acrylic acid)/attapulgite

(CTS-*g*-PAA/APT). In this process, the –OH groups of attapulgite (APT) and –OH and $–NH_2$ groups of chitosan molecule reacted and forms graft polymer with acrylic acid (AA). In addition, incorporation of APT could improve thermal stability and develop a porous surface. Subsequently, the CTS-*g*-PAA/APT composite hydrogel was used as an adsorbent for the removal of Cu^{2+} from aqueous solution (Wang et al. 2009). The adsorption process was very rapid, and 90% of equilibrium adsorption capacity was achieved within 15 min of reaction. Wang and Wang (2010) also reported CTS-*g*-PAA/APT composite as adsorbent for removal of Cd^{2+} from aqueous solution. Results from kinetic experiments revealed that more than 90% of Cd^{2+} adsorption capacity of the hybrid hydrogel achieved within the initial 3 min, the adsorption process reached equilibrium level within 10 min. In another experiment, vermiculite clay (VMT) incorporated CTS-g-PAA polymer composites (CTS-g-PAA/VMT) was also employed for removal of Pb $^{2+}$ and Cd $^{2+}$ from aqueous medium (Wang and Wang 2012). Here also a very rapid removal was achieved and 90% of the total adsorption capacity reached in 3 min for both Pb $^{2+}$ and Cd^{2+} with the maximum adsorption capacity of 3.08 and 2.98 mmol/g for Pb^{2+} and Cd^{2+}, respectively. To develop a low-cost hydrogel adsorbent of Pb^{2+} with effective binding capacity, a polymer-clay composite was synthesized based on CTS, acrylic acid, sodium humate (SH) and APT (Zhang and Wang 2010). The adsorption capacity of the composite hydrogel for Pb^{2+} increased with increase in pH and initial Pb^{2+} concentration. Further, decrease in particle size of the adsorbent increase Pb^{2+} removal efficiency. CTS and CTS-PAA hydrogel beads cross-linked with glutaraldehyde (GLA) were synthesized and employed for removal of Cu^{2+} (Dai et al. 2010). The study showed that Cu^{2+} − adsorption process was temperature independent but dependent on pH of the fluid. Further, to make the separation process more efficient, magnetic nanoadsorbent based on CTS has been suggested (Zhou et al. 2011). Zhang et al. (2012) have prepared a magnetic hydrogel (Fe_3O_4/CTS/PAA) composite based on polymerizing AA in CTS and Fe_3O_4 aqueous solution with the properties of reusability, biodegradability and of high adsorption capacity for Cu^{2+} ions.

A series of hydrogels were synthesized based on starch backbone and designated as starch-g-poly (acrylic acid)/sodium humate (St-g-PAA/SH). The hydrogel was tested for Cu^{2+} removal from the synthetic wastewater. A series of batch experiments with varying pH values (2.0–5.0), initial Cu^{2+} content (0.003–0.02 mol/L) and contact times (0–90 min) were carried out. The results revealed that the incorporation of SH (5%) into the polymer of St-g-PAA improved initial adsorption rate and adsorption capacity for Cu^{2+}. This also significantly improved the regeneration ability of the adsorbent. FTIR spectra study revealed that complexation reaction was the main contributor for adsorption process (Zheng et al. 2010).

12.5 Possible Application of Adsorption-Based Remediation Technologies in Wastewater-Fed Aquaculture: Experimental Evidences

Aspé et al. (2012) demonstrated the efficiency of sawmill industry generated *Pinus radiata* bark (PRB) as a biosorbent for removal of iron (Fe), manganese (Mn) and aluminium (Al) from freshwater for Chilean Atlantic salmon farms. In this study, three processes were applied: firstly, an oxidation followed by column (PRB packed) filtration; secondly, oxidation followed by granular (small particle) filtration; and, thirdly, carbon dioxide and chemical treatment followed by granular (small particle) filtration. In all these process, Mn removal of 97, 99 and 29% and Fe removal of 93, 97 and 98%, respectively, were achieved. The study revealed that Fe concentration below the tolerance limit (< 0.1 ppm) for salmon life was achieved in all the three processes. The PRB bark removed aluminium (Al) to the tune of greater than 99.5% and achieved Al concentration of 0.01 mg/l, safe limit for salmon. Hence, the study demonstrated that PRB packed column is effective to achieve safe level of aluminium (Al) and iron (Fe) concentrations for salmon life.

With a view to developing columns in commercial aquaculture system for treating the nutrient-enriched effluent generated from intensive aquaculture system, Kioussis et al. (2000) have prepared a hydrogel based on polyallyl amine hydrochloride (PAA-HCl) and applied for efficient removal of nitrate, nitrite and orthophosphate nutrient anions from the aquaculture effluent. Eutrophication often leads to fish kill due to nutrient enrichment or crash of a phytoplankton bloom. Therefore, in such situation, these types of hydrogels could be used as a nutrient scavenger to manage the eutrophication problem. However, further research is needed in this direction.

12.6 Conclusions

Various techniques are developed for removing micro pollutants from wastewater, including chemical precipitation, ion exchange, membrane filtration, coagulation and flocculation, electrochemical treatment, adsorption, etc. Adsorption is a less expensive technique that is being used widely to remove both organic and inorganic pollutants from wastewater. It has been suggested that the use of different types of biomass (biosorbent) and different types of polymeric adsorbents including superabsorbent polymers is more useful for the removal of contaminant ions from wastewater. Further, exhaustive study needs to be carried out to get conclusive results for utilizing various adsorbents for wastewater treatment. More experiment with real industrial effluent and its effectiveness in a pilot plant must be evaluated.

Studies on preliminary design and also the economic feasibility should be conducted to apply the technology in wastewater-fed aquaculture. Research work on remediation of wastewater under *ex-situ* condition and its subsequent utilization for aquaculture needs to be explored in future.

References

Ahmed EM (2015) Hydrogel: preparation, characterization, and applications: a review. J Adv Res 6(2):105–121

Ajmal M, Rao RAK, Siddiqui BA (1996) Studies on removal and recovery of Cr (VI) from electroplating wastes. Water Res 30(6):1478–1482

Anirudhan TS, Ramachandran M (2008) Synthesis and characterization of amidoximated polyacrylonitrile/organobentonite composite for Cu (II), Zn (II), and Cd (II) adsorption from aqueous solutions and industry wastewaters. Ind Eng Che Res 47(16):6175–6184

Anirudhan TS, Suchithra PS (2010) Humic acid-immobilized polymer/bentonite composite as an adsorbent for the removal of copper (II) ions from aqueous solutions and electroplating industry wastewater. J Ind Eng Che 16(1):130–139

Annadurai G, Juang RS, Lee DJ (2002) Adsorption of heavy metals from water using banana and orange peels. Water Sci Tech 47(1):185–190

Aspé E, Roeckel M, Fernández K (2012) Use of biomass for the removal of heavy metals at low concentrations from freshwater for Chilean Atlantic salmon farms. Aquac Eng 49:1–9

Barakat MA (2011) New trends in removing heavy metals from industrial wastewater. Arab J Chem 4(4):361–377

Bhatnagar A, Sillanpää M, Witek-Krowiak A (2015) Agricultural waste peels as versatile biomass for water purification–a review. Chem Eng J 270:244–271

Borda MJ, Sparks DL (2008) Kinetics and mechanisms of sorption-desorption in soils: a multiscale assessment. In: Violante A, Huang PM, Gadd GM (eds) Biophysico-chemical processes of heavy metals and metalloids in soil environments. Wiley, Hoboken, pp 97–124

Bulut Y, Akçay G, Elma D, Serhatlı IE (2009) Synthesis of clay-based superabsorbent composite and its sorption capability. J Hazard Mater 171(1):717–723

Dai J, Yan H, Yang H, Cheng R (2010) Simple method for preparation of chitosan/poly (acrylic acid) blending hydrogel beads and adsorption of copper (II) from aqueous solutions. Chem Eng J 165(1):240–249

Denault J, Labrecque B (2004) Technology group on polymer nanocomposites–PNC-Tech. Industrial Materials Institute. National Research Council Canada, 75

Dhankhar R, Hooda A (2011) Fungal biosorption–an alternative to meet the challenges of heavy metal pollution in aqueous solutions. Environ Technol 32(5):467–491

Dinu MV, Dragan ES (2010) Evaluation of Cu^{2+}, Co^{2+} and Ni^{2+} ions removal from aqueous solution using a novel chitosan/clinoptilolite composite: kinetics and isotherms. Chem Eng J 160(1):157–163

Gadd GM (2009) Biosorption: critical review of scientific rationale, environmental importance and significance for pollution treatment. J Chem Technol Biotechnol 84(1):13–28

Gupta VK, Ali I (2004) Removal of lead and chromium from wastewater using bagasse fly ash—a sugar industry waste. J Colloid Interf Sci 271(2):321–328

Inglezakis VJ, Loizidou MD, Grigoropoulou HP (2003) Ion exchange of Pb^{2+}, Cu^{2+}, Fe^{3+}, and Cr^{3+} on natural clinoptilolite: selectivity determination and influence of acidity on metal uptake. J Colloid Interf Sci 261(1):49–54

Junior OK, Gurgel LVA, de Melo JCP et al (2006) Adsorption of heavy metal ion from aqueous single metal solution by chemically modified sugarcane bagasse. Bioresour Technol 98:1291–1297

Kang SY, Lee JU, Moon SH, Kim KW (2004) Competitive adsorption characteristics of Co^{2+}, Ni^{2+}, and Cr^{3+} by IRN-77 cation exchange resin in synthesized wastewater. Chemosphere 56(2):141–147

Kioussis DR, Wheaton FW, Kofinas P (2000) Reactive nitrogen and phosphorus removal from aquaculture wastewater effluents using polymer hydrogels. Aqua Eng 23:315–332

Ku Y, Jung IL (2001) Photocatalytic reduction of Cr (VI) in aqueous solutions by UV irradiation with the presence of titanium dioxide. Water Res 35(1):135–142

Kumar U, Bandyopadhyay M (2006) Sorption of cadmium from aqueous solution using pretreated rice husk. Bioresour Technol 97(1):104–109

Kumar ASK, Kalidhasan S, Rajesh V, Rajesh N (2011) Application of cellulose-clay composite biosorbent toward the effective adsorption and removal of chromium from industrial wastewater. Ind Eng Chem Res 51(1):58–69

Liu P, Jiang L, Zhu L, Wang A (2014) Novel approach for attapulgite/poly (acrylic acid) (ATP/PAA) nanocomposite microgels as selective adsorbent for Pb (II) ion. React Funct Polym 74:72–80

Liu P, Jiang L, Zhu L et al (2015) Synthesis of covalently crosslinked attapulgite/poly (acrylic acid-co-acrylamide) nanocomposite hydrogels and their evaluation as adsorbent for heavy metal ions. J Ind Eng Chem 23:188–193

Marshall WE, Champagne ET (1995) Agricultural byproducts as adsorbents for metal ions in laboratory prepared solutions and in manufacturing wastewater. J Environ Sci Health Part A 30 (2):241–261

Michalak I, Chojnacka K, Witek-Krowiak A (2013) State of the art for the biosorption process—a review. Appl Biochem Biotech 170(6):1389–1416

Mirmohseni A, Dorraji MS, Figoli A, Tasselli F (2012) Chitosan hollow fibers as effective biosorbent toward dye: preparation and modeling. Bioresour Technol 121:212–220

Mohan D, Sarswat A et al (2014) Organic and inorganic contaminants removal from water with biochar, a renewable, low cost and sustainable adsorbent–a critical review. Bioresour Technol 160:191–202

Nethaji S, Sivasamy A, Mandal AB (2013) Preparation and characterization of corn cob activated carbon coated with nano-sized magnetite particles for the removal of Cr (VI). Bioresour Technol 134:94–100

Nishikiori H, Shindoh J, Takahashi N et al (2009) Adsorption of benzene derivatives on allophane. Appl Clay Sci 43(2):160–163

Park D, Yun YS, Park JM (2010) The past, present, and future trends of biosorption. Biotechnol Bioprocess Eng 15(1):86–102

Quek SY, Wase DAJ, Forster CF (1998) The use of sago waste for the sorption of lead and copper. Water SA 24(3):251–256

Rehman H, Shakirullah M, Ahmad I et al (2006) Sorption studies of nickel ions onto sawdust of Dalbergia Sissoo. J Chin Chem Soc 53(5):1045–1052

Rivas BL, Munoz C (2009) Synthesis and metal ion adsorption properties of poly (4-sodium styrene sulfonate-co-acrylic acid). J Appl Polym Sci 114(3):1587–1592

Roy D, Greenlaw PN, Shane BS (1993) Adsorption of heavy metals by green algae and ground rice hulls. J Environ Sci Health A 28(1):37–50

Saber-Samandari S, Saber-Samandari S, Gazi M (2013) Cellulose-graft-polyacrylamide/hydroxyapatite composite hydrogel with possible application in removal of Cu (II) ions. React Funct Polym 73(11):1523–1530

Sarkar S, Datta SC, Biswas DR (2013) Using nanoclay polymer composite for efficient delivery of N and P to pearl millet grown in a smectite dominant soil in a greenhouse experiment. Clay Res 32(2):102–113

Sarkar S, Datta SC, Biswas DR (2014) Synthesis and characterization of nanoclay–polymer composites from soil clay with respect to their water-holding capacities and nutrient-release behavior. J Appl Polym Sci 131. https://doi.org/10.1002/app.39951

Sarkar S, Datta SC, Biswas DR (2015) Effect of fertilizer loaded nanoclay/superabsorbent polymer composites on nitrogen and phosphorus release in soil. Proc Natl Acad Sci India B 85 (2):415–421

Shawky HA (2011) Improvement of water quality using alginate/montmorillonite composite beads. J Appl Polym Sci 119(4):2371–2378

Şölener M, Tunali S, Özcan AS et al (2008) Adsorption characteristics of lead (II) ions onto the clay/poly (methoxyethyl) acrylamide (PMEA) composite from aqueous solutions. Desalination 223(1):308–322

Tan WT, Ooi ST, Lee CK (1993) Removal of chromium (VI) from solution by coconut husk and palm pressed fibres. Environ Technol 14(3):277–282

Tarley CRT, Ferreira SLC, Arruda MAZ (2004) Use of modified rice husks as a natural solid adsorbent of trace metals: characterisation and development of an on-line preconcentration system for cadmium and lead determination by FAAS. Microchem J 77(2):163–175

Thayyath SA, Sreenivasan R, Abdul Rauf T (2010) Adsorptive removal of thorium (IV) from aqueous solutions using poly(methacrylic acid)-grafted chitosan/bentonite composite matrix: process design and equilibrium studies. Colloids Surf A Physicochem Eng Asp 368:13–22

Unuabonah EI, Olu-Owolabi BI, Adebowale KO, Yang LZ (2008a) Removal of lead and cadmium from aqueous solution by polyvinyl alcoholmodified kaolinite clay: a novel nanoclay adsorbent. Adsorpt Sci Technol 26(6):383–405

Unuabonah EI, Adebowale KO, Olu-Owolabi BI, Yang LZ (2008b) Comparison of sorption of Pb and Cd on kaolinite clay and polyvinylalcohol-modified kaolinite clay. Adsorption 14(6):791–803

Unuabonah EI, Olu-Owolabi BI, Okoro D, Adebowale KO (2009) Comparison of two-stage sorption design models for the removal of lead ions by polyvinylalcohol modified kaolinite clay. J Hazard Mater 171:215–221

Unuabonah EI, Olu-Owolabi BI, Fasuyi EI, Adebowale KO (2010) Modeling of fixedbed column studies for the adsorption of cadmium onto novel polymer–clay composite adsorbent. J Hazard Mater 179(1–3):415–423

Unuabonah EI, El-Khaiary MI, Olu-Owolabi BI, Adebowale KO (2012) Predicting the dynamics and performance of a polymer–clay based composite in a fixed bed system for the removal of lead (II) ion. Chem Eng Res Des 90:1105–1115

Volesky B (1990) Biosorption of heavy metals. CRC press, Boca Raton

Volesky B (2003) Sorption and biosorption. BV Sorbex Inc, Montreal

Wang X, Wang A (2010) Removal of Cd (II) from aqueous solution by a composite hydrogel based on attapulgite. Environ Technol 31(7):745–753

Wang X, Wang A (2012) Equilibrium isotherm and mechanism studies of Pb (II) and Cd (II) ions onto hydrogel composite based on vermiculite. Desalin Water Treat 48(1–3):38–49

Wang X, Zheng Y, Wang A (2009) Fast removal of copper ions from aqueous solution by chitosan-g-poly (acrylic acid)/attapulgite composites. J Hazard Mater 168(2):970–977

Wong KK, Lee CK, Low KS, Haron MJ (2003) Removal of Cu and Pb by tartaric acid modified rice husk from aqueous solutions. Chemosphere 50(1):23–28

Zhang J, Wang A (2010) Adsorption of Pb (II) from aqueous solution by chitosan-g-poly (acrylic acid)/attapulgite/sodium humate composite hydrogels. J Chem Eng Data 55(7):2379–2384

Zhang J, Wang Q, Wang A (2007) Synthesis and characterization of chitosan-g-poly (acrylic acid)/attapulgite superabsorbent composites. Carbohydr Polym 68(2):367–374

Zhang W, Ding Y, Boyd SA, Teppen BJ, Li H (2010) Sorption and desorption of carbamazepine from water by smectite clays. Chemosphere 81(7):954–960. https://doi.org/10.1016/j.chemosphere.2010.07.053

Zhang S, Zhou Y, Nie W, Song L (2012) Preparation of Fe_3O_4/chitosan/poly (acrylic acid) composite particles and its application in adsorbing copper ion (II). Cellulose 19(6):2081–2091

Zheng Y, Hua S, Wang A (2010) Adsorption behavior of Cu^{2+} from aqueous solutions onto starch-g-poly (acrylic acid)/sodium humate hydrogels. Desalination 263(1):170–175

Zhou L, Jin J, Liu Z, Liang X, Shang C (2011) Adsorption of acid dyes from aqueous solutions by the ethylenediamine-modified magnetic chitosan nanoparticles. J Hazard Mater 185 (2):1045–1052. https://doi.org/10.1016/j.jhazmat.2010.10.012

Part IV
Economic Perspectives of Wastewater, Environmental Impact Assessment and Environmental Law and Regulations

Chapter 13
Multiple Reuse of Wastewater: Economic Perspectives

S. Jana, Ken Gnanakan, and B. B. Jana

Abstract Municipal wastewater is a valuable resource because of its immense nutrient and water reuse potentials though untreated sewage has negative impacts on environment and human health. Properly treated wastewater is, however, safe and can be reused for aquaculture, agricultural and landscape irrigation, industrial processes, etc. In urban areas, reclaimed wastewater are used mainly for non-potable purposes such as recreation centre; sports grounds; school yards; play grounds; edges and central reservations of highways; irrigation of landscaped areas around public, residential, commercial and industrial buildings; and many other allied sites. Partially reclaimed wastewater is used for decorative and ornamental purposes such as fountains, reflecting pools and waterfalls, etc. It is frequently used for fire protection and toilet and urinal flushing in commercial and industrial buildings. In general, low-quality wastewater is widely used for agriculture and aquaculture; high-income countries, however, use treated wastewater for agriculture and landscape irrigation and for different food crops and other crops and nursery products. Currently, industrial water consumption was up to 22% of global water use. Industrial water use in Europe and North America accounted for half of their total water use, whereas in developing countries, it was about 4–12% of national water use, though there is enough scope for increase.

S. Jana (✉)
Department of Fisheries Economics and Statistics, West Bengal University of Animal & Fishery Sciences, Kolkata, West Bengal, India

Centre for Environmental Protection & Human Resource Development, Kalyani, West Bengal, India
e-mail: santanajana3@gmail.com; ken@gnanakan.com

K. Gnanakan
William Carey University, Shillong, Meghalaya, India

ACTS Group of Institutions, Bangalore, India

B. B. Jana
International Centre for Ecological Engineering, University of Kalyani, West Bengal, India

Centre for Environmental Protection & Human Resource Development (Kalyani Shine India), Kalyani, West Bengal, India

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_13

Wastewater can be reused within a business itself or between several businesses through industrial symbiosis. The exchange of waste products for the mutual benefits of two or more businesses is also known as industrial symbiosis. It is suggested that the high cost-treated wastewater should be made efficient in use, and there should be appropriate sector-wise use of recycled wastewater. Efficiency of recycling of wastewater implies that allocation of recycled water to different sectors be made in such an optimal way that the overall economic efficiency is maximized. Recycled water is often more expensive than existing water supply. Efficiency of wastewater recycling in developed countries should be increased to reduce the cost of supply of recycled water so that it can compete efficiently with alternative sources of water. In cost-effective analysis, costs included both direct and indirect costs that are associated with the programme together with the intangible positive and negative externalities. An effective planning, management and regulations are necessary for profitable reuse of municipal wastewater for different economic-driven activities.

