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Debesh Chakraborty
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Water Pollution and Abatement Policy in India

A Study from an Economic Perspective

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Foreword

Shortly before the publication of this book, Professor Debesh Chakraborty, the renowned academician, internationally acclaimed economist, and, most importantly, the main author of this book, passed away after a short illness. Having meticulously worked on the proofreading of this manuscript, Professor Chakraborty, however, did not have the opportunity to see the printed volume. His inspiration and guidance saw me through every line of this book, and I dedicate this book to the memory of him.

Professor Chakraborty was a faculty at the department of Economics, Jadavpur University, Calcutta, India, for more than three decades. He began his academic career as a postdoctoral researcher at New York University with Nobel Laureate Prof. W.W. Leontief, a distinction that shaped him into one of the pioneers and forerunners of multisector quantitative research in Applied Economics and Input-output modeling in India. He will be remembered for developing emerging areas of research with special focus on Application of the Input–Output framework, Global CGE model, and Applied Quantitative Techniques in Economics. He was, without any doubt, one of the most renowned and most thoughtful academicians in the field of Input-Output Economics.

Professor Chakraborty coauthored several books and leaves behind more than 100 publications in various peer-reviewed journals. He had contributed extensively to the analysis of multisectoral models and was one of the early researchers in that field in India. His works have been widely cited, setting the trend for many young researchers in that field. Always on the lookout for research on fundamental and emerging issues, he continued his engagement in supervising Ph.D. students and directed large research projects even after his retirement. Twenty-three scholars earned their doctoral degrees under his supervision in diverse fields in economics.

Professor Chakraborty was attached as a fellow or visiting fellow to various universities and institutions such as UNESCAP in Bangkok, New York University in the USA, Tilburg University and MERIT-Maastricht University in the Netherlands, the East-West Center at the University of Hawaii, the Korea Institute of Population and Family Planning in South Korea, the University of Newcastle in the

UK, Oulu University in Finland, and the Department of Agricultural Economics, McGill University, Canada.

He possessed the rare personality that could blend academics with real issues of our daily life to develop a vision for societal progress at large. A keen observer with a sharp intellect and empathy for the common man, he befriended people from all walks of life. Above all, he was a wonderful human being who always gave his best to his students, friends, and colleagues. I will forever remember a man with such deep commitment to academics and society and love for equality and balance. It is hard to believe that such a vigorous human presence is no more.

With great sadness,
Kakali Mukhopadhyay

Preface

The growing ecosystem degradation around the world is affecting the vast population especially the poor in developing countries who often depend solely on ecosystem services. Water is one of the most fundamental natural resources and is vital to the survival of all living organisms and smooth functioning of ecosystem and society. Decades of rapid industrialization, urbanization, and agricultural development have resulted in lifestyles that increase the demands on water resources along with dramatic increases in water pollution levels. Polluting wastewater from industrial discharges is one of the main causes of ecosystem degradation. Apart from industrial wastewater, agrochemicals, fertilizers, organic manure, and nutrient solution pollute water significantly when they enter into the water through rains. Water pollution is one of the main reasons behind a decline in freshwater reserves. Polluted water has adverse effects on both environment and health. Water pollution has been increasing in alarming proportions over time, and this needs immediate attention and calls for appropriate measures.

Traditionally, India has been well endowed with large freshwater reserves but increasing population, urbanization, and agricultural growth are leading to overexploitation of surface and groundwater over the past few decades. Thus, the availability and the quality of the freshwater resources is the most pressing of the many environmental challenges India is facing today. Growth of the Indian economy is driving increased water usage across sectors. On the other hand, wastewater amount is increasing significantly and, in the absence of proper measures for treatment and management, is polluting existing freshwater reserves. As a result, water pollution has emerged as one of the gravest environmental threats to India. In this backdrop, the current study makes a comprehensive analysis of water pollution in India.

A significant number of industries such as livestocks, chemical industries, beverages, leather, cotton textiles, miscellaneous textile, paper, pesticides, milk, and milk products in India are producing water pollution above MINAS by several times. We have also seen that a number of industries are controlling water pollution. Since pollution abatement activities involve cost, they affect the price and output of different industries.