Keywords Safe reuse · Management · Agricultural crops · Municipal wastewater

Contents

13.1 Introduction

Water has been increasingly scarce in many countries of the world especially in developing countries and water-scarce countries. Safe reuse of wastewater has become inevitable to meet the increasing demand of water in the future. Municipal wastewater poses a win-win strategy towards environmental protection as well as for conservation of water through its reuse in various economic-driven activities. Management plays a key role in utilizing the potentials of domestic wastewater. In the planning and implementation process, the intended wastewater reuse applications determine the extent of wastewater treatment required, or vice versa the available wastewater quality limits possible reuse applications. Despite the benefits of reuse, utmost care should be taken to avoid health risks and groundwater pollution and surface water contamination due to discharge of untreated municipal wastewater. However, it is suggested that groundwater system used for drinking purposes should be protected from sewage contact (Abdel-Shafy et al. 2008). Also, a clear-cut distinction should be made between potable and non-potable groundwater sources. In general, water reuse projects are often underestimated when compared to other projects because the reuse benefits have not been highlighted properly with respect to public interests. However, information about the reuse of municipal wastewater is rather meagre under Indian scenario. The present chapter attempts to highlight the current status of multiple uses of municipal wastewater generated and treated by conventional system.

13.2 Multiple Uses of Wastewater

Properly treated wastewater is safe and can be reused for aquaculture, agricultural and landscape irrigation, industrial processes, etc. (Fig. 13.1). At present, technically proven wastewater treatment and purification process are available which are highly efficient to produce water of almost any quality desired (Edwards 2000; Abbassi and Baz 2008) though these treatment processes may not be cost-effective and suitable for poor countries. Therefore, cost-effective technologies should be developed and promoted in the economically poor countries.

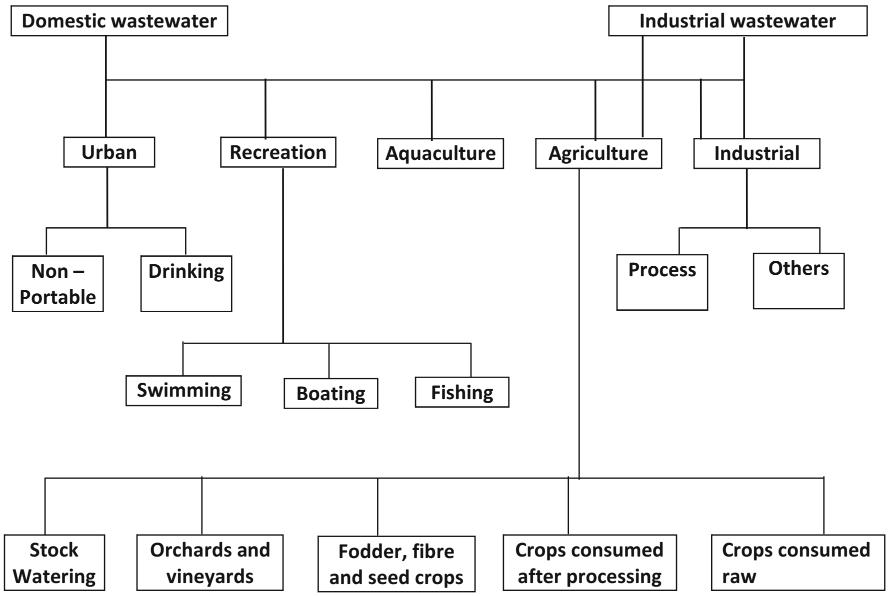


Fig. 13.1 Multiple uses of wastewater (WHO 2006)

13.2.1 Global Scenario

In general, low-quality wastewater is widely used for agriculture and aquaculture; these areas use the large volume of wastewater relative to other sectors. A study undertaken by the United Nations University has revealed the volume of wastewater generation and the percentage use of this type of water in different countries of the world. It is revealed that reuse of wastewater in irrigation ranges from 1.5% to 6.6% of the global irrigated area of 301 million ha and that about 10% of the world food is produced using wastewater (Table 13.1).

The data revealed that an estimated 46% of California's annual reclaimed wastewater was used in agriculture, whereas in Florida the proportion was little less at 44%. In the water-scarce countries like Middle East, North Africa, Saudi Arabia and Israel, the volume of treated wastewater used for irrigation ranged from 51 to 70%. It is projected that the reuse of wastewater in Saudi Arabia would be increased to 65% by 2016. About 70% of the generated wastewater was used in the domestic sector of Israel and that represents about 10% of the national water supply and 20% of the water supply for irrigation. In Kuwait, wastewater is primarily used for cultivation of only vegetables (potatoes and cauliflower) that are eaten after cooking, industrial corps, forage corps (alfalfa and barley) and highway landscape irrigation. Wastewater use in agriculture in Japan is not adequate; its use has mainly focused on meeting urban water needs. In China, an estimated 1.3 million ha are irrigated with wastewater. About 9500 ha area is irrigated with untreated wastewater in Vietnam of which at least 2% of the agricultural land around the most Vietnam cities was irrigated with wastewater. Most of the wastewater used in Pakistan where nearly 32,500 ha are irrigated with wastewater (UN 2015). Direct use of wastewater is practiced in agriculture and aquaculture in India as well. According to a report of the United Nations University, as much as 73,000 ha land area were irrigated with wastewater in India in 1985, but the data on the current use of wastewater is hardly available.

It is observed that mainly high-income countries use treated wastewater for agriculture and landscape irrigation, and at least 20 different food crops and 11 other crops and nursery products are being irrigated with treated wastewater (Table 13.2).

13.2.2 Types of Reuse of Wastewater

13.2.2.1 Agriculture

Wastewater reuse for agricultural production is a common practice in several countries of the world. Generally, low-quality wastewater is used for agriculture and aquaculture. However, there is a growing concern about the environmental and health impacts of wastewater reuse. Many developing countries adopted the WHO

Table 13.1 Summary of the volume of wastewater generated and uses of treated wastewater in different countries of the world

Sl. no.	Countries	Wastewater generated	Volume of wastewater used	Types of use
1	North America	85 km^3		
2	California		46% of annual reclaimed wastewater	Agriculture
3	Florida		44%	Agriculture
4	Latin America		20%	
5	Europe		71%	
6	Southern Europe		44%	Agriculture, irrigation
			37%	Urban project, environmental application
7	USSR	14 km^3/year		
8	Middle East and North Africa	22.3	51%	Agriculture and landscape irrigation
9	Israel		70%	Domestic sector
10	Kuwait			Potatoes, cauliflower, industrial and forage crops and highway landscape irrigation
11	Australia		19%	
12	Oceania		45%	Agriculture sector
13	New Zealand			Golf course and industrial application
14	Japan (2009-10)	0.2 km^3	More than 50% used	Golf course and industrial application
15	China	13 million ha irrigated with wastewater		
16	Vietnam	9500 ha are irrigated with untreated wastewater		
17	Pakistan	32,500 ha irrigated with untreated wastewater		

(1989) guidelines with respect to maximum permissible limits of indicator pathogens in the effluents of treatment plants. In the newly suggested guidelines of the WHO (2006), it does not require pathogen removal to occur solely at the wastewater treatment plant; natural die-off, farming practices, applied irrigation system and produce washings are considered very effective in reducing pathogens to acceptable safe limits. In a study carried out in Palestine (Mansour et al. 2008), it has been

Table 13.2 Types of food crops and non-food crops irrigated with reclaimed water in California, USA

Food crops	Non-food crops
Apple	Alfalfa
Asparagus	Christmas trees
Avocados	Clover
Barley	Eucalyptus trees
Beans	Flower seeds
Broccoli	Hay
Cabbage	Maize
Cauliflower	Sod
Celery	Trees
Citrus	Vegetable seeds

revealed that the level of contamination in the fruits of broad bean (*Vicia faba*) with respect to faecal coliform, total coliform *Salmonella* and *Staphylococcus aureus* was not different between the fruits irrigated with reclaimed wastewater and that with freshwater.

The effectiveness of sewage sludge has also been evaluated in order to examine the responses of Durum wheat to organic amendment using sewage sludge in Algeria. The results indicated significant rise in crop yields attributed to the beneficial effects of soil sludge on soil structure and nutrient content. Studies have confirmed that crop yields would be further increased provided wastewater irrigation is done following a managed protocol. In Mexico, there has been tremendous increase in agricultural income from almost zero to the tune of 16 million Mexican pesos per hectare in 1990 (Helmer and Hespanhol 1997).

The trials evaluating the impact of municipal wastewater on crop production are rather scanty in India. However, some available information (Shende 1985) suggested its utility in crop production in Maharastra. The studies carried out by the National Environmental Engineering Research Institute (NEERI), Nagpur (Table 13.3), have clearly indicated the effects of wastewater irrigation on crops (Shende 1985). In a study to ascertain the fate of pathogens in tomato plants and soil irrigated with secondary-treated wastewater in Amman (Middle East), the results suggested that disinfection of reclaimed wastewater may not be necessary when proper agricultural practices are applied downstream of the treatment plant (Halalsheh et al. 2008).

13.2.2.2 Urban

In urban areas, reclaimed wastewaters are used mainly for non-potable purposes such as in recreation centre, sports ground, school yards and play ground, edges and central reservations of highways and irrigation of landscaped areas around public, residential, commercial and industrial buildings. Partially reclaimed wastewater is used for decorative and ornamental purposes such as fountains, reflecting pools and waterfalls, etc. It is frequently used for fire protection and toilet and urinal flushing

Table 13.3 Responses of yields of different crops to wastewater irrigation in Nagpur, Maharastra (Shende 1985)

	Wheat (tons ha^{-1})	Moong bean (tons ha^{-1})	Rice (tons ha^{-1})	Potato (tons ha^{-1})	Cotton (tons ha^{-1})
Irrigation water	8 years[a]	5 years[a]	7 years[a]	4 years[a]	3 years[a]
Raw wastewater	3.44	0.90	2.97	23.11	2.56
Settled wastewater	3.45	0.87	2.94	20.78	2.30
Stabilization pond effluent	3.45	0.78	2.98	22.31	2.41
Fertilizer + NPK	2.70	0.72	2.03	17.16	1.70

[a]Years of harvest used to calculate average yield

in commercial and industrial buildings. The reclaimed wastewater has been frequently used for recreation and landscape enhancement. It ranges from small fountains to landscape areas to full water-based recreational sites for swimming, boating and fishing.

13.2.2.3 Industries

Generally, industries demand heavy amount of water for various activities. It is estimated that industrial water consumption was up to 22% of global water use (UN 2015, 2016). According to the available data in 2009, industrial water use in Europe and North America accounted for half of their total water use, whereas in developing countries, it is about 4–12% of national water use (Pain and Spuhler 2007).The common uses of wastewater in industries are (1) evaporating cooling water particularly for power stations, (2) boiler feedwater, (3) processed water and (4) irrigation of ground surrounding the industrial plant. This shows that there is good market for selling wastewater for using in industries in both developed and developing countries.

Wastewater Use Through Industrial Symbiosis

Wastewater can be reused within a business itself or between several businesses through industrial symbiosis. It may either be reused directly or treated before reuse, depending on the type and quality of wastewater. It has a potential to reduce the cost for business for both water bill and wastewater treatment. The exchange of waste products for the mutual benefits of two or more businesses is also known as industrial symbiosis. All members profit from the arrangement by either reducing the inputs necessary in the production process or by reducing the cost of water treatment. Industrial symbiosis can take place in three ways: (a) exchange of bioproducts, (b) sharing the management of utilities and (c) sharing ancillary services. Direct use of wastewater in industrial symbiosis is the example of direct reuse that includes exchange of process water from one business to another and subsequent direct reuse (such as irrigation, washing, pH adjustment, fire protection, etc.). Reuse of wastewater for large-scale biogas production through anaerobic digestion can be used to generate electricity.

13.2.2.4 Integration of Agriculture and Aquaculture

Land application of wastewater is an effective water pollution control measure as well as for increasing water resources especially in water-scarce countries. There has been marked rise in the use of wastewater for irrigation of crops during the last two decades. Studies on the integration of agriculture and aquaculture for utilization of municipal wastewater are rather very limited. Some studies carried out on paddy cum fish culture for utilizing sewage water (Datta et al. 2000) revealed that fish production using municipal wastewater ranged from 1.95 to 8 t/ha/year under different treatment conditions, whereas the same from vegetable cultivation ranged from 85.9 to 120 t/ha/year (Roy et al. 2000).

13.3 Assessing Median Infection Risks in Irrigation

There is a possibility that wastewater-saturated soil would contaminate the workers or children's fingers and thus may enter into the mouth and ingested. It is reported that the quantity of soil involuntarily ingested in this was up to ~ 100 mg/person/day of exposure. Risk simulation model for labour-intensive agriculture suggests that median rotavirus infection risk is ~ 10^3 pppy for a wastewater quality of 10^3–10^4 *E. coli*/100 ml (WHO 2006; Mara and Kremer 2008).

The exposure scenario used for irrigation of all crops including those eaten uncooked is the consumption of wastewater-irrigated lettuce (Mara and Kramer 2008), onion and other leaf and root crops. The median rotavirus infection risk is 10^3 pppy for a wastewater quality of 10^3–10^4*E. coli*/100 ml. According to the WHO (2006), the tolerable rotavirus infection risk is 10^3 pppy. In England, the acceptable limit of faecal coliforms in prepared sandwiches and salads on sale in local shops is 10,000 faecal coliform/100 g.

13.4 Reuse of Grey Water

The health risk of grey water is lower than domestic wastewater. Unrestricted irrigation with grey water is profitable as it increases crop yields and pathogen levels are low (WHO 2006). A study (WHO 2015) reported that a 1.6–2.9 log unit reduction is needed for protozoan pathogens and 2.3–3.3 log unit reduction for viral pathogens (rotavirus) so that tolerable additional disease burden of 10^{-6} DALY loss pppy is not exceeded. These reductions can be achieved by a combination of treatment and posttreatment health protection control measures.

13.5 Efficiency of Wastewater Recycling

Since wastewater treatment process is highly expensive, the developing countries lack fund and infrastructure for investment in wastewater treatment to appropriate level. In developed countries also, high costs of wastewater treatment is a major problem. So this highly cost-treated wastewater should be made efficient in use, and there should be appropriate sectoral use of recycled wastewater. Efficiency of wastewater recycling in developed countries should be increased to reduce the cost of supply of recycled water so that it can compete efficiently with alternative sources of water. In developing countries' setting, the problem is different. As wastewater is used untreated or partially treated, the recycling is unsustainable, because of its various harmful effects. To make the recycling sustainable in developing countries, a realistic cost-sharing approach among the different stakeholders to recover wastewater treatment costs to ensure treatment of wastewater to achieve safe level and make the process of recycling self-sustaining may be undertaken. This has been proposed in a case study of recycling of wastewater in the city of Hyderabad (Mekala et al. 2008). The cost-sharing would be between polluters of water (household and industries), government, funding agencies and users of recycled water. From the economic perspective, the following factors are to be considered for efficiency in water recycling such as to set the price of wastewater, cost recovery, the rate of people's willingness to pay for using recycled water depending on water quality and restrictions on the people's use of this resources and distribution mechanism of wastewater. The efficiency of recycling can be enhanced through a number of strategies at different levels: at the treatment level, through new technologies, information on demand and supply sides, appropriate pricing of wastewater and also through proper allocation among different sectors such as industry, agriculture, recreation and environmental purposes.

13.5.1 Allocative Efficiency

Recycling efficiency of wastewater implies allocation of recycled water to different sectors in an optimal way so that the overall economic efficiency is maximized. Recycled water is often more expensive than existing water supply. Price mechanism may play a role in allocation of recycling of wastewater. A very low price for wastewater may encourage inefficient use of wastewater. On the other hand, if the price of recycled water is fixed at a level close to the price of potable water, users may have the tendency to use potable water for all purposes. It is suggested that price signals from the use of wastewater should be set at the long-run marginal costs of supply. Actually there has not been any clear-cut guideline on specific factors to be considered while allocating the recycled water to different sectors so that overall economic efficiency is maximized. According to Freebairn (2003), economic efficiency is maximized by allocating limited water among alternative uses so that marginal social benefits are equated across the different users. However to attain efficiency, a policy decision is necessary as to what extent should wastewater be recycled, in which sectors be used and at what costs. For this purpose, a cost-effective analysis of wastewater recycling across one sector over the other can be performed to assess the relative desirability of recycling in one sector over the other depending upon the objectives of stakeholders and budget constraints. Then a choice modelling technique is used to weight the different objectives and to determine appropriate sectoral use of wastewater (Mekale et al. 2008). A ranking exercise is conducted for the different objectives among the stakeholders, and each objective would be weighted accordingly. Wastewater recycling can satisfy more than one objective like reducing the discharge of nutrients to natural water bodies, saving/substituting potable water, saving water for environmental purposes, etc. Cost-effective analysis is performed to evaluate the best alternatives. A combination of two techniques was used to develop a decision support tool that can be employed to allocate wastewater efficiently and optimally among different sectors.

13.5.2 Cost-Effective Analysis

Cost-effective analysis is performed to compare the cost-effectiveness of an intervention and to determine whether the intervention is worth doing. Programmes of intervention may be of two types: (1) completely independent where the costs and effects of one intervention are not affected by the introduction of the other intervention and (2) those that are mutually exclusive where costs and effects of one intervention affect the other. In cost-effective analysis, costs included are direct costs and indirect costs associated with the programme together with the intangible positive and negative externalities.

If wastewater recycling is considered as independent programme, cost-effective analysis requires the estimation of cost-effectiveness ratios (CER), calculated as:

$$\text{CER} = \text{costs of intervention}/\text{effects produced}$$

Interventions with the least CER should be given priority, but for taking decision which programme to implement, the extent of the availability of resources must be considered. In mutually exclusive intervention, incremental cost-effectiveness ratios (ICER) are calculated as:

$$\text{ICER} = \text{difference in costs between programmes P1 and P2} / \text{difference in effects between programmes P1 and P2}$$

The alternative interventions are ranked according to their effectiveness on the basis of securing maximum effects rather than costs. The cost-effectiveness analysis should be subjected to sensitivity analysis.

13.6 Planning and Management

A proper planning and management (Fig. 13.2) are necessary for effective reuse of municipal wastewater. The following is a scheme for a master plan to be implemented for reuse of wastewater as proposed by Helmer and Hespanhol (1997).

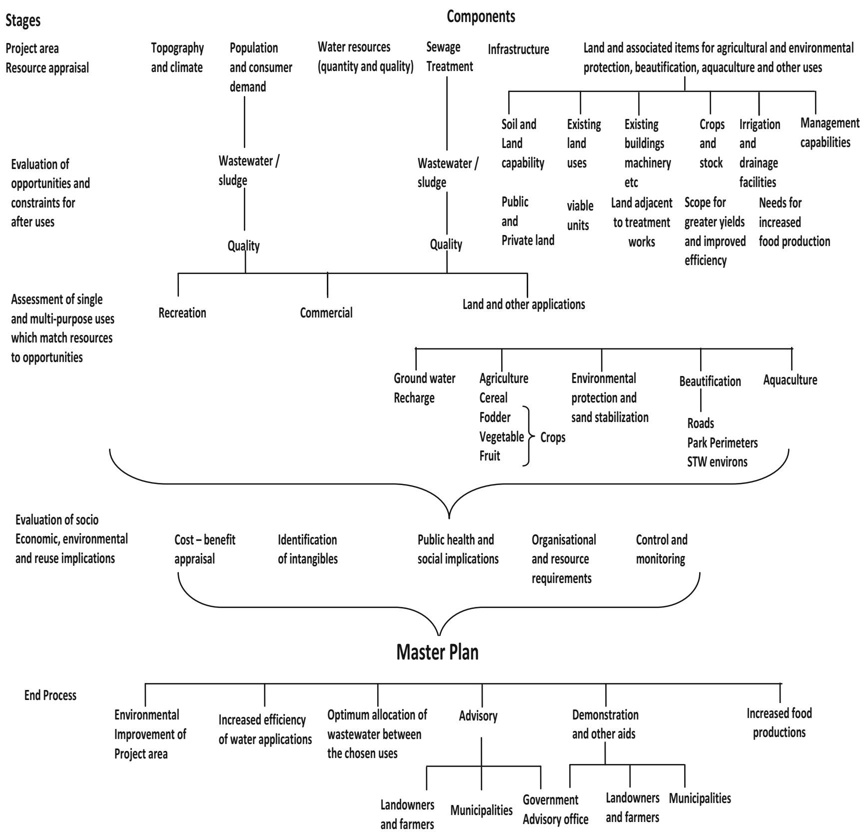


Fig. 13.2 Reuse of wastewater as proposed by Helmer and Hespanhol (1997)

13.7 Conclusions

Properly treated wastewater is a valuable economic resource and reused for economic benefits.Wastewater reuse reduces the demand on conventional water resources. For proper selection of appropriate reuse technology, an integrated approach is required where all aspects such as technological, economical, legal, social, environmental, public health and institutional are considered. A successful wastewater management decision requires a comprehensive, impartial evaluation of centralized and decentralized treatment systems. A proper planning and management are necessary for effective reuse of municipal wastewater.

References

Abbassi B, Al Baz I (2008) Integrated wastewater management: a review. In: Al Baz I, Otterpohl R, Wendland C (eds) Efficient management of wastewater- its treatment and reuse in water scarce countries. Springer, Berlin/Heidelberg, pp 29–40

Abdel-Shafy H, Guindi KA, Tawfik NS (2008) Groundwater contamination as affected by affected by long term sewage irrigation in Egypt. In: Al Baz I, Otterpohl R, Wendland C (eds) Efficient management of wastewater- its treatment and reuse in water scarce countries. Springer, Berlin/Heidelberg

Datta AK, Roy AK, Saha PK (2000) Comparative evaluation of sewage fed and feed based aquaculture. In: Jana BB, Banerjee RD, Guterstam B, Heeb J (eds) Waste recycling and resource management in the developing world. University of Kalyani/International Ecological Engineering Society, Kalyani/Wolhusen, pp 97–104

Edwards P (2000) Wastewater fed aquaculture: state-of-the-art. In: Jana BB, Banerjee RD, Guterstam B, Heeb J (eds) Waste recycling and resource management in the developing world. University of Kalyani/International Ecological Engineering Society, Kalyani/Wolhusen, pp 37–49

Freebarin J (2003) Principles for allocation of scarce water. Aust Econ Rev 36:203–212

Halalsheh M, Abu Ghunmi L, Al-Alami N (2008) Fate of pathogens in tomato plants and soil irrigated with secondary treated wastewater. In: Al Baz I, Otterpohl R, Wendland C (eds) Efficient management of wastewater- its treatment and reuse in water scarce countries. Springer, Berlin/Heidelberg, pp 81–90

Helmer R, Hespanhol I (1997) Chapter −5, Wastewater as a resource. In: Water pollution control – a guide to the use of water quality management principles. United Nations Environment Programme, The Water Collaborative Council and the World Health Organization, New York

Mara D, Kramer A (2008) Guidelines for wastewater and greywater use in agriculture: a practical interpretation. In: Al Baz I, Otterpohl R, Wendland C (eds) Efficient management of wastewater- its treatment and reuse in water scarce countries. Springer, Berlin/Heidelberg, pp 1–17

Mekala DB, Samad M, Boland A (2008) A framework for efficient wastewater treatment and recycling systems, IWMI working paper-129. International Water Management Institute, Colomo. 23p

Monsour N, Mimi Z, Harb J (2008) Allevation of salinity stress imposed on broad bean (*Viciafaba*) plants irrigated with reclaimed wastewater mixed with brackish water through exogenous application of Jasmonic acid. In: Al Baz I, Otterpohl R, Wendland C (eds) Efficient management of wastewater- its treatment and reuse in water scarce countries. Springer, Berlin/Heidelberg, pp 91–112

Pain A, Spuhler D (2007) Wastewater reuse in industries. Seecon International,GmbH SSWM (Sustainable Sanitation and Water Management). www.sswm.info/category/implemention-tools/water-use/hardware/optimization
Roy AK, Rai SP, Datta AK (2000) Comparative evaluation of different resource recovery practices from sewage. In: Jana BB, Banerjee RD, Guterstam B, Heeb J (eds) Waste recycling and resource management in the developing world. University of Kalyani/International Ecological Engineering Society, Kalyani/Wolhusen, pp 91–96
Shende GB (1985) Status of wastewater treatment and agricultural reuse with special reference to Indian experience and research and development needs. In: Pescod MB, Arar A (eds) Proceedings of the FAO Regional Seminar on the Treatment and Use of Sewage Effluent for Irrigation. Nicosia, Cyprus, 7–9 October, Butterworths, London
UN (2015) Transforming our world: the 2030 agenda for sustainable development. A/RES/70/1. United Nations, New York
UN (2016) Sustainable development goals. http://www.un.org/sustainabledevelopment/sustainable-development-goals/. Accessed 1 July 2016
WHO (1989) Health guidelines for the use of wastewater in agriculture and aquaculture. Technical Report Series No. 778, Report of a Scientific Group Meeting. World Health Organization, Geneva
WHO (2006) Safe use of wastewater, excreta and greywater, vol. 1. Policy and Regulatory Aspects. World Health Organization, Geneva
WHO (2015) Sanitation Fact Sheet No. 392. World Health Organization, Geneva

Chapter 14
Socioeconomic Impacts and Cost-Benefit Analysis of Wastewater-Fed Aquaculture

S. Jana

Abstract In view of present scarcity and qualitative degradation of freshwater due to myriad factors such as rapid rise in population growth, indiscriminate use of insecticides and pesticides, industrialization, global warming, and many others, wastewater has been considered as potential resource with its multiple types of reuse and applications in industry, urban areas, agriculture, irrigation, aquaculture, etc. The economic as well as environmental benefits of wastewater are immense by the way of reducing pollution and generating income and employment and conserving water resource. In the process of reusing wastewater in aquaculture, the system incurs some costs which are regarded as externality costs in addition to capital cost and operational costs of farms. This externality costs are social costs incurred for public health protection as the system is associated with health risk. This chapter attempts to examine all the positive as well as negative impacts of wastewater aquaculture and quantify the impacts. In cost-benefit analysis, total benefits accrued are weighed against total costs incurred. The conventional cost-benefit analysis of wastewater aquaculture is not sufficient to evaluate the impact as it does not take into account the indirect benefits (costs) of environmental impacts which are nonmonetary issues being public good in nature. In order to perform a comprehensive cost-benefit analysis, this study attempts to evaluate all these environmental, social, and ecological impacts by valuing them in monetized way by eliciting people's willingness to pay (WTP), shadow price, and opportunity cost. Appropriate policy measures are suggested for maintenance, proper management, monitoring, safeguarding public health, and upscaling of the system with the objective to maximize economic, environmental, and social gain with minimum costs and sustainable development.

S. Jana (✉)
Department of Fisheries Economics & Statistics, West Bengal University of Animal & Fishery Sciences, Kolkata, West Bengal, India

Centre for Environmental Protection & Human Resource Development, Kalyani, West Bengal, India
e-mail: santanajana3@gmail.com

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_14

Keywords Economic benefit · Environmental benefit · Social costs · Willingness to pay · Opportunity cost

Contents

14.1 Introduction

Wastewater is a valuable resource of water due to its immense nutrient potential that can be effectively utilized in fish production through food chain as well as in agriculture and irrigation. Wastewater-fed aquaculture is an ancient activity and is being practiced in several countries of the world especially in some Southeast Asian countries. It plays a profound role in the conservation of water through reuse of wastewater in industries, urban services, and different economic-driven activities. As a result, sewage treatment plant and waste stabilization ponds have gained much importance for treatment cum reuse of wastewater in many countries. Because of high capital and maintenance costs, it is hardly possible for proper treatment of wastewater for want of high cost sophisticated equipment and infrastructure in developing countries. As a consequence, about two thirds of urban wastewater in the developing countries is discharged directly into the open surface water without any treatment.

It is a fact that wastewater treatment integrated with ecological processes and fish culture as practiced in the waste stabilization ponds is the cheapest way of producing fish; the ecological processes result in self-purification of the culture ecosystem and produce fish with low cost and high productivity. Though the practice of using raw or partially treated wastewater in fish culture was very popular and widespread in India, Bangladesh, Vietnam, China, and Southeast Asia, such practice is at present on the declining phase due to apprehension of health risk imposed on human health by the consumption of fishes raised in wastewater system. There has been drastic decline in East Kolkata (EKW) wastewater-fed fisheries from its initial 12,500 ha area to currently 3000 ha attributable primarily to urbanization resulting in closure of many wetlands and thereby lesser availability of wetlands for fish culture. Increasing population and industrialization may also affect the composition of wastewater with increase in pathogenic load and toxic elements that may pose negative impact on fisheries. Nevertheless, the positive impacts of wastewater are visible through economic benefits of fish yield and environmental benefits of usable water for different activities. It provides significant benefits to the farming communities and society in general so long as the wastewater and its nutrient contents are used in aquaculture. Therefore, the primary objective of wastewater-fed aquaculture in using wastewater is to earn maximum benefits from utilizing this resource and minimizing the negative impacts on environment.

For a comprehensive valuation of the benefits and costs of the impacts of wastewater aquaculture, conventional cost-benefit analysis is not adequate as the environmental impacts are of public good by nature. The conventional cost-benefit analysis takes into account of only the cash flows in the system, but environmental costs and benefits have to be considered and need to be taken into account for a proper evaluation of the system. Hence the valuation of environmental impacts are of very importance and pertinent. Valuation of environmental impacts in monetized way can be done applying the techniques in environmental economics. A broader economic analysis of wastewater aquaculture will, therefore, include not only economic impacts but will also include social and environmental impacts. The purpose of this chapter is to make the analysis of socioeconomic, health, and environmental aspects of wastewater aquaculture and a cost-benefit analysis of the system. The specific objectives are to identify all possible impacts of wastewater aquaculture and explain the methods for assessing, valuing, and analyzing the impacts.

14.2 Positive Impacts of Wastewater

14.2.1 Economic Benefits

Wastewater aquaculture helps secure food security and improvement of the socioeconomic conditions of the poor people. Fish farmers use wastewater in aquaculture with the primary motivation of recycling the nutrients that are present in the sewage effluents into fish yield which is system-dependent productivity with a very low cost as the system bears practically no supplementary feed costs and requires no fertilizers and wetlands are available at a reasonable rate. The farmers do not pay for wastewater as wastewater has no price and only treatment cost of wastewater is incurred to make wastewater useful for fish culture. Since no supplementary feed is required in wastewater-fed fisheries, it is the major benefit of this system. Hence, the primary motive of adopting this kind of enterprise is fish production with lower costs than in traditional fish farming system with application of fertilizers and supplementary feed. The farmer community derives the benefits from the system by producing huge amount of saleable fish and vegetables that are produced from the adjacent farming lands. This practice creates more employment, generates income, and supports the local population by providing services in different ways such as in marketing channel, e.g., traders and market intermediaries. It is also a source of livelihood to urban poor and nearby rural laborers who can enjoy urban facilities and get a more secured job than in rural areas. The system provides high protein food which increases the nutritional status of urban poor.

There are studies for raising production of fishes in wastewater-fed system in different countries (Table 14.1). Experiment conducted in Suez, Egypt (Easa et al. 1995), has shown that by using waste stabilization pond system-treated wastewater, average yield of fish was as high as 5–7 mt/ha/year. The studies have shown that these fish are reared with no supplementary feeding and pathogen free and safe for human consumption. In Vietnam, farmers engaged in wastewater-fed aquaculture seem to have a higher net income than farmers in growing other agricultural products and producing fish 4–5 mt/ha/year (Anders 1996). East Kolkata wastewater-fed aquaculture is the largest in the world in terms of landmass and massive urban impact. Initially it covered an area of 12,500 ha and then declined to 8000 ha. Now it has reduced to 3000 ha with an average productivity of 3500 kg/ha/year. The fish production using wastewater was much higher in China ranging from

Table 14.1 Production of fish raised in wastewater-fed systems in different countries

Country	Potential area	Nature of wastes used	Year	Fish yield	Efficiency/ turnover rate	References
China	8000 ha	Excreta and municipal wastewater	1985	30,000 t/ 8000 ha/year	2–4 times higher than ordinary farms	Kumar and Sierp (2003)
Vietnam		Sewage-fed wastewater	1994	4–5 mt/ha/year	Highly productive	Anders (1996)
Germany	233 ha	Municipal wastewater	1996	100–150 t/233 ha/year	Good performance	Prein (1996)
Egypt		Municipal wastewater	1995	5–7 mt/ha/year	More than average productivity	Easa et al. (1995)
Hungary		Domestic wastewater	1990	12–20 kg/ha/ day	Highly effective	Olah (1990)
EKW – India	3000 ha	Municipal wastewater	1998, 2000, 2010	3500–4500 kg/ ha/year	Has been source of livelihood of 40 thousand people	Jana (1998), Edwards (2000) and Bunting et al. (2010)

1.5 to 11 t/ha/year (Kumar and Sierp 2003). Hungary was the first country of the world to produce fish from wastewater producing as high as 12–20 kg/ha/day using domestic wastewater (Olah 1990). In Peru, research has shown the technical, economic, and social feasibility for growing fish in wastewater implying that such fish farms could recover 100% of the wastewater treatment costs.

14.2.2 Environmental Benefits

A properly planned and managed wastewater aquaculture scheme would certainly have a positive environmental impact.

1. Reusing of discharged wastewater in aquaculture helps in conserving water as well as protects environmental degradation. Thus, wastewater-fed aquaculture leads to conservation of water resource and does more rational use of wastewater.
2. The system offers low-cost water treatment, recycles wastewaters, and converts it into resource.
3. The system also reduces pollution control cost of societies protecting environment from water pollution. The treatment of wastewater is performed in a cheapest way through aquaculture. Savings are realized as there is reduced expenditure on wastewater treatment in societies.
4. The system also helps flood control as the wetlands act as reservoirs of excess rain water.
5. Wastewater aquaculture would increase the amenity values of environment by creating recreational sites near the pond areas by providing amenities for fishing, boat rental, food court, etc. This makes the area attractive as a recreational site. The greenery views of the surrounding areas, the farmlands growing vegetables which get fertilized with wastewater ponds, has increased the aesthetic values of the environmental attributes of the areas.
6. Improvement of this environmental quality affects the property values in the vicinity of the pond areas. Wastewater aquaculture may lead to increase in bequest values of environment. People are willing to pay higher price for the land for amenities created near the vicinity of the pond area. Improvement of environmental attributes can enhance land and house values if they are viewed as attractive or desirable or they can reduce values if they are viewed nuisances and the people implicitly reveal their willingness to pay more for improved environmental features. This is the hedonic price approach for measuring the valuation of environmental features like clean air, amenities created, clean water, etc.
7. Increase in biodiversity affects the values of buildings and land in the vicinity and leads to rise in price of buildings and land in the vicinity of the complex. The WTP indirectly express the money value of the improvement of environmental attributes.

14.3 Costs of Wastewater-Fed Aquaculture

Wastewater-fed aquaculture incurs economic costs as well as social costs. Economic costs are those which are incurred in the production process and the on-farm costs such as (1) cost for labor; (2) cost for pond construction and preparation; (3) treatment cost of wastewater for usable state in fish pond which is the additional marginal cost for using wastewater; (4) cost of fish seed, fry, and fingerlings; (5) supplementary costs for fertilizer (if needed); (6) cost of chemicals (lime and potassium) used; (7) cost of electricity consumption; and (8) maintenance cost and other miscellaneous expenditure.

The operation of wastewater-fed aquaculture also creates externality costs as the use of wastewater has some adverse effects on human health, environment, social and loss in biodiversity.

14.4 Negative Impacts of Wastewater

Negative impacts of wastewater and their intensity depend on various factors including the source, intensity, and composition of wastewater. These are the following.

14.4.1 Public Health Aspect

The use of untreated or partially treated wastewater from industrial effluents and municipal wastes in aquaculture in developing countries imposes social costs impairing the health of fisher and related people. Use of contaminated wastewater in aquaculture may cause occupational health risk to handlers and consumers. Wastewater also contains pathogenicmicroorganisms such as bacteria, viruses, and parasites which cause various diseases among the fish handlers, fish consumers, and users of wastewater and in neighboring communities. The intensity of this impact increases if the wastewater contains more industrial effluents which have heavy metals such as chromium, cadmium, lead, and other toxic elements.

Exposures of farmers and fish handlers to wastewater may result in waterborne diseases and infectious diseases such as skin disease and parasite infection. This consequently reduces the working capacity of labors, loss of potential earnings, and rise in medical costs of the affected persons. It is, therefore, necessary to have safe culture practices, hygienic handling practices, safe food washing, proper cooking, and preparation with proper and effective management which can minimize health risks. WHO (2006b) recommended the guidelines to be followed in scheme of wastewater-fed aquaculture for the improvement of hygienic condition of the people. The system is highly beneficial if the reuse practice of wastewater-fed fish culture safeguards the public health by minimizing health and environmental risks.

14.4.2 Soil Degradation

Long-term use of wastewater in agriculture lands through irrigation may result in accumulation of heavy metals, salts, and toxic elements in the soil that reduces soil productivity in the long run. Recently, many wastewater-fed aquaculture ponds in EKW complex have been converted into paddy lands due to siltation and reduced amount of partially treated wastewater for fish culture.

14.5 Impacts on Biodiversity

Since the adjoining areas of wetlands are extensively used for fisheries and allied activities, impact of pollution and heavy usage of chemicals and inorganic fertilizer in agriculture and fishery-related activities have resulted in habitat degradation for residential and migratory water birds. Reed beds, nesting sites, roosting grounds – the shelter of water birds have been lost. As a result, biodiversity in general and diversity of birds in particular have been reduced. Extinction of species imposes a loss to society. This is an alarming situation. It deprives the future generation of deriving amenities and gain in utility from the existence of the extinct species. This social cost can be measured by the willingness to pay to conserve these environmental resources.

14.6 Social Impacts

Social impact means concern/doubts expressed by people about their perception on the reuse of wastewater such as nuisances, poor environmental quality, poor hygiene, odor, etc. which may arise from the operation of the system. Social concern, e.g., food safety, health, welfare, impaired quality of life, loss of property value, pollution of resources, etc., fall under the category of social impact. In many societies there is hesitation for consumption of fish raised in wastewater. This is more in European and some Asian countries. Similar objections are also raised in America, Australia, and some African countries. As fish produced using wastewater is generally considered as low-value fish, people with their rise in income may tend to purchase high-value fish which may reduce the demand of wastewater-fed fish, considered as inferior type compared to high-value fish (Giffen's goods) in spite of its low price. So income effect is not positive in this case. However, in some developing countries of Asia, China, Java, Vietnam, and India, wastewater-fed aquaculture is regarded as economical and is ecologically sound and acceptable to a large section of poor people as a source of low-cost animal protein (Hanjra 2000). Health risks are not detected if the fish are processed and cooked properly.

14.7 Valuation of Impacts and Cost-Benefit Analysis

14.7.1 Framework of Comprehensive Cost-Benefit Analysis

It is pertinent to deal with the methodological approaches for valuation of impacts to perform a comprehensive cost-benefit analysis that incorporates economic, health, environmental, social, and ecosystem impacts of wastewater use in aquaculture. This will enable to examine whether the wastewater aquaculture project is viable and economic. It is necessary to perform financial appraisal of the project done in different steps such as (1) to provide economic justification which requires cost benefits and cost-effectiveness of the project concerned and (2) financial feasibility. In cost-benefit analysis, total benefits accrued in the system are weighed against costs. A rewarding project is one for which discounted value of the benefits exceeds the discounted value of costs, that is, net benefit is positive. The criterion to justify a worthwhile project is that the project should generate a positive net present value (NPV) of benefit. Present values of benefits are obtained by discounting the future values of benefits derived by a discount rate. If the sum of the net discounted benefits over the lifetime of the project is positive, the project should be approved. This is the same as the principle as in welfare in economics, Pareto improvement, according to which a project is worthy of consideration if the net benefit from the project is positive, that is, $B–C > 0$ where B and C are benefits and costs. Other two discounted methods for economic appraisal are cost-benefit ratio (CBR) and the internal rate of return (IRR) of the project. Another method used is payback period, the undiscounted technique.

CBR is the ratio of the present value of future net cash flows over the lifetime of the project to the net investment. If $CBR>1$, the project is worthwhile. The internal rate of return is the interest rate that will equate the sum of net cash flows of the farms to the initial investment of farm. The designing for a wastewater-fed aquaculture project for implementation would be in such way so that NPV becomes positive, cost-benefit ratio becomes greater than one, and IRR is competitive. In financial appraisal of the wastewater fishery, only marginal costs are taken into account, for example, the additional cost required to attain local affluent standard for reuse.

As the use of wastewater in aquaculture has environmental, economic, and social impacts, valuation of total impacts for cost-benefit analysis has to be done in a consistent manner which needs the estimation of all the impacts to be measured with a common monetary yardstick.