The current book attempts to develop an input–output model to link water pollution generated by different industries with various economic activities of the Indian economy. It constructs a detailed water pollution coefficient matrix involving different types of water pollutants and estimates the total amount of water pollution generation directly and indirectly from different sectors/activities of India. The analysis of the effect of pollution abatement scheme shows that the demand for sectoral output will change and so also the price of the different sectors of the economy. We find that chemical, mining, and electricity are key sectors which have extensive linkages in the demand for clean water.

Further, the study derives an interesting finding from the water pollution content in trade. India is exporting more water pollution-intensive goods, while importing less. So India is pollution heaven particularly for a number of water pollution parameters such as dissolved solids, chloride, sulfide, BOD, and COD for the years 2006–2007.

The book also offers a portfolio of pollution abatement policies and evaluates the implications of such policies on pollution generation in the economy. Analysis reveals that water pollution-generating sectors such as inorganic and organic chemicals, mining, sugar, and cotton textile will grow rapidly and therefore also the clean water sector. The study calculates the water pollution load at the end of the 12th five-year plan. Furthermore, the study accounts for defensive expenditure arising from water pollution and estimates Green GDP of India for the year 2006–2007. We have applied various scenarios to estimate the loss in GDP due to water pollution and related activities. The loss accounted for GDP varies according to scenarios ranging from 3.50 to 3.91 %.

There is a controversy regarding the setting up of CETP/or ETP plant in India. An assessment has been made in the book through different case studies across different states in India. The findings on West Bengal reveal that measures to control water pollutants by setting up Environmental Treatment Plant (ETP) in five industries have been successful. The experiences from leather industry in North and South India show a similar result. Both of them have used CETP to control water pollution. On the other hand, a typical cluster of pulp and paper industry in Northern India shows the feasibility of ETP compared to CETP.

The book suggests that the foremost attempt should be made to achieve clean water and for that technological improvement is a must. Increase in research and development expenditure has to be taken by the different industries and the government involving scientists, social scientists, and technologists. The book has also analyzed the possibility of using economic instruments and command and control policies for the abatement of water pollution. It concludes that the use of economic instruments together with existing command and control approaches will bring great benefit.

We hope this effort will make a modest contribution to solving the water pollution problem of a developing country like India and provide some direction for abatement policies. It presents a thorough review of water pollution generation from different sectors of the Indian economy and the impact of abatement policies. The book integrates macroeconomic and microeconomic approach on a single platform, a rare attempt in the literature on water pollution in India. The book will help policy makers, researchers, and the world bodies like ADB, World Bank, UNEP, IWMI, and Water Research Institutes derive policies and pursue further research for thorough investigation. In addition, the central pollution control board and various state pollution control boards of India will also find the book useful. Thus, the book will be a good addition to the field of water pollution in developing countries particularly in Asia.

18.11.2013

Debesh Chakraborty
Kakali Mukhopadhyay

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The authors would like to express sincere thanks to the officials and staffs of the Central Pollution Control Board, New Delhi, West Bengal Pollution Control Board, Calcutta, and Tata Energy Research Institute, New Delhi, for their cooperation in using the library facilities. Thanks are also due to Prof. Paul Thomassin (McGill University) for his constant encouragement.

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Introduction

1.1 Environment and Development

The international conference held in Sweden in 1972 emphasized strongly the interdependence between environment and development issues. In 1980, the International Union for the Conservation of Nature and Natural Resources (IUCN), the World Wildlife Fund for Nature (WWF), and the United Nations Environment Programme (UNEP) stressed the linkage between conservation and development. In 1983, the Brandt Commission also focused on this relationship. As a result of recommendations from the Stockholm Conference and Brandt Commission, the World Commission on Environment and Development produced a valuable report "Our Common Future" in 1987(WCED 1987). The term "sustainable development" started to figure in the global community discussion. The first Earth Summit in 1992 and other subsequent summits such as the World Summit on Sustainable Development (WSSD) and the UN Commission for Sustainable Development addressed the issues and actions on social, economic, conservation, and resource management dimensions of the globe.