14.7.2 Valuation of Benefits and Costs of Wastewater-Fed Aquaculture

Direct economic cost and benefits are readily estimated in monetary term, and they are reflected in the cash flows of the farms, and market price exists for output and input. For a comprehensive cost-benefit analysis of wastewater aquaculture, environmental and social impacts have also to be taken into account in addition to economic cost benefit. Economists have developed several methods for the valuation of environmental benefit and costs. Some of these methods could be applied for valuing environmental impacts of wastewaters. As there is no market for environmental goods and services, they have no market price. Willingness to pay (WTP) is the standard measuring stick in economics for valuation. Technique for valuation of environment uses the concept of WTP of people. Environmental benefits can be measured by eliciting individual's willingness to pay for incremental changes in environmental quality using the following methods.

14.7.2.1 Valuation of Environmental Benefits and Costs

For the assessment of benefits and costs, impacts are to be valued in monetary terms. Output and inputs which are traded in the market have market price. Environmental goods and services have no market price, but they can be given a monetary value. Individuals purchase the product when their willingness to pay equals or exceeds the market price of the product. Prices are expressions of willingness to pay by the consumers. Monetary measurement of social benefit from an environmental project can be reflected by willingness to pay of people for having that benefit. While benefit values can be measured by WTP, costs can be monetized using the concept of opportunity cost which is the measure of alternative return foregone.

Methods for Valuation

- Conventional Market-Based Approach/Market Pricing Approach

  This approach is used when the environmental improvement under consideration causes an increase or decrease in real output and/or inputs and goods are traded in the market and market price exists for input and output. Benefit and cost can be valued using market prices, for example, expected increase in fish harvest due to the implementation of a new water pollution control technology. The increase in fish production is the result of this improved environmental quality through pollution control. The values of output and input used in production process are measured by market prices. The value of incremental fish production due to improvement in environmental quality reflects the value of environmental impact.

- The Replacement Cost Approach

The replacement cost approach can be used for valuing environmental benefits when the damage can be avoided as a result of improved environmental condition and this benefit can be approximated by the market value of what it costs to restore to replace the damage and assessed on the basis of savings realized from reduced expenditure as a result of restoration or replacement of damage. This method can elicit people's willingness to pay to the extent that the reduction in replacement and restoration costs due to improved environmental conditions reflects willingness to pay to avoid environmental damage (Pearce 1993). Wastewater-fed aquaculture system reduces wastewater treatment cost of societies to some extent. It saves the damage of environment to the extent that it treats wastewater which otherwise gets discharged into environment. The benefits can be measured by the reduced expenditure on wastewater treatment.

- Revealed Preference Approach

This approach is used to infer willingness to pay for environmental goods and services where market prices do not exist from the observation of people's behavior in market for related goods. Value is inferred from actual behavior of consumers revealed in the market. Willingness to pay for a good and service is thus estimated indirectly. Hedonic price approach is a revealed preference approach as discussed earlier.

- Contingent Valuation Method

In this approach, peoples' willingness to pay is obtained through hypothetical market where people are asked to express their willingness to pay for a good and service through surveys. These types of environmental goods and services have only nonuse values. Economic value of environmental asset has two parts, use and nonuse value. Use value can easily be estimated from the recreational values to current user. For example, commercial and recreational fishing create jobs and income. These are the benefits received by the individual who are directly utilizing natural environment. This is measured by willingness to pay which is reflected in market price. But some attributes has nonuse values, for example, wildlife preservation for future users. Environmental asset is characterized not only by economic factors but also by the attributes of uniqueness, irreversibility, and uncertainty. So the total value of environmental asset is composed of several willingness to pay. It is not possible to assess nonuse values by using implicit prices. Method has been developed based on surveys which create a hypothetical market condition that elicits willingness to pay for estimating nonuse values. This is contingent valuation method. For estimation of nonuse values, while conducting the survey, respondents in the sample selected are asked as how much they are willing to pay, contingent on changes in the availability and/or quality of an environmental amenity such as preservation of wetland or wild life or endangered species protection.

14.7.3 Application of Approaches to Measure Benefits and Costs

1. Quantification of wastewater impact on fish production

For cost-benefit analysis, quantification of impacts is required. This can be understood in physical terms also in the context of with wastewater or without wastewater project. The comparison of the production using wastewater and without wastewater, assuming other things remain the same, will indicate the extent in increase in fish production due to the use of wastewater. For cost-benefit analysis, differences between the two scenarios may be taken as a measure of impact of wastewater use in aquaculture. As wastewater as input has no market price, effect of wastewater in aquaculture thus can be estimated in indirect way.

Following is the analysis of two projects A and B.

In project A, wastewater is used in fish production along with other inputs such as fish seed, fertilizers, labor, etc. Farm B operates without wastewater, uses normal water in the same amount as A uses, and uses other inputs also in the same amount as A uses, with no change in quality of other inputs. Gross value of output of A and B is obtained from volume of fish produced times average farm-level price. Net value of output is derived by subtracting the total costs of production from the gross value of output. Difference between the net values of output of project A and project B represents the benefit of wastewater use in aquaculture.

Net value of output in A = (Gross value of output – total cost of production) in $A = A_{ww}$.

Net value of output in B = (Gross value of output –total cost of production) in $B = B_{w}$.

Value of impact of wastewater in fish production is $(A_{ww} - B_{w})$. A_{ww} is net production with wastewater and B_w without wastewater.

The net present value output for a number of years of a wastewater-fed aquaculture farm can be estimated using a proper discount rate for discounting the future values.

2. Marginal productivity of wastewater in aquaculture can also be estimated empirically. Let us assume a Cobb-Douglas type of production function in a wastewater-fed aquaculture farm such as

$$Q = A\left(F^{\alpha}S^{\beta}L^{\lambda}WW^{\eta}X_1{}^{\mu}\ldots\ldots\ldots X_n{}^{\delta}\right)$$

where Q, F, S, L, and WW denote quantity of output, fertilizer, seeds, labor, and wastewater, $X_1\ldots\ldots\ldots X_n$ are the other inputs used, and λ, α, β, η, $\mu\ldots\,\delta$, etc. are partial elasticity of factors used with respect to output.

Marginal product of using wastewater to fish yield is

$$\delta Q/\delta WW = A\eta(Q/WW)$$

which is the measure of impact of wastewater on fish yield (Hussain et al. 2001).

3. Valuation of impact on public health

There is risk of diseases with the use of wastewater in aquaculture. Pond workers suffering with these diseases may lose potential income due to the reduction in their working capacity. Fish consumers of sewage-fed fish and the people who suffered from adverse health effects of wastewater have to bear growing medical expenditure. All these impacts can be estimated using opportunity cost principle. Hussain et al. (2001) have proposed the following method for quantifying the harmful effects on human health. The loss of potential earnings of laborers, due to morbidity caused by wastewater aquaculture, can be estimated in the following manner. The present value of labor productivity losses due to wastewater-related diseases is

$$PV_{pi} = \sum\left\{\left(SD_i^{*}WR_i^{*}ID_{ww}^{*}TP_i\right)/(1+d)^i\right\} + \ldots\ldots + \left\{\left(SD_n^{*}WR_n^{*}ID_{ww}^{*}TP_n\right)/(1+d)^n\right\}$$

where PV_{pi} is the present value of labor productivity loss, SD is the number of sick days attributed to wastewater use per person per year, WR is the average wage rate n is the total period of employment where $i = 1\ldots\ldots\ldots n$, ID is the percent of population affected, TP is the total population in a given community or project area, and d is the discount rate (Hussain et al. 2001).

The medical costs include the cost of medical consultations, cost of medication, transport cost, and other illness-related expenses. The private treatment cost can be used as proxy (opportunity cost) for medical costs as public health is subsidized in most developing countries.

4. Valuation of social impacts

The community groups are mostly concerned with the potential risks associated with wastewater-fed aquaculture such as poor hygiene, odor of fish, food safety, health and welfare, impaired quality of life, pollution of water resources, and loss of exotic species. Some social concerns can be addressed with community awareness program and public education. Thus, the cost of public education, awareness, and demonstration program can be used as a measure for the valuation of social impacts of wastewater aquaculture.

14.7.4 Cost-Benefit Analysis of Wastewater-Fed Aquaculture

Based on the estimations of the benefits and costs of environmental, economic, and social impacts of wastewater aquaculture, total benefits accrued are weighed against total costs incurred in the system. Cost-benefit analysis is performed in policy-making decision as whether to start a newly designed wastewater aquaculture project, that is, its worthiness for consideration to accept. To perform the analysis, the approach requires information on the flow of expected benefits and costs of the project in question. After monetary estimation of all types of benefits and costs including economic, environmental, social, and ecological elements, the value of aggregate discounted benefits and value of aggregate discounted costs are estimated. If total discounted benefits are greater than total discounted costs over the lifetime of the project, the project is declared acceptable. A cost-benefit analysis weighs the benefits and cost streams of a project using the following decision rule:

Estimation of net present value (NPV) = $\sum(B_t - C_t)\{1/(1+r)^t\}$where B_t and C_t represent stream of benefits and costs in t period where $t = 1,2,\ldots. n$ and n is the lifetime of the project. The expression $1/(1+r)^t$ represents the present value of a rupee of net benefit coming at the end of t years, r represents the discount factor for discounting future values of benefits and costs, and $r > 0$. A project is acceptable if the sum of the net discounted benefits over the lifetime of the project is positive, so the project is justified if NPV > 0 in the system. Optimum utilization of the resources in the system along with costs minimization of economic and environmental and removal of other constraints to wastewater aquaculture and also with effective management, might generate a positive NPV. For policy-making decision, the designing and planning of the system would be in such a way so that NPV > 0.

14.8 Comparison of East Kolkata Wastewater Fishery with Conventional and Rational Design Model

East Kolkata wastewater-fed fishery, the largest in the world, has declined over the last three decades by more than 50% because of urbanization (CRG 1998). Bunting (2007) has attempted to compare the scenario in fisheries in East Kolkata wetlands based on Kolkata wastewater fishery which uses a wastewater flow of 550,000 m^3 day^{-1}, conventional and rational designs for lagoon-based wastewater treatment, treating wastewater of flow of 550,000 $m^3 day^{-1}$ and reuse through aquaculture with that of bioeconomic modeling. The developed financial indicators implied that both the rational design and conventional system are much more productive and highly profit-making enterprise and economically viable than in the traditional practice used in wastewater aquaculture in peri-urban area of East Kolkata. Lagoons and fish ponds for the rational design require greater area than used in traditional practice in East Kolkata wastewater fishery. In the context of present infrastructure in peri-urban area of East Kolkata, it may not be possible to implement the rational design system due to limited land availability. Conventional system with lower capital costs and lower financial risks might attract private investment in wastewater fishery, though the internal rate of return is much lower (9.5%) than in rational design (20.6%). Greater fish production, better-quality employment, and hygienic culture method complying with WHO (2006a) in rational design offer an improvement over the existing system of traditional practice working in East Kolkata wastewater fishery. But there appear some difficulties in implementation.

The East Kolkata wastewater-fed fishery has been assigned at Ramsar Site for the conservation and the sustainable use of wetlands. In East Kolkata wastewater-fed aquaculture, fish pond area covers 2480 ha. Size of fish farms varies from 0.4 to 162 ha (CRG 1997), producing 4.5 t/ha/year. A study was carried out by the present author in 2006–2007 on the basis of information provided by 30 sewage-fed fish farms in the East Kolkata wastewater fishery which consists of 150 bheries (large water bodies) covering an area of 3000 ha. Fishes comprising carps, catfishes, and tilapia produced from the system are supplied to the nearby wholesale market and then are supplied to rural and city markets and produce roughly 16% of city's fish sale (Jana 2007). The study revealed that the system has created a sufficient amount of value addition to fish protein. In the total cost of fish production, labor cost is the lion's share accounting nearly 60% followed by cost for seed (20–25%), and the rest is incurred toward miscellaneous expenditure. The average income earned by fish farmer was around Rs. 2000–2500 per person per month. However, in the government-owned wastewater-fed fish farm, the labors are paid Rs. 5000–6000 per person per month (Nalban government-owned fishery). The system has high turnover rate as it was found that out of 30 farms, more than 80% farms had profit with a turnover rate of more than 80% (Jana 2007).

The system has high potential to generate employment creating as many as 40,000 jobs (Carlisle 2013). Many of the laborers engaged in EKW migrated from rural areas where they were under disguised unemployment in agriculture. Laborers migrate from rural to this urban area as they consider jobs in this wastewater fishery a more secure job and to enjoy urban facilities. The system working in EKW is delivering huge economic, social, and environmental benefits.

14.9 Conclusions

The wastewater-fed aquaculture in developing countries now is facing constraints of inadequate and contaminated wastewater input problems and land scarcity problem as more and more land are being used for urbanization. Cost-benefit analysis indicates that if rationally designed, the system is highly productive. But the problem is that in most developing countries, traditional practices using raw or partially treated wastewater are working. Scientific evidence suggests that health risks can be avoided if wastewater is adequately treated prior to the reuse in aquaculture. Further, there is provision of segregating pond using clean water where fish should be kept for 2 weeks for decontamination before marketing. It is expected that if the negative impacts and the costs associated with it can be minimized, the system would likely to generate a positive net present value. In a study in Morocco (Kfouri 2009), the estimated value of NPV of using wastewater has been positive. The net benefit of implementing wastewater reuse in Morocco is at least 2.035 billion USD, nearly 1.62% of GDP, 2008 (Kfouri 2009). This shows that the wastewater is a useful resource for economic-driven activities. However, it has to be properly planned and implemented effectively with regular careful monitoring and safeguarding public health and environmental risks. For this purpose, the system requires prior treatment of wastewater, continuous monitoring, and upscaling, and finally control measures should be taken for decontamination of fishes grown in wastewater system by keeping them in the clean water for 2 weeks or more, prior to marketing. It is also necessary to undertake appropriate policy on legislation, institutional framework, and regulation at the international and national level.

References

Anders D (1996) Wastewater-fed aquaculture in Vietnam. Mekong Fish. Catch and Culture, vol. 4, ISSN: 0859-290X

Bunting SW (2007) Confronting the realities of wastewater aquaculture in peri-urban Kolkata with bioeconomic modeling. Water Res 4:499–505

Bunting SW, Pretty J, Edward P (2010) Wastewater fed aquaculture in the East Kolkata Wetlands, India: anachronism or archetype for resilient ecocultures. Rev Aquaculture 2:138–153

Carlisle S (2013) Productive filtration: living system infrastructure in Calcutta. Scenario 03: Rethinking infrastructure. http://scenariojournal.com/article/productive-filtration-living-system-infrastructure-in-calcutta/

CRG (1997) East Calcutta wetlands and waste recycling region. Creative Research Group, Kolkata. https://en.wikipedia.org/wiki/East_Kolkata_Wetlands

CRG (1998) East Calcutta wetlands and waste recycling region. Creative Research Group, Kolkata. https://www.revolvy.com/main/index.php?s=East%20Kolkata%20Wetlands

Easa ME, Schereif MM, Shaaban II, Mancy KH (1995) Public health implications of wastewater reuse for fish production. Water Sci Technol 32:145–152

Edwards P (2000) Wastewater fed aquaculture: state of the art. In: Jana BB, Banerjee RD, Guterstam B, Heeb J (eds) Waste recycling and resource management in the developing world. University of Kalyani/International Ecological Engineering Society, Kalyani/Wolhusen, pp 37–49

Hanjra MA (2000) Socio economics and environmental effects of wastewater irrigation: state of the art, problem areas and policy alternatives. International Water Management Institute, Colombo, p 56

Hussain I, Raschid L, Hanjra MA, Marikar F, van der Hoek W (2001) A framework for analyzing socioeconomic, health and environmental impacts of wastewater use in agriculture in developing countries. Working Paper – 26. International Water Management Institute, IWMI, Colombo, Sri Lanka

Jana BB (1998) Sewage fed aquaculture: the Calcutta model. Ecol Eng 11:73–85

Jana S (2007) Analysis of impact assessment of credit structure in fisheries: formulation of proper credit policy conducive to agriculture development with emphasis on the role of Institutional credit. Final Report of the ICAR Project (Principal Investigator – S. Jana) submitted to the ICAR, New Delhi, p 66

Kfouri C (2009) Water reuse cost-benefit analysis: the Morocco example, Water Week
Kumar MS, Sierp M (2003) Integrated wastewater treatment and aquaculture production. Rural Industries Research and Development Corporation. Publication no. 03/026 pp. 66
Olah J (1990) Wastewater fed fish culture in Hungary. In: Edwards P, Pullin RSV (eds) Wastewater fed aquaculture. In: Proceedings of the international seminar on wastewater reclamation and reuse for aquaculture, Calcutta, India 6–9 December, 1988, p 296. Environmental Sanitation Information Centre, Asian Institute of Technology, Bangkok, Thailand, pp 79–89
Pearce DW (1993) Economic values and the natural world. MIT Press, Cambridge
Prein M (1996) Wastewater-fed aquaculture in Germany: a summary. Environ Res Forum 5–6:155–160
World Health Organization (WHO) (2006a) Safe use of wastewater, excreta and greywater. Vol. 1. Policy and regulatory aspects. World Health Organization, Geneva
World Health Organization (WHO) (2006b) Guidelines for the safe use of wastewater, excreta and greywater: wastewater and excreta use in aquaculture, vol 3. World Health Organization, Geneva, p 140

Chapter 15
Environmental Impact Assessment: A Case Study on East Kolkata Wetlands

A. R. Ghosh, S. Mondal, and D. Kole

Abstract Wetlands are renewable and cost-effective complex nature of integrated natural biological resources. The wise use of aquaculture in the form of sewage-fed fishery provides a multitude of ecological functions such as flood reduction, groundwater recharge, habitat and biodiversity restoration, employable opportunity, etc. Wetlands are classified into 19 categories to include all varied nature of wetlands starting from plain land to high altitude as well as man-made to natural. Sharp decline or destruction of these ecosystems due to serious human intervention poses a threat to environmental sustainability. The present study highlights the steps of impact assessment, its different processes, evidences of impact assessment, impact analysis using diverse parameters to establish a report on management and monitoring of wetlands with special reference to East Kolkata Wetlands (EKW). The US Environmental Protection Agency (USEPA) has adopted three tiers or levels of methods for assessment system. East Kolkata Wetlands are unique ecological sensitive areas and are established as wise use of wetlands where the city sewage is used by mastering the activities of resource recovery. It also focused on the process of initial environmental examination (IEE) and strategic environmental assessment (SEA) which are recognized as the outcome of Agenda 21. Finally, impact analysis of biological organisms, especially fish through histological, histochemical, topological, enzymological and hormonal studies would be the important and added methods and techniques for future workers in the process of conceptual modelling on wetlands.

Keywords Environmental impact assessment · East Kolkata Wetlands · Impact analysis

Contents

A. R. Ghosh (✉) · S. Mondal · D. Kole
Ecotoxicology Lab, Department of Environmental Science, The University of Burdwan, Burdwan, West Bengal, India
e-mail: apurbaghosh2010@gmail.com

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_15

15.1 Introduction

Wetlands are recognized as environment-friendly, less energy-intensive and cost-effective natural resources. Wetlands are complex and integrated ecosystems in which water, plants, flora, fauna, microorganisms and the environmental factors interact with each other (Guirguis 2004). Functionally, a natural wetland arises where the level of water is near the surface for enough time to keep the soil below saturated. The self-purification mechanism involving physical, chemical and biological process interactions is responsible for detoxifying the pollutants to some extent.

Though a precise definition of wetlands can be controversial due to enormous variety of wetland types, it has been broadly defined as 'any areas of swamp, pond, peat, or water, natural or artificial, permanent or temporary, stagnant or flowing water, including estuaries and marine water, the depth of which at low tide does not exceed six meters' (Mitsch and Gosselink 1986).

The most important ecological services provided by the wetlands are maintenance of habitats for wild species of flora and fauna, homeostasis of the ecological systems, fish wealth, groundwater recharge, purification of water, recycling and retention of nutrients, flood control, carbon sequestration and water security which ultimately protect and regulate the water resources, conservation of biodiversity and maintain an ecological balance as so-called natural kidney. It also creates good recreational, scientific and aesthetic value and generates the employment opportunity to the local people. Due to its rich biodiversity and extensive food chain, the wetlands are also called biological supermarkets (Mitsch and Gosselink 1993).

The wetlands comprise 7.7% of the Earth's landscape or a total surface area of 11.65 million km^2. According to UNEP-World Conservation Monitoring Centre, it is about 570 million hectares (5.7 million km^2) – roughly 6% of the Earth's land surface (Ramsar 1971). Recently, much attention has been paid to those wetlands which were used as wastelands (Gopal 1999) and convenient wastewater discharge sites to collect sewage (Kadlec and Knight 1996). Aquaculture including wetland fishery is the fastest-growing food-producing sector in the world. Despite tremendous importance of wetlands for ecological and economical reasons, there has been serious decline in the number of wetlands mainly due to urbanization and allied activities. In India, only 50% of the total wetlands are in existence, and the rate of decrease is 2–3% every year. The decline in wetlands would result in environmental and ecological imbalance.