Is there any link between environment and development? Opinions do differ, however. The growing economic activity throughout the world requires larger inputs of energy and material resources and generates larger quantities of waste by-products (Georgescu-Roegen 1971; Meadows et al. 1972). Increased extraction of natural resources, accumulation of waste, and concentration of pollutants would outweigh the carrying capacity of the biosphere leading to the degradation of environmental quality and a decline in human welfare, despite rising incomes (Daly 1977). Thus, growth may result in "excessive" environmental degradation through the use of natural resources and generation of pollution aggravated by institutional failures (GOI 2006). Furthermore, the degradation of the resource base would eventually impact adversely the economic activity. Thus, to save the environment is our primary concern today.

At the other extreme, it is argued that the fastest road to environmental improvement is along the path of economic growth. Higher incomes result in increased

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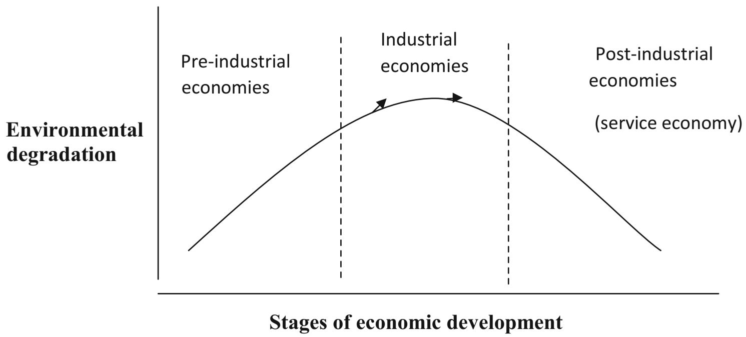

Fig. 1.1 The environmental Kuznets curve: a development–environment relationship (Source: Panayotou 1993)

demand for goods and services that are less material intensive and improved environmental quality. This would lead to the environmental protection measures. It is claimed that environmental regulation may actually reduce environmental quality by reducing economic growth (Bartlett 1994).

Others opined in a different way (e.g., Shafik and Bandyopadhyay (1992), Panayotou (1993, 1995), Grossman and Kreuger (1993), and Selden and Song (1994)). They hypothesized that the relationship between economic growth and environmental degradation, whether positive or negative, is not fixed along a country's development path. It may move from positive to negative as a country reaches a level of income at which people demand a cleaner environment. The implied inverted-U relationship between environmental degradation and economic growth is known as the "environmental Kuznets curve" (EKC). At low levels of development, both the quantity and the intensity of environmental degradation are limited to the impacts of subsistence economic activity on the resource base and to limited quantities of biodegradable wastes. As an economy moves from lower to higher development path, both resource depletion and waste generation accelerate. At higher levels of development, structural change takes place towards information and service-based industries. The demand for environmental quality increases and ultimately leads to a steady decline of environmental degradation (Panayotou 1993). This is as shown in Fig. 1.1.

Thus, EKC analysis indicates a well-defined relationship between economic growth and environmental degradation (Dasgupta et al. 2002). It also shows that economic growth could be compatible in the long run with the environment by implementing efficient environmental policies (de Bruyn and Heintz 1999; O'neill et al. 1996; Ezzati et al. 2001; Suri and Chapman 1998).

There are a host of studies relating economic growth and environment across a number of developing as well as developed countries (Beckerman 1992; Shafik 1994; Selden and Song 1994; Grossman 1995). The most common argument in these studies is that economic growth in the long run has led to an improvement in environmental quality in developed countries. Similarly, it is also expected that developing countries can also achieve such environmental quality improvements once they reach a higher level of per capita income. However, the EKC evidence for water pollution is mixed. Few studies found an inverted-U-shaped curve for biological oxygen demand (BOD), chemical oxygen demand (COD), nitrates, and some heavy metals (arsenic and cadmium) (Yandle et al. 2002). In most cases, the income threshold for improving water quality is much lower than the one for improving air pollution (Yandle et al. 2002). Several authors (Shafik 1994; Grossman 1995) found evidence of an N-shaped curve for some water quality indicators like fecal coliform (Borghesi 2000). Paudel et al. (2005) in their study investigated the EKC on water pollution using parish-level data aggregated to the watershed level in the state of Louisiana. Their results found the evidence of an EKC in water pollution. A study by Liu and Chen, for Shenzhen City in China, found that river water quality follows an inverted-U-shaped curve, but air quality and the quality of near coastal waters follow a U-shaped curve (Barua and Hubacek 2008).