15.2 Classification of Wetlands

Wetlands are classified into 19 categories to include all varied nature of wetlands starting from plain land to high altitude as well as man-made to natural etc. (Kadlec and Knight 1996). There are 19 classes of wetlands in India based on the definition of Ramsar with three-level hierarchical system (Table 15.1).

In Level 1, two classes of wetlands are recognized, inland and coastal; in Level 2, they are subdivided into another two categories such as natural and man-made; and in Level 3, these include all the 19 classes of wetlands.

Panigrahy et al. (2012) proposed eight wetland themes as follows:

Layer 1: It indicates the wetland boundary.
Layers 2 and 3: It means spreading of water during pre-monsoon and post-monsoon.
Layers 4 and 5: It provides the information on presence of aquatic vegetation.
Layers 6 and 7: This is qualitative estimation of turbidity of the open water, ranged as low, medium and high during pre- and post-monsoon seasons.
Layer 8: These are the wetlands of small size with the area < 2.25 ha.

India possesses diverse types of wetlands situated at high-altitude lakes of 5000 m elevation in the Himalayas up to marine systems covering mangroves and corals. According to LISS-III data (2006–2007) the total wetland area in India is estimated to be as 15.260 m ha which covers around 4.63% of the total geographical area of

Table 15.1 Categories of wetlands

(A) Inland	(B) Coastal
(a. Natural)	(a. Natural wetlands)
1. Lakes/ponds	11. Lagoons
2. Ox-bow lakes/cut-off meanders	12. Creeks
3. High-altitude wetlands	13. Sand/beach
4. Riverine wetlands	14. Intertidal mudflats
5. Waterlogged	15. Salt marsh
6. River/stream	16. Mangroves
(b. Man-made)	17. Coral reefs
7. Reservoirs/barrages	(b. Man-made)
8. Tanks/ponds	18. Salt pans
9. Waterlogged	19. Aquaculture ponds
10. Salt pans	

555,557 ha. This includes 43.4% of inland-natural wetlands (69.22% or 10.564 m ha) and 27.13% (4.14 m ha) of coastal-natural wetlands, and high-altitude wetlands of 126,249 ha.

15.3 Methods of Impact Study

15.3.1 Levels of Assessment

USEPA (US Environmental Protection Agency – Region 8) developed a three-tier, or three-level, method of assessment of wetlands such as Level 1 (Assessment Methods – Digital National Wetland Inventory (NWI) and Landscape Integrity Model (LIM)), Level 2 (Assessment Methods – Ecological Integrity Assessment EIA) and Level 3 (Assessment Methods – Floristic Quality Assessment (FQA), Vegetation Index of Biotic Integrity (VIBI)).

Level 1 provides the Digital National Wetland Inventory (NWI) mapping. Using this method the wetlands can be measured (in acres), its type, and distribution in a certain landscape. Landscape Integrity Model (LIM) provides a state-wise data based on GIS application.

In the Level 2, assessment is based on Ecological Integrity Assessment (EIA) which gives a framework of ecological studies and biological responses. It evaluates wetland condition based on a multi-matrix system which includes three major factors like landscape context, condition and size of the ecological periphery.

According to Level 3, the Floristic Quality Assessment (FQA) is the use of coefficients of conservatism (C-values) focusing on the concept of conservatism. This is the existence and framing of all native species of flora. Actually, these C-values species possess a wide tolerance to human interferences. FQA furnishes the data on species richness and species abundance. FQA also provides an idea on effective integration of spatial and temporal human impacts to ecological condition. Level 3 also includes another subsystem called Vegetation Index of Biotic Integrity (VIBI) which discloses the ability of an ecosystem to 'support and maintain a balance adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habits within a region'. During the assessment process of wetland, the biotic integrity poses its cost-effectiveness as well as human interventions as biotic community. It can help in restoration, enhancement and successful preservation of ecological integrity of the wetlands by different projects.

In addition to these, Dr. Brad Johnson has developed another assessment method known as 'Functional Assessment of Colorado Wetlands' (FACWet); along with this Proper Functioning Condition (PFC) is adopted by the Bureau of Land Management for assessment of the physical functions of riparian and wetland regions.

15.3.2 *Impact Assessment on East Kolkata Wetlands (EKW)*

15.3.2.1 Geographical Location of EKWL

East Kolkata Wetlands (EKW), located in the eastern part of Kolkata under the districts of North and South 24 Parganas of West Bengal, India, are an important portion of the mature delta of Ganga River. Presently, the total area of the wetland is 12,500 ha, among which there are 364 sewage-fed fisheries (5852 ha), agriculture (4781 ha) and solid waste farms (603 ha) and some built-up areas for human settlements (1326 ha) (Table 15.2). East Kolkata Wetlands lie approximately between latitudes 20°25′ to 22°40′ North and longitudes 88°20′ to 88°35′ East. Its monsoonal climate is usually hot and humid with an average annual rainfall of nearly 1600 mm (mainly concentrated in the months of mid-June to mid-October). Usually, January is recognized as the coolest and May as hottest. Ganga River encompasses this region is a portion of the mature delta, and in this delta wetlands form the inter-distributor marshes. The part of these streams once was the active tributaries, distributaries and re-distributaries of the Ganga. But with the shifting of the main river, the streams became inactive, and some of them even died with consequent loss of headwaters, while some of them were still building land on both sides. Between those raised tracts, the land was comparatively depressed, being deprived of the annual deposition of silt. It was once covered with saltwater marshes. These saltwater marshes were between the Hooghly River to the west and the Bidyadhari River to the East. The mouths of some of the streams opened into the Bay of Bengal and were influenced by tidal action, which accounted for the tides and salinity of these saltwater lakes in the east of Kolkata. These lakes were actually the spill reservoirs of the tidal channel Bidyadhari which opened into the Bay of Bengal through the Matla River. One of the spill channels of the Bidyadhari, the Central Lake Channel, extended practically into the heart of the city even until early in the twentieth century and was the main drainage line for the city of Kolkata.

Local people in and around the EKW is exclusively dependent of this sewage-fed fisheries which contributes a substantial portion of fish demand in the city of Kolkata. City sewage was used for fish farming, agriculture and horticulture in the adjoining areas. The mechanism of desiltation process of the canals carrying sewage can be considered as an important method of conservation of EKW. There are major four types of land use classes in the EKW areas, which are as follows: (1) substantially

Table 15.2 Description of land use pattern in the Study area in East Kolkata Wetlands (EKW)

Land use	Area (in hectare)
Substantially water body	5852.14
Agricultural area	4718.56
Productive farming area	602.78
Urban/rural settlement area	1326.52 (91.53 ha urban + 1234 ha rural)
Total area	12,500

Source: Kundu et al. (2008)

water body-oriented area, (2) agricultural area, (3) productive farming or garbage farming area and (4) settlement area (Table 15.2). The settlement area again may be categorized into urban and rural settlement area.

East Kolkata Wetlands have been recognized as ecologically sensitive areas and named as Wetland of International Importance under the Article 8 of the Ramsar Convention; site number 1208. The EKW sewage-fed fisheries have been recognized as the largest site of wastewater-based fish cultivation in the world and providing livelihood of more than 20,000 core group of people by yielding about 15,000 t of fish per year. Among these core group of people, 8500 are directly involved and 90% of them are local. In fact, the sewage-fed fisheries act as ecologically balanced wastewater treatment system converting it in an acceptable effluent quality before discharge in the inland surface water because they act as natural filters, also a container of harbouring pollutants and retention of nutrients.

15.3.2.2 Study on Impact Assessment

Impacts of parameters are divided into direct impacts, also called as primary or first-order impacts, and indirect impacts, i.e. secondary or second order, third order and so on. As per report of Initial Environmental Examination (IEE) – 2000 prepared by the Project Preparatory Technical Assistance (PPTA), the assessment process of EKW requires revision and upgradation for necessary screening and evaluation of environmental impact potentiality and copes with the proper mitigation measurements (Pragatheesh and Jain 2013). As early as 1690, the managers and planners of Kolkata selected the eastern part of Kolkata as a reservoir of both liquid and solid wastes as a discharge of the city to save the Hugli River from receiving those wastes. There is an enough restructuring of wetland networks during the last 5 years. Construction and formation of new sewerage and drainage in Borough VII and pouring of untreated sewage in Borough VII, XI and XII into the Dry Weather Flow (DWF) channels are made which is already in operation and feeding of the wastewater fisheries. There is a combined drainage system in Kolkata Municipal Area (KMA) – the DWF is the man-made channel started from Topsia Point A through EKW from the east to west until it meets the Kulti River. DWF mainly comes from Palmer Bazar and Ballygunge pumping stations. DWF is 36 km long possessing a varying bed width of about 6 m. Presently, approximately 10% of the total wastewater load, i.e. 1300 litre per second (lps), are discharged in DWF channels through the pumping stations in Borough VII and XII and parts of Borough XI.

It has been estimated that every day these wetlands receive approximately 250 million gallons of sewage water through these DWF. It is measured that the Kolkata Municipal Corporation (KMC) every day produces roughly 600 million litres of sewage and wastewater and more than 2500 metric tons of garbage.

The owners of fisheries of EKW draw this sewage and wastewater into the wetlands locally called bheries. There are all total 364 operating bheries in EKW. It can accommodate about 18,800 litres of wastewater per seconds (lps) in the existing 4400 ha of sewage-fed fisheries. Gradually, within a few days the wastewater and content of the organic compounds undergo biodegradation. In the fish ponds the quantum of organic load ranges from 20 to 70 kg per ha per day. Overall report of the environmental impact assessment on East Kolkata Wetlands is positive.

Initially, the EKW was considered as a conservation area by the order of the Kolkata High Court in 1992, and subsequently the government has taken initiative to conserve these water bodies by forming a management committee for EKW in 2004. In March 2006 the East Kolkata Wetlands (Conservation and Management) Act became enacted as a law. The East Kolkata Wetlands (Conservation and Management) Act, 2006, came into force on the 16th day of November 2005 which supports the policy of conservation and management of EKWs and the allied matters concerned with it.

15.3.2.3 Steps in EIA

The generic six-step model is followed (Canter 1996) for environmental impact assessment (EIA). These six-step activities are as follows:

Step 1: Identification of problems such as types, sources and quantities of water pollutants
Step 2: Description of the environment of wetlands including its meteorological data like precipitation, evaporation and annual temperature and pollution loadings
Step 3: Procurement of data on wetland water
Step 4: Preparation of statement on impact prediction
Step 5: Study on impact significance
Step 6: Suggestions on appropriate mitigation measures

In the first step, the objectives are to determine the features of the wetlands in terms of:

1. Type of wetland and its operational nature in the order of water usage and generation point of wastewater and causes of changes in water quality or quantity
2. Location including mapping of the wetlands
3. Period or history of origin of wetland
4. Prime information based on its outcomes including disposals

In order to prepare a list of materials to be utilized during the study and their subsequent disposal, the qualitative assessment of the wastewater in the wetlands can be compared as population equivalent in the form:

$$PE = \frac{(A)(B)(8.34)}{0.17}$$

where:

PE = population equilibrium based on organic constituents in industrial water
A = industrial water flow, mgd (million gallon per day)
B = industrial wastewater BOD (mg/l)
8.34 = lb/gel
0.17 = lb BOD per person/day

It is also applicable for suspended solids, nutrients and other pertinent constituents discharged both from point and non-point sources, and aquatic environment receives maximum pollutants from non-point sources.

Step 2 is the background study of the wetlands including collection of data on water body in terms of quantity and quality. The records of data can be compared with the standard water quality. It is also true that water quality standards vary according to the mode of uses. Therefore, selection of parameters of assessing the water quality of wetlands is also important and essential in the context of uses of these water resources.

In step 3, the impacts of the wetland are considered based on production, particularly on pisciculture. It is also pertinent to consider the water quality management policies in this respect.

Fourth stage of generic impact studies is impact prediction. Actually, it provides data on quantification or qualitative description of anticipated impacts of the wetlands and its factors. To make out this, the environmental index methods like WQI (water quality index) or some other related techniques are required for addressing the anticipated impacts that will result into anticipated changes in the water body, although different types of pollutant load like organic (non-conservative), inorganic (conservative), solid, nutrient and bacterial pollutants are involved but cannot be quantified sometime due to different reasons. In wetlands, different discharge streams are mixed together to form a final discharge canal received by the local wetlands, so it requires to calculate the quantity of water flow and the characteristic pollutants of that flow separately to frame in a mathematical model called mass-balance approach, which can be expressed as follows:

$$C_{avg} = \frac{\varepsilon C_i \theta_i}{\varepsilon \theta_i} = \frac{\varepsilon M_i}{\varepsilon \theta_i}$$

It is the summation of the mass contribution of all individual streams dividing by total mass of the total flow from all the streams, where

C_{avg} = average concentration of constituent for combined discharge stream
C_i = concentration of constituent in *i*th discharge stream
Q_i = flow for *i*th discharge stream
M_i = mass of constituent in *i*th discharge stream

Different models such as CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management System) and GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) have been developed to measure the water pollutant loadings from various non-point sources and its subsequent impacts. It can be taken into account that urban area or rural runoff discharges constitute the non-pollutant and municipal and/or industrial charges that endorse the point sources (Knizel and Nicks 1980; Williams and Nicks 1982; Leonard 1988).

Fifth step in impact studies is very important, because it highlights the significance of impact assessment followed by impact mitigation measures. Assessment literally elicits the significant interpretation of anticipated impacts comparing after the specific standards, here wastewater discharge standards.

Step 6, it is final stage of impact assessment which mainly deals with the identification and incorporation of probable mitigation measures which are meant for decreasing the magnitude of impacts of discharge water into the receptors through separation, pre-treatment, sedimentation or dilution. Depending on the non-point pollution sources, it is advised to adopt the best management practices (BMPs) determined by the area-wise or project-wise operators/users. Olson and Marshall (1991) proposed the furnished constructed wetlands to control the discharge of non-source pollution by endorsing the control of nutrients, pesticides and sediments. This can minimize the detrimental impact of wastewater.

15.3.2.4 Evidences of Impact Assessment

Impact implications of wetlands can be represented by its quantitative and/or qualitative changes which in turn cause changes in aquatic faunal or floral species. Wastewater-fed wetlands from industrial charges; municipal, agricultural, commercial hazardous waste disposal; and domestic discharges are required to address the quantity-quality considerations. The total maximum daily loads (TMDLs) influence the status of the receiving water body. The common physical parameters are colour, odour, temperature, residual solids, turbidity, oil and grease content, etc. Among the chemical parameters, BOD, COD, TOC and TOD are important. Inorganic chemical properties of wetland water are ascertained by salinity, hardness, pH, acidity and alkalinity, including the presence of chlorides, sulphates, phosphates, heavy metals, etc. Biological parameters include the qualitative and quantitative estimation of phyto- and zooplankton, bacteriological and fish health.

Wetlands are fed through two main sources – the point and non-point sources. Non-point pollutants are added as a result of discharges from urban area, industrial area, or rural runoff; it is the main supplements to wetlands but difficult to trace the origin of locations of the non-points; and point sources are due to discharges from municipalities or industrial complexes. Depletion of dissolved oxygen concentration due to increase in soluble solids or organic materials causes serious excess microbial load, high BOD and finally effects on fish health.

From the point of human health risk assessment study, the consumption of sewage-fed fish and the fishermen intimately associated with fish culture also need an intensive research for careful assessment and mitigation. As mitigation measures reduce the impacts on water quality, the following aspects can be considered:

- Checking of improper dumping of solid wastes into the DWF channels.
- Introduction of restriction, enforcement and regular monitoring by KMC.
- Provision of fencing, repairing and checking the DWF channels will be strengthened.
- Regular monitoring of water quality of DWF channels.
- Proper management of DWF channels through periodical cleaning, at least every 3 years, and lining checking and repairing on every 6 years.

The DWF channels receive the drainage of the core area of Kolkata which starts from Topsia Point A and runs to the east through the EKW until it falls into Kulti River.

In the wetlands there are some interactions between its constituents like water, soil, air, energy, rocks, plants and animals and to form a complex ecosystem. The basic pre-requirement for impact assessment of wetlands is to build up a conceptual understanding on:

– Interaction between a wetland and its sources – generally, the water sources, which are one of the three types, like rainfall, surface flow and groundwater
– Identification of possible impacts
– Suggestion on mitigation measures

After the Ramsar Convention (Ramsar 1971), 160 nations joined in the convention as Contracting Parties in October 2010, and they documented and included in the list a total of 1900 wetlands around the world covering over 186 million ha of area. Actually, there are two outcomes of Agenda 21 and Rio Summit Declaration from the 'UN Conference on Environment and Development' held in 1992, where it was clearly mentioned to undertake EIA for every activities likely to make thrust adversely on the environment; subsequently in the Plan and Implementation Committee called it to use all levels.

EIA is a continuous process that reveals some mitigation process in final for the concerned project which is culminated into preparation of a report called Environmental Impact Statement (EIS). EIA process is directly related with local, regional and national development schemes, although sometimes it is rushed due to some unwanted pressures from different point of interests. In EIA, environmental evaluation system is followed to study the impact and to identify the impact of particular parameters by selecting indirect and direct forms of data.

15.4 Impact Analysis Through Histophysiological Investigations of Fish

Different biochemical and physiological investigations (Table 15.3) are key tools to evaluate the health status of fish species as well as health of wetlands. The histopathological changes at cellular or tissue level direct an indication of exposure to environmental toxicants, changes in target organs like gill and gastrointestinal tract and information on the mechanism of action of the toxicants (Das and Mukherjee 2000). Biochemical alterations and pattern of fish growth reflect the environment and the feeding state of fish (Grund et al. 2010; Poleksić et al. 2010; Rajeshkumar and Munuswamy 2011). Likewise, changes in the ultramicroscopic level through topological study of the gastrointestinal system of fish disclose the toxicity of environmental pollutants (Grau et al. 1992). Biochemical assessments using various intestinal enzymes such as amylase, pepsin, trypsin, esterases and alkaline phosphatase (Moriarty 1973; Li and Fan 1997) are also good responsive factors of toxicosis. Exposure to chemical pollutants can influence either increases or decreases in haematological levels in the fishes. The enzymological as well as hormonal levels of fish are more related to the effects on fish survival, growth and reproduction (Yaron et al. 2003; Levavi-Sivan et al. 2010).

Embryonic and larval malformations are documented as a habitual problem in fish aquaculture and characterize both ethical and economical challenges for the fishery industry (Takle et al. 2005). It is well known that some environmental factors such as temperature, salinity, pH, etc. can strongly influence the embryonic development of fish (Kjørsvik et al. 1990). This information is pertinent on the ground that sewage-fed wetland resources may be developed as a good source of fish spawn by the development of a modified hatchery system.

15.4.1 Histopathological Observations of Fish Tissues

The histopathological investigations of fish reared in wastewater-fed aquaculture pond systems would reflect the cumulative effects of different toxicants like heavy metals and pesticides in different trophic levels of fish. The studies carried out on two widely cultured fish species, *Oreochromis niloticus* and *Glossogobius* sp., in EKW revealed the clear-cut histopathological lesions in the stomach, intestine, gill, liver and kidney. Evaluation of these lesions can be used as suitable biomarkers.

Stomach: The stomach of *Oreochromis niloticus* and *Glossogobius* sp. showed distortion of mucous epithelium; vacuolation in submucosa, especially in the lamina propria; and degeneration of columnar epithelium, goblet cells and basement membrane. The secretory cells and cuboidal cells of gastric glands undergo necrosis.

Table 15.3 Grading of toxicosis and effects

Observations and analysis						
Stomach	Histopathology		Histochemical		Topological (SEM)	
Features	*Evaluation/analysis*	*Grading*	*Evaluation/ analysis*	*Grading*	*Evaluation/analysis*	*Grading*
Mucous layer (MC)	Distortion	++	PAS-AB reaction is less intense	+	Mucosal folds (MFs) anatomized showing zigzag pattern	++
Columnar epithelial cells (CECs)	Degeneration	++	Intense reaction	++	Contour of CEC altered	++
					MRs undergo degenerative changes	++
					Microvilli disrupted	++
Goblet cells (GCs)	Profuse secretion of mucus	++	Intense reaction	++	GCs secrete profuse mucus	++
					Ruptured cell membranes and exocytosis are prominent features	+++
Gastric gland cells (GGs)	Disintegration and disruption of basement membrane	++	Moderate reaction	++	Profuse secretion of mucus from GG	+++
	Necrosis of GGs	+++				
Intestine	*Evaluation/analysis*	*Grading*	*Evaluation/ analysis*	*Grading*	*Evaluation/analysis*	*Grading*
Mucous cells mucous layer	Degeneration and formation of oedema	++	PAS-AB reaction is less intense	+	Irregular arrangement of MFs	++
					Fragmentation and appearance of concretions of MFs	++
Absorptive columnar epithelial cells and brush border	Disorganized and necrosed CECs with eccentric nuclei	++	Intense reaction	++	MVs are short, less and blunt	++
Liver	*Evaluation/analysis*			*Grading*	*Evaluation/analysis*	*Grading*
Hepatic lobules	Disorganized and disarray of lobules			++	PAS-AB reaction is less intense	++
Hepatic cells	Appearance of syncytial mass			+++	Less intense reaction	+
	Appearance of pyknotic and enlarged nuclei			+++		
	Breaking and dissolution of cell membranes			++		

Acinar cells and zymogen granules	Degeneration of pancreatic acinar cells	++	Sporadic reaction	+
	Shrinkage of exocrine acinar cells	++		
	Dispersion and degranulation of zymogen granules	++		
Tissues	Histopathology			
Kidney	*Evaluation/analysis*			*Grading*
Haematopoietic tissue	Distortion and vacuolations in the haematopoietic tissues			++
Bowmen's capsule	Enlargement of Bowmen's capsule			++
	Vacuolation and rupture of capillaries in glomerulus			+
PCT & DCT	Enlargement of lumen of PCT and DCT			++
	Eccentric nucleus and damaged brush border in PCT			++
Tissues	Digestive enzymes			
	Evaluation/analysis			*Grading*
Liver	Activities of digestive enzymes were largely induced by water quality parameters:			
	Enzymes spilled into blood, raising the enzyme level in blood			++
	Fluctuations of total plasma proteins and albumin			++
	Increased level of SGOT and SGPT			++
	Total bilirubin level increased			+++
Stomach and intestine	Reduced amylase activity			+
	Lower lipase activity			++
	Decreased protease activity			+
	Increased level of SGOT, SGPT			++
	Increased alkaline phosphatase			++
Hormonal study	*Evaluation/analysis*			*Grading*
LH	Increased level of LH in breeding seasons followed breeding, post- and pre-breeding seasons			++
FSH	Increased level of FSH in breeding seasons followed by post- and pre-breeding seasons			++

Grading pattern: [+] = Low, [++] = Moderate, [+++] = High

Intestine: Severe degenerative changes in the intestinal mucosa cause oedema between the intestinal submucosa and mucosa in *Glossogobius* sp. and in *Oreochromis niloticus*. The intestinal region offers a good source of lipase enzyme and also helps in digestion of carbohydrate due to presence of amylase as in *Tilapia* (Lagler et al. 1977).

Liver: The liver plays the most important role in detoxification of xenobiotics, and it is known as the prime organ responsible for the detoxification biotransformation and excretion of xenobiotics (Thophon et al. 2003). The liver of the fish *O. niloticus* showed distortion of the hepatic cords, appearance of syncytial mass, dilation of the sinusoids, degeneration of endothelial lining cells, clumping and pyknosis of nuclei and distortion of acinar cells, loss of zymogen granules and shrinkage of exocrine acinar cells which are rather similar with analysis of many workers (Sepulveda et al. 2004; Benli et al. 2008).

Kidney: In the sewage-contaminated condition, the fish *O. niloticus* discloses the vacuolation and distortion of the glomerulus and the haematopoietic tissue and enlargement in Bowman's capsule and lumen of the proximal tubules. In the proximal tubule, intercellular partitions are lost, nuclei became eccentric and the brush border becomes damaged (Benli et al. 2008), effluents of pulp and paper mills (Khan et al. 1994), and mixed environmental contaminants (Schwaiger et al. 1997; Camargo and Martinez 2007).

15.4.2 Histochemical Observations of Fish Tissues

Gastric mucosa of *Oreochromis niloticus* and *Glossogobius* sp. showed positive reaction to PAS-AB, which indicated presence of acid and neutral mucin with a little alteration in the intensity of reaction. The columnar epithelial cell lining of fish intestine produces different glycoconjugates (Scocco et al. 1997). So, the abundance of mucus in the lumen of the digestive tract of the teleosts is the common feature. The intestines of *Glossogobius* sp. contained numerous goblet cells in the mucosa which react positively to PAS-AB; the number of total goblet cells was affected in the stomach of *Glossogobius* sp. and decreases in the number of PAS-positive goblet cells in *Oreochromis niloticus*. Sewage water alters the mucin composition in the goblet cells as compared to control.

15.4.3 Scanning Electron Microscopic Observations (SEM)

Evaluation of ultra-morphological symptoms by using scanning electron microscope depicts the various tissue alterations at the topological level due to intoxication of different xenobiotics (Kammenga et al. 2000).

Gill: The topology of the cellular unit of gill lamellae is stratified epithelial cells with double-ridged outer membrane and concentric microridges on the surface as viewed through SEM, and the lesions like necrosis, hyperplasia, inflammation, epithelial cell lifting, cell swelling and hypersecretion of mucus were the prominent features. According to Kossakowski and Ostaszewska (2003), excessive mucus secretion is the first reaction; subsequently epithelial cell lifting, hypertrophy and fusion of gill lamellae attribute the defence response of fish against xenobiotics.

Buccopharynx: The buccopharyngeal epithelium of *O. niloticus* and *Glossogobius* sp. exhibited the wrinkling and shrinkage of the polygonal stratified epithelial cells, loss of double-ridged structure and disorganization of the regular array of microridges. In *Glossogobius* sp., the most important alterations took place that were different from an ideal pattern of cell array such as shrinkage of the stratified epithelial cells, disorganization of the normal arrangement of concentric microridges as well as lateral fusion of the epithelial cells.

Stomach: The topography of the stomach revealed that the gastric mucosa, stapled together (anatomized) with each other to give appearance of an uneven depressions, provided with numerous gastric folds. A few epithelial cells encircle the gastric pits noticed in this region. O. *niloticus* showed that the apical surface of the mucous folds was densely packed with oval or rounded columnar epithelial cells hold with short and broad microridges. Secretions of mucus along with the distortion of columnar epithelial cells on the mucosal surface were the distinct observations in the stomach of *O. niloticus* in field condition. The mucin masses were also adhered with the mucosal epithelium. In *Glossogobius* sp. mucin masses were clogged in the gastric pits, and in some cases cellular contents moved away from the ruptured cells.

Intestine: In *O. niloticus* the intestinal mucosal folds showed irregular orientation. In *Glossogobius* sp., the important observations of the intestine were the presence of irregular and wavy mucosal folds in zigzag prototype surrounding a number of concavities. The internal mucosa was supported by regularly arranged, elongated or oval columnar epithelial cells.

Due to pollution load and contamination in EKW, large areas of intestinal mucosal folds of *O. niloticus* got injured and wreckage of the fragmented secondary mucosal folds that was observed in the concavities in between the primary mucosal folds. Intestinal columnar epithelial cells were disrupted due to metal contamination. The microvilli on the apical portion of the columnar epithelial cells were necrosed. Mucin masses were clogged in certain areas of epithelial cell surfaces; some damages occurred in the columnar epithelial cells along the basement membrane. Significant damages also brought into intestinal absorptive columnar epithelial cells.

15.4.4 Enzymological Study of Blood Parameters

The activities of the digestive enzymes were largely induced by environmental parameters, such as temperature, pH, salinity and heavy metals as stressors. Under normal circumstances, these enzymes remain within the cells of the liver. Under stress condition and in the injured liver, these enzymes are spilled into the blood stream, raising the enzyme levels in the blood and signalling liver damage. Among the most sensitive and widely used of these liver enzymes are the amino transferases. The regular structural orientation of the hepatocytes and their enzyme activities are greatly influenced by the diesel and grease contamination in the water body (Azad 2005; Dimichele and Taylor 1978). The fluctuations in plasma proteins (total protein and albumin) and liver enzymes (SGOT, SGPT, amylase, alkaline phosphatase) and in the bilirubin level may be caused by the disturbance in metabolic pathways caused by petroleum exposure. The increase in SGOT and SGPT activities is the indicator of liver damage which may have occurred due to petroleum exposure.

Amylase: The physiological functions of fishes under sewage contamination conditions in EKW recorded that some enzymological analysis like amylase activity was reduced. It has also been recorded that three different fish species of different trophic levels, viz. *Labeo bata*, *Labeo rohita* and *Oreochromis niloticus*, showed reduced amylase activity in the stomach and intestine.

Lipase: The experimental fish, viz. *L. bata*, *L. rohita* and *O. niloticus*, collected from EKW showed lower lipase activity.

Protease: The protease activity of *L. bata*, the inhabitant of EKW, was decreased in the stomach and intestine.

Serum glutamate oxaloacetate transaminase (SGOT): In the fish *L. bata*, *L. rohita* and *O. niloticus*, the mean plasma SGOT (AST) values were higher in EKW condition.

Serum glutamate-pyruvate transaminase (SGPT): The mean plasma SGPT (ALT) values of the fish collected from EKW were higher.

Alkaline phosphatase (ALPase): The plasma alkaline phosphatase activity of the fish collected from EKW was also higher in *L. bata*, *L. rohita* and *O. niloticus.*

Total bilirubin: The average total bilirubin concentration in *L. bata* was slightly lower, but in case of *L. rohita* the average total bilirubin level was elevated. In *O. niloticus*, the mean plasma total bilirubin level was higher.

15.4.5 Hormonal Observations

In fish, follicle-stimulating hormone (FSH) is generally important for early gonadal development and vitellogenesis. In case of mammals, it is a heterodimer comprised an alpha subunit which is associated with the hormone-specific beta subunit noncovalently. Low concentration of pollutants could affect any part of this process. Hormones, the endocrine secretions, are released into the blood stream for onward transportation to their target organs.

Luteinizing hormone (LH): In females, a sharp rise of LH causes ovulation and development of the corpus luteum. In males, LH also called interstitial cell-stimulating hormone (ICSH) stimulates production of testosterone by Leydig cells which has a synergistic action with FSH. In the breeding season, the concentration of LH in the fishes like *L. bata*, *L. rohita* and *O. niloticus* was higher followed by post- and pre-breeding seasons.

Follicle-stimulating hormone (FSH): Follicle-stimulating hormone (FSH) also followed the similar trends as LH where the increased values in breeding were followed by post- and prebreeding seasons.

15.5 Conclusions

Due to rapid urbanization and industrial growth, wetlands are facing reduction of its available space and contamination by excessive runoff from agricultural fertilizers, pesticides or herbicides. Therefore, EIA of wetlands is required to prevent the loss and destruction. It also requires conservation and collaborative sustainable strategy to promote its restoration. Study of impact analysis based on histological, histochemical, topological, enzymological and hormonal studies in regard to the fish health discloses some prominent lesions or alterations in the intestine, liver and kidney of the fishes. However, this suggests an adoption of good management of wetlands for 'wise use of wetlands' for converting organic loads into protein sources. Extensive research is needed to the better solution for formulation of the national strategy and planners to save the wetlands.

References

Azad M (2005) Toxicity of water soluble fractions of crude oil on *Metamysidopsis insularis*, an indigenous tropical mysid species. Environ Monit Assess 104:37–40

Benli ACK, Köksal G, Özkul A (2008) Sublethal ammonia exposure of Nile tilapia (*Oreochromis niloticus* L.): effects on gill, liver and kidney histology. Chemosphere 72:1355–1358

Camargo MMP, Martinez CBR (2007) Histopathology of gills, kidney and liver of a Neotropical fish caged in an urban stream. Neotropical Ichthyology 5:327–336

Canter LW (1996) Environmental impact assessment, 2nd edn. McGraw-Hill, Inc., Singapore

Das BK, Mukherjee SC (2000) A histopathological study of carp *Labeo rohita* exposed to hexachlorohexane. Veterinarski Arhiv 70:169–180

Dimichele L, Taylor MH (1978) Histopathological and physiological responses of *Fundulus heteroclitus* to naphthalene exposure. J Fish Dis 5:186–190

Gopal B (1999) Natural and constructed wetlands for wastewater treatment: potentials and problems. Water Sci Tech 40(3):27–35

Grau A, Crespo S, Sarasquete MC, de Canales MLG (1992) The digestive tract of the amberjack, *Seriola dumerili* Risso: a light and scanning electron microscopic study. J Fish Biol 41:287–303

Grund S, Keiter S, Bottcher M, Seitz N, Wurm K, Manz W, Hollert HTB (2010) Assessment of fish health status in the Upper Danube River by investigation of ultrastructural alterations in the liver of barbel *Barbus barbus*. Dis Aquat Org 88:235–248

Guirguis M (2004) Treatment of wastewater: a reed bed environmental case history. In: Paper SPE86673 presented at the 2004 SPE International conference on health, safety, and environment in oil and gas exploration and production held 29–31 March 2004 in Calgary, Alberta Canada

Kadlec RH, Knight RL (1996) Treatment of wetlands. CRC Press, Boca Raton, p 893

Kammenga JE, Dallinger R, Donker MH, Kohler HR, Simonsen V, Triebskorn R, Weeks JM (2000) Biomarkers in terrestrial invertebrates for ecotoxicological soil risks assessment. Rev Environ Contam Toxicol 164:93–147

Khan RA, Barker DE, Hooper R, Lee EM, Ryan K, Nag K (1994) Histopathology in winter flounder (*Pleuronectes americanus*) living adjacent to a pulp and paper mill. Arch Environ Contam Toxicol 26:95–102

Kjørsvik E, Mangor-Jensen A, Holmefjord I (1990) Egg quality in fishes. Adv Mar Biol 26:71–113

Knizel GW, Nicks AD (1980) CREAMS: a field scale model doe chemicals, runoff, and erosion from agricultural management system. Conservation Research Report No. 26, US Department of Agriculture, Washington, DC

Kossakowski MK, Ostaszewska T (2003) Histopathological changes in the Juvenile carp *Cyprinus carpio*. Arch Pol Fish 11:57–67

Kundu PM, China SS, Chemelil MC (2008) Automated extraction of morphologic and hydrologic properties for River Njoro catchment in Eastern Mau, Kenya. J Sc Technol Educ Manag 1 (2):14–27

Lagler KF, Bardach JE, Miller RR, May Passino DR (1977) Ichthyology, 2nd edn. Wiley, New York

Leonard RA (1988) Modelling pesticides metabolite transport with GLEAMA. In: Proceedings on planning now for irrigation and drainage, IR DIV/ASCE, Lincoln, Neb

Levavi-Sivan B, Bogerd J, EL M˜a's, Go'mez A, Lareyre JJ (2010) Perspectives on fish gonadotropins and their receptors. Gen Comp Endocrinol 165:412–437

Li SN, Fan DF (1997) Activity of esterases from different tissues of freshwater fish and responses of their isoenzymes to inhibitors. J Toxicol Environ Health 51:149–157

Mitsch WJ, Gosselink JG (1986) Wetlands. Van Nostrand Reinhold, New York

Mitsch WJ, Gosselink JG (1993) Wetlands, 2nd edn. Wiley, New York

Moriarty DJW (1973) The physiology of digestion of blue-green algae in the cichlid fish, *Tilapia nilotica*. J Zool (Lond) 171:25–39

Olson RK, Marshall K (1991) Workshop proceedings: the role of created and natural wetlands in controlling nonpoint source pollution. EPA 600/9-91-042, ManTech Environmental Technology, Corvallis, Oregon

Panigrahy S, Murthy TVR, Patel JG, Singh TS (2012) Wetlands of India: inventory and assessment at 1: 50, 000 scale using geospatial techniques. Curr Sci 102(6):852–856

Poleksić V, Lenhardt M, Jarić I, Djordjević D, Gačić Z, Cvijanović G, Rašković B (2010) Liver, gills, and skin histopathology and heavy metal content of the Danube starlet (*Acipenser ruthenus* Linnaeus, 1758). Environ Toxicol Chem 29:515–521

Pragatheesh A, Jain P (2013) Environmental degradation of the Coimbatore wetlands in the Noyyal River Basin. EIA Resource and Response Centre (ERC), Tamil Nadu, India, © EIA Resource and Response Centre (ERC), Legal Initiative for Forest and Environment (LIFE), New Delhi 110048, India

Rajeshkumar S, Munuswamy N (2011) Impact of metals on histopathology and expression of HSP 70 in different tissues of Milk fish (*Chanos chanos*) of Kaattuppalli Island, South East Coast, India. Chemosphere 83:415–421

Ramsar, Convention on Wetlands (1971) Proceedings of the 6th meeting of the conference of the contracting parties (Brisbane, Australia, 19–27 March 1996)
Schwaiger J, Wanke R, Adam S, Pawert M, Honnen W, Triebskorn R (1997) The use of histopatological indicators to evaluate contaminant-related stress in fish. J Aqua Ecosyst Stress Recovery 6:75–86
Scocco P, Menghi G, Ceccarelli P (1997) Histochemical differentiation of glycoconjugates occurring in the tilapine intestine. J Fish Biol 51:848–857
Sepulveda MS, Gallagher EP, Gross TS (2004) Physiological changes in largemouth bass exposed to paper mill effluents under laboratory and field conditions. Ecotoxicology 13:291–301
Takle H, Baeverfjord G, Lunde M, Kolstad K, Andersen Ø (2005) The effect of heat and cold exposure on HSP70 expression and development of deformities during embryogenesis of Atlantic salmon (Salmo salar). Aquaculture 249:515–524
Thophon S, Kruatrachue M, Upathan ES, Pokethitiyook P, Sahaphong S, Jarikhuan S (2003) Histopathological alterations of white seabass, Lates calcarifer in acute and subchronic cadmium exposure. Environ Pollut 121:307–320
Williams JR, Nicks AD (1982) CREAMS hydrology model – option I. in applied modelling in catchment hydrology. In: Proceedings of the international symposium on rainfall-runoff modeling. Water Resources publication company, Littleton, Colo
Yaron Z, Gur G, Melamed P, Rosenfeld H, Elizur A, Levavi-Sivan B (2003) Regulation of fish gonadotropins. Int Rev Cytol 225:131–185

Chapter 16
Law and Regulation of Wastes and Wastewater: Indian Perspective

S. K. Sadhu and A. R. Ghosh

Abstract The United Nations Conference on the Human Environment, 1972, declared environment of quality is the basic right of human being. It laid emphasis on protection and improvement of environment for inter- and intra-generational equity. India as a participatory nation by the 42nd amendment of the constitution incorporated provisions under Art. 48A and Art. 51A (g) for protection and improvement of natural environment. Environment (Protection) Act, 1986, is the elaborate text of such constitutional mandate. The Act has made provisions for creation of institutions to shape an environmentally sound future. Consequently, by considering alarming effects of wastes – solid, liquid or e-waste – on environment, various rules are framed by the Central Government for the establishment of regulatory authorities to manage the situation. Present study covers the enforceability of such laws and rules to achieve the end, i.e. salubrious environment for all.

Keywords Wastewater · Wetlands · Wastes · Rules · Act

Contents

S. K. Sadhu (✉)
Department of Law, University of Burdwan, Burdwan, West Bengal, India
e-mail: saritsadhu@gmail.com

A. R. Ghosh
Department of Environmental Science, University of Burdwan, Burdwan, West Bengal, India

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2_16

16.1 Introduction

16.1.1 Why Wetland and Wastewater Laws and Regulations?

Wetlands are the most important beneficial ecosystems for human beings. It harbours as well as makes a habitat for large number of diverse flora and fauna maintaining a certain depth of water as its characteristics. Classification of wetlands is based on different aspects. Most commonly, they are classified with respect to types of vegetation, types of soil, availability of water (constant wet and temporary dry up), etc. Wetlands have a diverse nature of distribution starting from coastal plain to middle (marshes) up to high altitude of mountain areas (seeps). It includes floodplains, marshes, bogs, swamps, peat lands, estuaries, lakes, etc. Wetlands are natural filters of immense importance in maintaining the ecosystem balance in the climate change of the world. It performs many important functions maintaining the homeostasis in the ecological physiology, reducing flood flow and its impact, groundwater recharge by soaking and releasing the water, reduction of soil erosion, maintenance of biological diversity and habitats, nutrient cycling, fish production, creation of employment opportunity by providing pisciculture, building materials and handicrafts and agricultural and recreational usages. But in recent times, this ecosystem is under serious threat due to rapid urbanisation and industrial development by reducing its total available space and severe contamination from discharge materials like pesticides, herbicides and fertilisers causing direct impact on functioning of wetlands. So, for the management and monitoring, introduction of environmental assessment process and application of laws and regulations are inevitable. The present chapter is intended to highlight the importance of laws on wetlands with historical background and finally culmination into implementation of laws.

Protection of environment has emerged as a challenging issue in modern world. Strain on environment for rapid betterment of human civilization reflects hard reaction against world population. Pollution episodes throughout the world forced the world community to manage the situation expeditiously.