Thus, the interaction between economic growth and environmental degradation is one of the most controversial issues in environmental economics. The environment-growth debate has centered on several questions: robustness and generality of the relationship and role of other factors, such as population growth, income distribution, international trade, and ecosystem, and role of policy. As environmental degradation poses an increasing threat to the prospect of economic growth and development, environmental considerations are becoming a part of the overall development policy of every nation.

1.2 Water Pollution and Development

Water, an abiotic component of our environment, plays an indispensable role in our lives but is one of the most abused resources. As an environmental resource, it is regenerative in the sense that it could absorb pollution loads up to certain levels without affecting its quality. In fact, water pollution problem exists only if the pollution loads exceed the natural regenerative capacity of a water resource. Water pollution is any physical or chemical change in water that can adversely affect organisms. Water contamination weakens or destroys natural ecosystems that support human health, food production, and biodiversity (Chakraborty et al. 2001; CAG 2011).

Water pollution is caused by a variety of human activities – including agriculture, industry, mining, disposal of human waste, population growth, urbanization, climate change, etc. So it is often rightly said that pollution is a by-product of regular economic activity (Leontief 1970). Agriculture can cause nutrient and pesticide contamination where increased salinity and nutrient enrichment has become one of the most widespread water quality problems of the world. Effluents of organic and inorganic pollutants from industrial activities are also a major cause of water quality degradation. Polluting substances include organic matter, metals, minerals, sediments of solid wastes, suspended solids, bacteria, toxic chemicals, acids, and alkali. Pollutants like ammonia, chloride, sulfide, zinc, phenol, phosphate, chromium, sulfate, etc., are also found.

Waterways are often used directly as drinking water sources or connected with shallow wells used for drinking water. In addition, they are used for washing and cleaning, fishing and fish farming, and recreation. Another major source of drinking water is groundwater. This often has low concentrations of pathogens because water is filtered during its transit through underground layers of sand, clay, or rocks. Toxic chemicals such as arsenic and fluoride can dissolve from the soil or rock layers into groundwater. Direct contamination can also occur from badly designed hazardous waste or industrial sites. Seawater pollution with persistent chemicals, such as polychlorinated biphenyls (PCBs) and dioxins, can also be a significant source of pollution.

Poor water quality affects livelihoods such as agriculture, fishing, and animal husbandry. The use of polluted water leads to a decrease in produced quantity as well as in quality of the crops. It may take two forms: (a) the crops may accumulate heavy metals or toxic substances dissolved in the wastewater, making them unsuitable for consumption, and (b) polluted water may affect the level of nutrients and vitamins the crops would normally have. Further, the polluted water adversely affects the soil quality that results in reductions in quantity and quality of future harvests (Cheppi 2012).

Biodiversity, especially of freshwater ecosystems, is under threat due to water pollution. Runoff from farmland, in addition to carrying soil and sediments that contribute to increased turbidity, also carries nutrients such as nitrogen and phosphates. These are often added in the form of animal manure or fertilizers. These chemicals cause eutrophication (excessive nutrient levels in water), which increases the growth of algae and plants in waterways, leading to an increase in cyanobacteria (blue-green algae). The toxins released during their decay are harmful to humans. The use of nitrogen fertilizers can also be a problem in areas where agriculture is becoming increasingly intensified as they increase the concentration of nitrates in groundwater, leading to high nitrate levels in underground drinking water sources. This can then cause methemoglobinemia, the life-threatening "blue baby" syndrome, in very young children (Yassi et al. 2001). The discharge of heated water mostly from industries, thermal power plants, and municipal sewage into rivers and sea causes thermal pollution and damages to aquatic life such as fish, shrimps, or crabs, thus leading to ecological disturbances of water. There is a possibility of future loses in fishery production due to reduced reutilization of natural fishery resources, reduced fertility, and damaged breeding grounds (Cheppi 2012).

The application of pesticides directly on the soil can also create seepage to groundwater or runoff to surface water. Moreover, the spraying of pesticides from a distance, even from airplanes, can create a spray drift when the wind carries the materials to nearby waterways. Efforts to reduce the use of the most toxic and long-lasting pesticides in industrial countries have largely been successful, but the rules for their use in developing countries may be more permissive, and the rules of application may not be known or enforced. Hence, health risks from pesticide water pollution are higher in such countries (WHO 1990).