The United Nations Conference on the Human Environment held in Stockholm, 1972, is the major initiative on the part of international organisation. Participating nations declared the right to live in an environment of quality is a basic human right and citizens have a duty to protect and improve environment for intra-generational and inter-generational equity. Such impressive international efforts are indeed genesis of modern environmental jurisprudence.

Principles of environmental equity give rise to the idea of sustainable development. World commission on environment and development in its report “Our Common Future” has specified it. The concept is obviously a new dimension in environmental law. “Agenda 21” is its best example. Under such Agenda, human beings “are entitled of healthy and productive life in harmony with nature”. Moreover eradication of poverty, satisfying the needs of majority of people, reducing the disparity of standard of living etc. are the indispensable part of sustainable development. The United Nations Conference on Sustainable Development (Earth Summit, 2012 or Rio 2012 or Rio^{+20}) has widened this concept under the framework of "The Future We Want". The ultimate objectives of such principles are to make strong legal instrument by sovereigns for ensuring a balance between development and preservation of natural environment.

In order to achieve the above stated objectives, jurisprudential concept in India has taken a new shape. Two Articles incorporated after the 42nd amendment in the Indian Constitution in 1976 are directly involved in environmental protection and improvement. Art. 48A relates to obligation of state to make law for protection and improvement of environment, while under Art. 51A (g), citizens have a duty to protect and improve natural environment. The Apex Court by wider interpretation of these provisions has evolved some principles which can be construed as law of the land. Stockholm declared quality environment is an inherent right of man. The Supreme Court in that spirit has observed the right to life enshrined in Art. 21 in the Indian Constitution includes the right to salubrious environment for all. State under Art. 48A has a duty to provide such right. For failure of state to perform such obligation, a person is deprived of his fundamental right, and he has remedy under Art. 32 or Art. 226 of the Constitution. A writ may lie against the state in such situation.

It is worth mentioning that pollution does not affect the individual only but it is deleterious for the whole society, therefore, pollution is a social wrong. At this juncture, the Supreme Court has strongly opined that the right of standing before the Supreme Court or High Courts for ecological disorder must not be confined to that person whose right has been infringed on the contrary for public interest on behalf of such person it would be extended to any public-spirited citizen or social action group. This new concept, mass advocacy against mass tort, has transformed the constitutional obligation of state to protect and improve the environment as constitutional mandate. It generates a new movement for ensuring quality environment through judicial intervention which can be termed as neo-environmentalism.

16.2 Laws for Waste Management

Generation of e-wastes by technological advancement is a serious threat to clean environment. The vision of the twenty-first century is "to ensure the promotion of economically, socially and environmentally sustainable future for our planet and for present and future generations" (Future we want – outcome document .... Sustainable Development Knowledge Platform; http://sustainabledevelopment.un.org/ft). Indian judiciary in the case of Vellore Citizens Welfare Forum vs. Union of India, AIR 1996 SC 2715, has also observed that the traditional views on ecology and environment are enemies no longer acceptable. Under the blueprint of the world community for survival of planet, sustainable development is the answer. Therefore, the statement, 'regulation is better than restriction' is more important in managing environmental quality.

Environment (Protection) Act, 1986, is a comprehensive legislation for protection and improvement of environment. The Act has defined environment on broader perspective. Under Sec. 2(a) of the Act, "Environment includes water, air and land and the inter-relationship which exists among and between water, air and land and human beings; other living creatures, plants, micro-organism and property". The law while defining environment had made no distinction between environment and ecosystem. It laid an emphasis on inter-relationship between biotic and abiotic components of earth. This act has conferred power to the Central Government to take all measures thinks inexpedient to protect and improve the environment quality and shall prevent, control and abate environmental pollution. To perform such statutory obligations, the Central Government may lay down procedures and safeguard for hazardous substances. Hazardous substance means substance which due to its characteristics is liable to cause harm to the environment. Wastes liable to cause harm to the environment are hazardous wastes. To prevent pollution, Central Government has power to take regulatory measures. The Central Government has power to appoint regulatory authority or authorities. Authorities can exercise statutory powers to maintain environmental order. Under such power, directions can be issued to any person or authority. Direction includes power to closure or regulation of any industry operation or process or stoppage or regulation or supply of electricity, water, etc. To comply such provisions, rule-making power in the form of delegated legislation has colossal importance in this connection.

16.3 Subordinate Legislations for Waste Management

Appropriate regulatory measure is the only solution to manage wastes which are harmful to fragile ecology. To protect sensitive ecosystem, a number of rules are made by the Central Government under the provisions of the Environment (Protection) Act, 1986. Such rules are:

1. Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 (envfor.nic.in > content > hazardous and . . . .)
2. Plastic Waste Management Rules, 2016 (www.moef.gov.in/content/gsr 320.e)
3. Solid Waste Management Rules, 2016 (www.moef.gov.in/content/so 1357 e-o)
4. Bio-Medical Waste Management Rules, 2016 (envfor.nic.in > content > gsr 343 e)
5. E-Waste (Management) Rules, 2016 (www.moef.gov.in/gsr 338 e)
6. Construction and Demolition Waste Management Rules, 2016 (www.moef.nic.in>content/gsr - 317 e)

Persons handling hazardous substances shall be liable to comply the procedural safeguards to be prescribed by the Central Government under hazardous waste management rules. These rules shall not be applicable to wastewater, biomedical waste, municipal wastes, etc., and the authorities to enforce such rules are the Ministry of Environment and Forest and Climate Change, Central Pollution Control

Board (CPCB) and State Pollution Control Board (SPCB) constituted under the Water Act, State Government, Union Territory, Directorate General of Foreign Trade and Port Authority.

Authorities have powers to take required steps for environmentally sound management for hazardous and other wastes. Steps shall also include the responsibility of occupier handling with such wastes to take measures for treatment facility either captive or common; prevention, minimising, reuse, recycling, recovery and safe disposal; transfer for disposal and obtaining permission for disposal from the concerned authority; utilisation after processing as resource with permission from concerned authority; permission from the special authority for import-export of such wastes. Non-compliance of rules is an illegal activity of the occupier, and he shall be punished under the Environment (Protection) Act.

Plastic Waste Management Rules, 2016, shall apply to every generator, local body, manufacturer, *gram panchayat* (the cornerstone of a local self-government organisation in India of the *Panchayati Raj* system at the village or small town level), producer and importer. Rules are made to give thrust to minimise, segregate and recycle plastic wastes. Waste pickers, waste possessors and waste recyclers shall be involved to collect plastic fractions from households. Another purpose of such rules is to adopt polluter pays principle for sustainability of waste management.

Manufacturers, importers, possessors, stockists, distributors, sellers and users of carry bags, plastic sheets, etc. are required to comply certain conditions as mentioned in rules. Under the rules, carry bags and plastic sheets shall not be less than 50 microns thickness. To manage plastic wastes, street food sellers and the sellers of food items have some responsibilities fixed under the provisions of these rules. These rules have also imposed obligations upon urban bodies, local bodies and *gram panchayats* (the cornerstone of a local self-government organisation in India of the *Panchayati Raj* system at the village or small town level) to take measures against pollution by plastic wastes.

E-Waste (Management) Rules, 2016, has come into force on October 2016. Rules provide manufacturers generating e-wastes are bound to collect and channelize such wastes for recycling or disposal for environmentally sound management. E-waste means "Electrical and electronic equipment, whole or in part discarded as waste by the consumer or bulk consumers as well as rejects from manufacturing, refurbishment and repair processes". Rules have introduced responsibility upon manufacturer, producer and refurbisher generating e-waste either for manufacturing or for end of life or for repairing to comply the directions of authority for environmentally sound management of such wastes.

Dealers on behalf of the producers have a responsibility to collect e-waste from consumer by providing box or bin or by take-back system or by demarcating areas to deposit e-waste. After collection, it would be sent to the collection centre or dismantler or recycler as designated by the producer. E-waste generated by consumer or by bulk consumers of electrical and electronic equipment listed in Schedule 1 have a responsibility to ensure that such wastes are channelized for dismantling or recycling under the process which the rules have prescribed.

Dismantler, collection centre and recycler shall perform their duties as prescribed in these rules.

Decent environment is not only the desire of human being but essential for existence. Solid waste is not less important than that of other kinds of pollutant. Law, though a key regulator to manage every evil in society, nevertheless is meaningless in the absence of interaction with society. Considering the matter, the Apex Court in the case of MC Mehta vs. Union of India, AIR 1992 SC 382, directed the Government to introduce environmental education in every educational institution of the country as a compulsory subject. People's response is the best way to solve every crisis.

Solid Waste Management Rules, 2016, have paramount importance in managing environmental crisis. These rules have laid emphasis on internalities to regulate solid waste hazards. Waste generators, namely domestic, street vendor, shop owners, market complex, gated community, hotel, restaurant and eating place, have a duty to store waste in separate bin or container after segregating it as biodegradable, non-biodegradable, sanitary waste, domestic hazardous wastes, etc. and shall hand over the separated wastes to the authorised waste collectors or waste pickers daily. Construction wastes or demolition wastes shall be stored in place by waste generator under directions of local authority. Under no circumstances, such wastes shall be thrown in drains or watercourse or water body.

Various ministries of Central Government, State Government, and state instrumentalities, namely the Central Pollution Control Board (CPCB), State Pollution Control Board (SPCB), urban authority, local authority, local self-government, etc., have responsibilities to ensure proper collection, treatment and disposal of such wastes. State authority has duties to make policy, review and monitor the system for sound management of wastes. Creating awareness among general masses regarding their rights and duties provided in law shall be the true mechanism to manage the prevailing crisis, and the state should play a pivotal role in this connection. Bio-Medical Waste Management Rules, 2016, and Construction and Demolition Waste Management Rules, 2016, have immense importance to regulate waste disposal causing harm to society. Prescribed authorities and waste generators have legal compulsion to manage the situation.

Unauthorised waste disposal is a serious threat to the environment. That is why the Supreme Court in a landmark judgement in the case of Sterlite Industries (India) Ltd. Etc vs. Union of India and Ors, [2013] 6SCR 573, relying on polluter pays principle, directed the appellant company to deposit rupees 100 crores with the Collector of Thoothukudi District of Tamil Nadu with a condition that it would be kept in a fixed deposit of a nationalised bank for 5 years and renewable after expiry and interest of such fixed deposit shall be spent to improve the quality of environment including water and soil of the vicinity. The Apex Court, however, by considering importance of sustainable development set aside the order of Madras High Court regarding closure of plant of appellant company in Tuticorin.

Wetland is the greatest service provider of the country. In the case of MC Mehta vs. Union of India and Ors. [WP(C) No 4677/85] (www.elaw.in), the Supreme Court observed "the Badkhal and Surajkund are monsoon fed water bodies. The natural drainage pattern of the surrounding hill areas feed these water bodies during rainy season. Large scale construction in the vicinity of these tourist resorts may disturb the rain water drains which in turn may badly affect the water level as well as the water quality of these water bodies. . . . the hydrology of the area may also be disturbed". Under such observation, the apex judiciary on 10th November 1996 ordered that no construction of any type shall be permitted within 5 km radius of Badkhal and Surajkund lakes.

To meet the challenges of pollution of wetland, the National Environment Policy (NEP) Action Plan 2006 was in favour of setting up regulatory forces. Consequently, rules under the title, Wetlands (Conservation and Management) Rules, 2017 (http://www.moef.nic.in/content/gsr-1203e-wetlands-conservation-and-management-rules-2017), are notified in Official Gazette. These rules relate to imposing prohibition in case of setting up industries in wetland area; manufacture, storage and disposal of hazardous substances; dumping up solid wastes; discharge of untreated wastes and effluents from industries, cities or towns; any construction of permanent nature; poaching; and an activity having adverse impact on ecosystem of wetland. Rules aim at constituting State Wetlands Authority to improve the conditions of wetland. Rules also relate to constituting the National Wetland Committee. The committee has an advisory jurisdction and shall perform functions to formulate policies for conservation of wetland. These rules surely would be an effective instrument for sound management of wetland ecosystem.

16.4 State Laws

State laws, namely East Kolkata Wetlands (Conservation and Management) Act, 2006 (Annexure I) and Kerala Conservation of Paddy Land and Wetland Act, 2008 (KERALA GAZETTE EXTRAORDINARY PUBLISHED BY 12 August 2008, www.sanitation.kerala.gov.in), are equally important for wetland management and conservation. East Kolkata Wetlands have international importance as per Convention on Wetlands of International Importance held in Ramsar, Iran, in 1971 and enforced in 1975 (www.ramsar.org). The East Kolkata Wetlands Act has provision of constituting the East Kolkata Wetlands Management Authority which shall exercise powers for conservation of flora, fauna and biodiversity of that area. The Authority may restrict activities having adverse impact on wetland ecosystem. Authority shall perform some functions to promote sewage-fed pisciculture.

16.5 Law for Wastewater

In MC Mehta vs. Union of India and Ors. (1997) SCC388, the Supreme Court by applying Roman law concept *res communious* decided that the natural property of natural resources must be protected for public interest. State as a trustee has an obligation to take effective measures for conservation of heritage property of natural resources. Natural resource, therefore, converted into waste for alteration of its natural properties must be protected. The Water (Prevention and Control of Pollution) Act, 1974, has a significant role to maintain wholesomeness of water. Pollution under the Water Act means alteration of properties of water or contamination of water for discharge of sewage or trade effluents into water in such a way that it renders the water harmful or injurious for health safety and various kinds of its uses. Water if polluted becomes wastewater.

The Act has plethora of provisions in respect of prevention and control of water pollution. Moreover to maintain or restore wholesomeness of water, some functions are to be performed by concerned authority. The Central Pollution Control Board and the State Pollution Control Board constituted under this Act are authorised to take appropriate action in respect of water pollution. It is the duty of CPCB to promote cleanliness of streams and wells of the country. Stream under this Act includes river, water course, inland water, groundwater and tidal water up to notified area. SPCB is also bound to perform statutory functions in respect of water pollution. Such functions are, inspection of plant's set up for treatment of wastewater, system for disposal of waste and trade effluents, evolve methods of utilisation of sewage and trade effluents in agriculture, evolve methods of disposal of sewage on land essential for noticeable condition of scant stream flows which cannot provide minimum degree of dilution in major part of the year, to make or revoke any order essential for prevention, control or abatement of discharge of waste into stream or wells, to give advice to the State Government in respect to location of industries whose carrying on is likely to cause water pollution, to send water sample to recognised laboratories for its analysis and to take measures on the basis of report of analyst. To bring into use new outlet for disposal of sewage or to establish any industry, prior permission from SPCB is essential.

16.6 Conclusions

Ignorance of law is the main hindrance to make regulatory measures more effective. Regulatory authorities need to be more effective to ensure mass participation in waste management. The essence of such target is sound knowledge of environmental protection.

Annexure-I

5. The East Kolkata Wetlands (Conservation and Management) Act, 2006

GOVERNMENT OF WEST BENGAL LAW DEPARTMENT NOTIFICATION
31 March 2006

No. 404-L.–31 March 2006–the following act of the West Bengal Legislature, having been assented to by the Governor, is hereby published for general information:

West Bengal Act VII of 2006

THE EAST KOLKATA WETLANDS (CONSERVATION AND MANAGEMENT) ACT, 2006
(Passed by the West Bengal Legislature)
[Assent of the Governor was first published in the Kolkata Gazette, Extraordinary, on 31 March 2006]

An Act to provide for conservation and management of the East Kolkata wetlands and for matters connected therewith and incidental thereto.

WHEREAS the wetlands act as regulator of water regime, source for underground water recharging, mechanism for wastewater treatment, air quality purifier and store of water for firefighting and have great ecological significance for human life

AND WHEREAS there is an increasing pressure on land for human settlement leading to filling up of the wetlands

AND WHEREAS the East Kolkata Wetlands are ecologically and socio-economically very important

AND WHEREAS it is expedient to provide for conservation and management of the East Kolkata Wetlands and for matters connected therewith and incidental thereto

1. **Short title and commencement**

   It is hereby enacted in the 57th Year of the Republic of India, by the legislature of West Bengal, as follows:

   (1) This Act may be called the East Kolkata Wetlands (Conservation and Management) Act, 2006.
   (2) It shall be deemed to have come into force on the 16th day of November, 2005.

2. **Definitions**

   In this Act, unless the context otherwise requires:

   (a) "Authority" means the East Kolkata Wetlands Management Authority constituted under Section 3

(b) "Chairperson" means the Chairperson of the Authority.
(c) "East Kolkata Wetlands" means such of the areas included in the list of Ramsar Sites as are specified in Schedule I and shown in the map in Schedule II.
(d) *Explanation I*. For the purposes of this Act, "Ramsar Sites" means the wetlands of international importance under Ramsar Convention.
(e) *Explanation II*. For the purposes of this Act, "Ramsar Convention" means the Ramsar Convention on Wetlands, Ramsar, Iran.
(f) "Land" includes any wetland.
(g) "Land and Land Reforms Department" means the Land and Land Reforms Department of the Government of West Bengal.
(h) "Local body" means a Panchayat within the meaning of clause (1) of Article 243B, or a municipality within the meaning of clause (1) of Article 243Q, of the Constitution, or, in the absence of a Panchayat or municipality, an institution of self-government constituted or established under any other provision of the Constitution or by or under any Central Act or State Act.
(i) "Member-Secretary" means the Member-Secretary of the Authority.
(j) "Notification" means a notification published in the Official Gazette.
(k) "Prescribed" means prescribed by rules made under this Act.
(l) "State Government" means the Government of West Bengal in the Department of Environment.
(m) "Water body" includes any land holding water.

3. **Constitution of East Kolkata Wetlands Management Authority**

(1) The State Government shall, with effect from such date as it may, by notification, appoint and constitute an authority to be called the East Kolkata Wetlands Management Authority.
(2) The Authority shall consist of the following Members:

(i) Chief Secretary to the Government of West Bengal	Chairperson
(ii) Secretary, Department of Environment, Government of West Bengal	Member-Secretary
(iii) Secretary, Department of Urban Development, Government of West Bengal	Member
(iv) Secretary, Department of Irrigation and Waterways, Government of West Bengal	Member
(v) Secretary, Department of Fisheries, Government of West Bengal	Member
(v) Secretary, Department of Fisheries, Government of West Bengal	Member
(vi) Secretary, Department of Forest, Government of West Bengal	Member
(vii) Secretary, Department of Municipal Affairs, Government of West Bengal	Member
(viii) Secretary, Department of Land and Land Reforms, Government of West Bengal	Member
(ix) Secretary, Department of *Panchayat* and Rural Development, Government of West Bengal	Member
(x) Chairman, West Bengal Pollution Control Board	Member

(continued)

(xi) Member-Secretary, West Bengal Pollution Control Board	Member
(xii) Chief Executive Officer, Kolkata Metropolitan Development Authority	Member
(xiii) Commissioner, Kolkata Municipal Corporation	Member
(xiv) District Magistrate, 24 Parganas (South)	Member
(xv) District Magistrate, 24 Parganas (North)	Member
(xvi) Three persons to be nominated by the State Government of whom one each shall be from among the representatives of:	Members
(a) The non-government organisations having expertise in the field of wetland conservation	
(b) The non-government organisations having expertise in the field of wetland management	
(c) The fishermen's co-operative societies formed for the purpose under the West Bengal Inland Fisheries Act, 1984	
(xvii) One representative of the Institute of Environmental Studies and Wetland Management, Kolkata, to be nominated by the State Government	Members

(3) The Authority shall be a body corporate with the name specified in Subsection (1) having perpetual succession and a common seal with power to acquire, hold and dispose of property and to contract and may, by the aforesaid name, sue or be sued.

4. **Functions and powers of Authority**

(1) The functions and powers of the East Kolkata Wetlands Management Authority shall be:

(a) To demarcate the boundaries of the East Kolkata Wetlands on the field as shown in the map in Schedule II
(b) To take measures or make an order to stop, undo and prevent any unauthorised development project in, or unauthorised use of, or unauthorised act on, the East Kolkata Wetlands
(c) To make an order directing demolition or alteration of any hoarding, frame, post, kiosk, structure, neon-signed or sky-signed, erected or exhibited illegally for the purpose of advertisement on any land within the East Kolkata Wetlands
(d) To make an order to prevent, prohibit or restrict any mining, quarrying, blasting or other operations of like nature, for the purpose of protecting or conserving the East Kolkata Wetlands
(e) To take measures to abate pollution in the East Kolkata wetlands and conserve the flora, fauna and biodiversity in general
(f) To prepare action plans conforming to the resolutions taken and recommendations made, from time to time, under the Ramsar Convention and to update the land use maps of the East Kolkata Wetlands
(g) To implement and monitor the activities specified in the action plans
(h) To promote research and disseminate findings of such research among the stakeholders

(i) To raise awareness about the utility of the wetlands in general and the East Kolkata Wetlands in particular
(j) To promote basic conservation principles like sewage-fed pisciculture and eco-tourism in the East Kolkata Wetlands
(k) To enforce land use control in the substantially water body oriented areas and other areas in the East Kolkata Wetlands
(l) To detect changes of ecological character and in land use in the East Kolkata Wetlands
(m) To establish network with other Ramsar Sites in India
(n) To conduct inquiry or scientific study for any purpose of this Act
(o) To constitute expert committee for any purpose of this Act
(p) To enter any land or premises, including to collect samples of air, water, soil and other biological resources, for any purpose of this Act
(q) To call for relevant records and documents and information from any department, organisation or local body for any purpose of this Act
(r) To do such act, or pass such order, which may be necessary and expedient for the purpose of conservation and management of the East Kolkata Wetlands

(2) The Authority shall, before making an order under clause (b), or clause (c), or clause (d), of Subsection (I), give the person affected thereby a reasonable opportunity of being heard.

5. **Term of office, allowances, etc. of nominated Member of Authority**

(1) The term of office and allowances of a nominated Member of the Authority shall be such as may be prescribed:
Provided that the State Government may, if it thinks fit, terminate, by order and for the reasons to be recorded in writing, the appointment of any nominated Member before the expiry of his term of office.
(2) A nominated Member of the Authority may resign his membership under his hand addressed to the State Government and, on acceptance of such resignation by the State Government, he shall cease to be a Member as such.
(3) Any vacancy, by resignation, death or otherwise, of a nominated Member shall be filled by fresh nomination by the State Government.

6. **Meeting of Authority**

(1) The Authority shall meet at such place and time, and the meeting shall be conducted in such manner, as may be prescribed.
(2) All orders and decisions of the Authority shall be authenticated by the Chairperson or by such other Members or such officer of the Authority as may be authorised in this behalf by the Chairperson.

7. **Vacancy, etc. not to invalidate acts or proceedings of Authority**

   No act or proceeding of the Authority shall be called in question on the ground merely of the existence of any vacancy in, or any defect in the constitution of, the Authority.

8. **Officers and employees of Authority**

   (1) The Authority may appoint such officers and employees as it considers necessary for the efficient performance of its functions.

   (2) The method of recruitment and the terms and conditions of service of the officers and employees shall be such as may be prescribed.

   Explanation. For the purposes of Subsection (1) and Subsection (2), the expression "officers and employees" does not include the Chairperson or the Member-Secretary or any other Member of the Authority.

   (3) Notwithstanding anything contained in Subsection (1) or Subsection (2), the State Government, on request of the Authority, may, by order in writing, require, for performance of any function of the Authority, services of any officer or employee of the State Government by way of duties in addition to his normal duties.

9. **Maintenance and preservation of land in East Kolkata Wetlands**

   Notwithstanding anything contained in any law for the time being in force, every person holding any land in the East Kolkata Wetlands shall maintain and preserve such land in a manner that its area is not diminished, or its character is not changed, or it is not converted for any purpose other than the purpose for which it was settled or previously held, except with the previous sanction of the Authority under Section 10.

10. **Procedure for granting sanction**

   (1) Any person holding a land in the East Kolkata Wetlands may apply, in such manner as may be prescribed, to the Authority for change of character or mode of use of the land.

   (2) The Authority shall, on receipt of the application, examine the merit of the case and, if necessary, inspect the proposed site.

   (3) After examination of the case and inspection, if any, of the proposed site under Subsection (2), the Authority shall refer the case to the Collector of the concerned District for taking necessary action for issuance of an order under Section 4C of the West Bengal Land Reforms Act, 1955.

   (4) On receipt of the order from the Collector of the concerned District, the Authority may pass, in such form and with such restrictions and conditions as may be prescribed, an order granting sanction for change of character or mode of use of the land:

   Provided that if the sanction may result in filling up of any water body, the Authority shall, prior to granting sanction under this subsection. Require the person to create at an appropriate place within the East Kolkata Wetlands a water body of which the area shall not be less than the area of the water body which may be so filled up.

(5) Nothing in this section shall empower the Authority to grant sanction for change of character or mode of use of a land unless the change is for improvement or upkeep of the local environment and its surroundings.

11. **Restoration of land to original character or mode of use**

(1) If the Authority is, either *suo motu* or on receipt of any information, satisfied that the character or mode of use of a land is being changed or has been changed in contravention of any provision of this Act, it may, by order in writing, require the person responsible for the change to restore the land, at his own expense, to the original character or mode of use within such period as may be specified in the order and, in case of default by such person, undertake the restoration by itself and recover the cost thereof as arrears of land revenue:

Provided that before passing the order, the Authority shall give the person a reasonable opportunity of being heard.

(2) The Authority may use appropriate technology and method in determining whether a land comprises or has comprised a wetland or whether water is being or has been drawn from a wetland so as to change the character or mode of use of the wetland or whether a wetland is being or has been filled up partially or fully or whether a wetland is being or has been encroached upon in any manner.

12. **Fund of Authority**

The Authority shall have its own fund and the sums which may be paid to the Authority by the State Government and all other receipts. By way of grants, gifts, donations, benefactions or otherwise of the Authority shall be carried to the fund, and all payments by the Authority shall be made therefrom.

13. **Accounts and audit**

(1) The Authority shall maintain proper accounts and other relevant records and prepare an annual statement of accounts in such form as may be prescribed.

(2) Subject to the provisions of the Comptroller and Auditor General's (Duties, Powers and Conditions of Service) Act, 1971, and the rules and orders made thereunder, the Governor of West Bengal may entrust the audit of the accounts of the Authority to the Comptroller and Auditor General of India.

(3) The Comptroller and Auditor General of India or any other person appointed by him in this behalf shall have the same rights, privileges and authority in connection with such audit as the Comptroller and Auditor General of India has in connection with the audit of the Government accounts.

(4) The accounts of the Authority as certified by the Comptroller and Auditor General of India or any other person appointed by him in this behalf together with the audit report and the audit certificate thereon shall be forwarded to the State Government, and the State Government shall cause

the same to be laid, as soon as may be after it is received, before the West Bengal Legislative Assembly.

14. **Annual report**

The Authority shall prepare for each financial year, in such form and at such time each year as may be prescribed, its annual report giving a full account of its activities during such financial year and forward a copy thereof to the State Government.

15. **Powers and duties of Chairperson and Member-Secretary**

(1) The Chairperson shall exercise such powers and discharge such duties as may be prescribed or as may, from time to time, be delegated to him by the Authority.
(2) The Member-Secretary shall exercise such powers and discharge such duties as may be prescribed or as may, from time to time, be delegated to him by the Authority or the Chairperson.

16. **Directions by State Government**

The Authority shall be guided in performance of its functions, by such directions as may be given from time to time to it by the State Government: provided that no such direction shall be inconsistent with any provision of this Act.

17. **Power to include any area in or enlarge any area of East Kolkata Wetlands**

(1) The State Government may, if it is of opinion that it is necessary or expedient in the public interest to do so, by notification, include any area in, or enlarge any area of, the East Kolkata Wetlands, and, thereupon, Schedule I and Schedule II shall be deemed to have been amended accordingly.
(2) Every notification issued under Subsection (i) shall, as soon as may be after it is issued, be laid before the state legislature.

18. **Penalties**

(1) Whoever fails to comply with or contravenes any provision of this Act or the rules made, or orders issued, thereunder shall be guilty of an offence and shall, in respect of each such failure or contravention, be punished with imprisonment for a term which may extend to 3 years or with fine which may extend to 1 lac rupees or with both and, in case such failure or contravention continues, with an additional fine which may extend up to 5000 rupees for every day during which such failure or contravention continues after the conviction for first such failure or contravention.
(2) Every such offence shall be cognizable and non-bailable.

19. **Offences by companies**

(1) Where an offence under this Act has been committed by a company, every person, who at the time the offence was committed, was in charge of, and was responsible to, the company for the conduct of the business of the

company, as well as the company, shall be deemed to be guilty of the offence and shall be liable to be proceeded against and punished accordingly: provided that nothing contained in this subsection shall render any such person liable to any punishment, if he proves that the offence was committed without his knowledge or that he had exercised all due diligence to prevent the commission of such offence.

(2) Notwithstanding anything contained in Subsection (1), where an offence under this Act has been committed by a company and it is proved that the offence has been committed with the consent or connivance of, or is attributable to, any neglect on the part of, any director, manager, secretary or other officer of the company, such director, manager, secretary or other officer shall also be deemed to be guilty of that offence and shall be liable to be proceeded against and punished accordingly.

Explanation. For the purposes of this section:

(a) "Company" means anybody corporate and includes a firm or other associations of individuals.
(b) "Director", in relation to a firm, means a partner in the firm.

20. **Offences by officers of State Government or local bodies**

If any officer of the State Government or of a local body permits or neglects doing, or wilfully fails to do, any act whereby an offence under this Act is committed, he shall, notwithstanding anything contained in the service law applicable to him for the time being in force, be deemed to have committed under such service law misconduct in discharge of his official duties and be subjected to the disciplinary proceedings and penalties accordingly.

21. **Protection of action taken in good faith**

No suit, prosecution or other legal proceeding shall lie against the Authority or any Member, officer or employee thereof or the State Government or any officer or employee thereof for anything or any damage caused or likely to be caused by anything, which is in good faith done or intended to be done under this Act or the rules made there under.

22. **Act to override other laws**

The provisions of this Act shall have effect notwithstanding anything contained in any law for the time being in force or in any contract, expressed or implied, or in any instrument having effect by virtue of any law or in any custom or usage.

23. **Power to make rules**

(1) The State Government may, by notification, make rules for carrying out the purposes of this Act.
(2) In particular and without prejudice to the generality of the foregoing power, such rules may provide for all or any of the following matters:

(a) The term of office and allowances of a nominated Member of the Authority under Subsection (1) of Section 5

(b) The place and time and manner of conducting the meeting of the Authority under Section 6
(c) The method of recruitment and the terms and conditions of service of the officers and employees of the Authority under Subsection (2) of Section 8
(d) The manner of making application for change of character or mode of use of the land under Subsection (1) of Section 10
(e) The form and the restrictions and conditions of an order granting sanction for change of character or mode of use of the land under Subsection (4) of Section 10
(f) The form of maintaining accounts and other relevant records and preparing an annual statement of accounts under Subsection (1) of Section 13
(g) The form and time for preparing the annual report under Section 14
(h) The powers and duties to be exercised and discharged by the Chairperson and the Member-Secretary under Section 15
(i) Any other matter which is required to be or may be prescribed

(3) All rules made under this section shall be laid, as soon as may be after it is made before the state legislature, while it is in session, for a total period of 14 days which may be comprised in one session or in two or more successive sessions. And, if before the expiry of the session immediately following the session or the successive sessions aforesaid the state legislature agrees in making any modification in the rules or the state legislature agrees that such rules should not be made, the rules shall thereafter have effect only in such modified form or be of no effect, as the case may be, so, however, that any such modification or annulment shall be without prejudice to the validity of anything previously done under those rules.

24. **Power to remove difficulties**

(1) If any difficulty arises in giving effect to the provisions of this Act, the State Government may, for the purpose of removing such difficulty, by order published in the Official Gazette, make such provisions not inconsistent with the provisions of this Act, as it may deem to be necessary or expedient:
Provided that no such order shall be made after the expiry of a period of 2 years from the commencement of this Act.
(2) Every order made under Subsection (1) shall, as soon as may be after it is made, be laid before the state legislature.

25. **Repeal and saving**

(1) The East Kolkata Wetlands (Conservation and Management) Ordinance, 2005, is hereby repealed.
(2) Notwithstanding such repeal, anything done or any action taken under the said Ordinance shall be deemed to have been validly done or taken under the corresponding provisions of this Act.

References

archive.india.govt.in
envfor.nic.in
envfor.nic.in>content>hazardous and . . . .)
envfor.nic.in>content>gsr 343 e
http://sustainabledevelopment.un.org/ft
KERALA GAZETTE EXTRAORDINARY PUBLISHED BY 12th August 2008
National Environment Policy, 2006
The Constitution of India, Government of India, Ministry of Law and Justice, Legislative Department
www.elaw.in
www.judis.nic.in
www.moef.gov.in/content/gsr 320.e
www.moef.gov.in/gsr 338 (e)
www.moef.nic.in
www.moef.nic.in/content/so 1357 e-o
www.moef.nic.in>content/gsr - 317 e
www.ramsar.org
www.sanitation.kerala.gov.in
www.un.org (https://www.Google.co.in)
http://www.moef.nic.in/content/gsr-1203e-wetlands-conservation-and-management-rules-2017

Glossary

Act It refers to a set of laws passed by the parliament to take action, take steps, take measures, take the initiative, make a move, do something, and go ahead for the benefit or achieving of something.

Adsorption It means to be the physical binding of atoms, ions, or molecules from a gas, liquid, or dissolved solid to the surface of another by adhesion.

Agricultural crops It refers to products that are grown on the Earth or intentionally managed by man for economic purposes.

Aquaculture It refers to the farming of economically important fish, crustaceans, mollusks, echinoderms, weeds, algae, plankton, and other aquatic organisms in natural or controlled conditions of freshwater, marine water, or brackishwater for human consumption or other uses.

Aquaponics It refers to a green and sustainable eco-technology integrating aquaculture in hydroponic system in which waste produced by farmed fish or other aquatic creatures or wastewater supplies the nutrients for plants grown hydroponically, which in turn reclaim the water.

Biodiversity It refers to the variety of species and ecosystems on Earth and the ecological processes of which they are a part. Three components of biodiversity are ecosystem, species, and genetic diversity.

Biological production It refers to the total amount of biomass produced by living organisms within a given area in a specific period of time.

Bioremediation It is a waste management technique that involves the use of naturally occurring organisms such as living plants and animals, microbes and bacteria, etc. to break down or neutralize hazardous substances to less toxic or nontoxic form.

Biosorption It is a physiochemical process that occurs naturally in certain biomass which allows it to passively concentrate and bind contaminants onto its cellular structure.

Contamination It means the presence of an unwanted, harmful constituent, contaminant or impurity in a material, physical body, natural environment, workplace, etc.

DPSIR It stands for Driving Forces-Pressures-*State*-Impacts-Responses used to assess and manage *environmental* problems.

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2

Ecological engineering It is defined as the design of sustainable ecosystem that integrates the human society and its natural environment for the mutual benefit of both.

Economic benefit It can be expressed numerically as an amount of money that will be saved or generated as I the result of an action.

Ecosystem resilient It refers to the capacity of an *ecosystem* to response to a peruturbation or disturbance by resisting damage and recovering quickly or withstand ongoing pressures or tolerate disturbance without collapsing into a different state that is controlled by a different set of processes.

Edible crops It refers here to ensure the most healthy, delicious, and inexpensive food which are grown easily by yourself in homestead or in backyard garden.

EKW It stands for East Kolkata Wetlands which is considered to be one of the largest wastewater fed aquaculture systems in Asia and declared as an important RAMSAR site.

Environmental benefit It refers to the reduction of biosolids amount, mentions the facility that is to reduce the *environmental* impacts associated with disposing of the biosolids, including less greenhouse gases emitted from landfills, fewer emissions from the heavy vehicles that transport the waste, and less pollution caused by litter and spills.

Environmental impact assessment (EIA) It is an important management tool for ensuring optimal use of natural resources for sustainable development or the *assessment* of the *environmental* consequences (positive and negative) of a plan, policy, program, or actual project.

Environmental management It offers research and opinions on the use and conservation of natural resources, protection of habitats, and control of hazards, spanning the field of *environmental management* without regard to traditional disciplinary boundaries.

Environmental valuation It refers to be an economic theory devised to assign monetary values to environmental goods and services, and these values can then be incorporated into decision-making at the project, sectoral, and national levels.

Eutrophication It refers to an excessive richness of nutrients in a water body due to runoff from the land, which causes a dense growth of plant life.

Fish diseases It refers to fish to suffer from deterioration of normal health due to physiological disorder or pathological infection.

Health assessment index (HAI) It refers to a biomonitoring technique, developed in the USA and subsequently tested in South Africa, to revaluate condition of health in the existing environmental context.

Heavy metal It may refer to a relatively dense metals and metalloids which create toxic and thus become harmful for any system, particularly organism.

Hydroponics It means a procedure of hydroculture, the method of growing plants without soil, using mineral nutrient solutions in a water solvent.

ICAR-CIFA ICAR stands for Indian Council of Agricultural Research and CIFA for Central Institute of Freshwater Aquaculture.

Impact analyses It is defined by Bohner and Arnold as "identifying the potential consequences of a change, or estimating what needs to be modified to accomplish a change."

In situ It refers to the natural or original position.

In vitro It expresses living state in the test tubes (in glass) or an artificial environment.

Management It means the process of dealing with or controlling things or people.

Microbial fuel cell It refers to a microbial fuel cell (MFC), or biological fuel cell, which is a bio-electrochemical system that drives an electric current by using bacteria and mimicking bacterial interactions found in nature.

Mud-water exchange It refers to mud as defined as a soil mixed with liquid or semiliquid mixture of *water* or any combination of different kinds of soil involved in exchanging of minerals between mud and overlying water through chemical reaction.

Municipal wastewater Also known as sewage which is usually transported through a combined sewer or sanitary sewer and treated at a *wastewater* treatment plant.

Nanocomposites It refers to be a multiphase solid material where one of the phases has one, two, or three dimensions of less than 100 nanometers (nm) or structures having nanoscale repeat distances between the different phases that make up the material.

Nanotechnology It refers to the branch of technology that deals with dimensions and tolerances of less than 100 nanometres, especially the manipulation of individual atoms and molecules.

Nutrients cycle It means the movement and exchange of organic and inorganic matter back into the production of living matter through a systematic food web pathway that decomposes organic matter into minerals.

Nutrients recovery It refers to the technique by which the desirable amount of nutrients may be restored from the system being lost by living biomass and chemical or physical processes, which may be reused for development.

Opportunity cost It refers to a benefit that a person could have received, but gave up, to take another course of action.

Phytoremediation It refers to the use of certain macrophytes, plants, or algae to remove pollutantsfrom wastewater soil or environment.

Polymer It refers to be a large molecule, or macromolecule, composed of many repeated subunits.

Polymerase chain reaction (PCR) It refers to a reaction using the enzyme DNA polymerase to catalyze the amplification of a DNA strand through multiple cycles of DNA synthesis.

Remedial measure It comprises some steps to eliminate something that we don't desire to experience.

Remediation It usually refers to environmental *remediation* which deals with the removal of pollution or contaminants from environmental substrata such as soil, groundwater, sediment, or surface water.

Reservoir It is a large natural or artificial lake used as a source of water storage.

Rules It refers to a set of explicit or understood regulations or principles governing conduct or procedure within a particular area of activity.

Safe reuse It means to reduce preventable harm by identifying specific, preventable medication risks and developing, implementing, and evaluating cross-sector interventions with partners who are committed to safe medication use.

Safety It refers to the state of being safe and protected from danger or harm.

SDGs It stands for sustainable development goals.

Social costs It may be distinguished from private cost and is considered to be the private cost plus externalities.

Socioeconomics It deals with a branch of *economics* that studies how *economic* activity affects and is shaped by *social* processes.

Soil composition It is the components of soils; it is a mixture of minerals, organic matter, gases, liquids, and countless organisms.

Soil structure It refers to the arrangement of the solid parts of the *soil* and of the pore space located between them. It is determined by how individual *soil* granules clump, bind together, and aggregate, resulting in the arrangement of *soil* pores between them.

STEPS It stands for social, technical, environmental, political/institutional and sustainability framework, used for assessment of quality of wastewater.

Stressor The factors which develop stress or are causes to create stress to any organism/individual/system.

Sustainability It refers to the property of biological systems to remain diverse and productive indefinitely.

SWOT It comprises four words strength, weakness, opportunity, and threat.

UN United Nation

Waste stabilization It is a natural process for wastewater treatment that includes a combination of ponds or water bodies used for treatment of municipal *wastewater*.

Wastes It means to any substance which is discarded after primary use or it is worthless, defective, and of no use. It is also called society's discarded product.

Wastewater systems It refers to the physical structure utilized for different purposes of wastewater treatment and its utility.

Wastewater treatment It is a process to convert wastewater—the water no longer needed or suitable for its most recent use—into an effluent that can be either returned to the water cycle with minimal environmental issues or reused.

Wastewater It refers to used water which is not used further for its wastes-laden substances.

Wetlands It refers to a land area that is saturated with water, either permanently or seasonally, such that it takes on the characteristics of a distinct ecosystem.

Index

B. B. Jana et al. (eds.), *Wastewater Management Through Aquaculture*,
https://doi.org/10.1007/978-981-10-7248-2