In many regions, household sewage disposal often remains untreated as the absence of proper sewage disposal system and poor maintenance of septic tanks generate pollution. Sewage contains various types of organic and inorganic matter, suspended particulate matter, and also different microorganisms which react to form acids or chemicals compounds. Alkalis and acids create disturbance to the pH value of the water resource. Extensive use of chemicals in agriculture (in the form of fertilizers and pesticides), household activities (through use of soaps and detergents), and industries is also the source of groundwater pollution. It is often found that toxic chemicals and solid wastes from industry effluents, household sewage, and agricultural fields, when disposed untreated into neighboring water source and land, mix with rainwater before seeping into and polluting groundwater reservoirs.

Chemicals can enter waterways from either a point or a nonpoint source. Point source pollution is due to discharges from a single source, such as an industrial site. Nonpoint source pollution involves many small sources that combine to cause significant pollution. For instance, the movement of rain or irrigation water over land picks up pollutants such as fertilizers, herbicides, and insecticides and carries them into rivers, lakes, reservoirs, coastal waters, or groundwater. Another nonpoint source is storm water that collects on roads and eventually reaches rivers or lakes (Kjellstrom et al. 2006).

Naturally occurring toxic chemicals can also contaminate groundwater, such as the high metal concentrations in underground water sources in mining areas. The most extensive problem of this type is the arsenic contamination of groundwater in Argentina, Bangladesh, Chile, China, India, Mexico, Nepal, Taiwan (China), and parts of Eastern Europe and the United States (WHO 2001). Fluoride is another substance that may occur naturally at high concentrations in parts of China, India, Sri Lanka, Africa, and the Eastern Mediterranean.

Drinking contaminated water is the most direct route of exposure to pollutants in water. The use of contaminated water in food preparation can result in contaminated food, because high cooking temperatures do not affect the toxicity of most chemical contaminants. Inhalation exposure to volatile compounds during hot showers and skin exposure while bathing or using water for recreation are also potential routes of exposure to water pollutants. Toxic chemicals in water can affect unborn or young children by crossing the placenta or being ingested through breast milk. Estimating actual exposure via water involves analyzing the level of the contaminant in the water consumed and assessing daily water intake (WHO 2003). Biological monitoring using blood or urine samples can be a precise tool for measuring total exposure from water, food, and air (Yassi et al. 2001).

Water disinfection using chemicals is another source of chemical contamination of water. Chlorination is currently the most widely practiced and most cost-effective method of disinfecting large community water supplies. This success in disinfecting water supplies has contributed significantly to public health by reducing the transmission of waterborne disease. However, chlorine reacts with naturally occurring organic matter in water to form potentially toxic chemical compounds, known collectively as disinfection by-products (International Agency for Research on Cancer 2004).

The quality and pollution level of water are generally measured in terms of concentration or load – the rate of occurrence of a substance in an aqueous solution. BOD (biochemical oxygen demand) measures the strength of an organic waste in terms of the amount of oxygen consumed (by the microorganism in water) in breaking it down. This is a standard water treatment test for the presence of organic pollutants. Moreover, the number of physical and chemical parameters (which defines the water quality), such as pH, DO (dissolved solids), total solids, and inorganic trace elements that also need to be monitored for proper assessment of water quality, is quite large.

Industrial activities are also an important source of water pollution. For example, paper and pulp mills consume large volumes of water and discharge liquid and solid waste products into the environment. This liquid waste is usually high in biological oxygen demand, suspended solids, and chlorinated organic compounds such as dioxins (World Bank 1999). The storage and transport of the resulting solid waste (wastewater treatment sludge, lime sludge, and ash) may also contaminate surface waters. Similarly, sugar mills emit effluent characterized by BOD and SS, and the effluent is high in ammonium content. Sugarcane rinse liquid may also contain pesticide residues. Leather tanneries, on the other hand, generate a significant amount of solid waste, including hide, hair, and sludge, while their wastewater contains chromium, acids, sulfides, and chlorides. Textile and dye industries are also associated with liquid effluent that contains toxic residues from the cleaning of equipment, and waste from petrochemical manufacturing plants contains suspended solids, oils and grease, phenols, and benzene (World Bank 1999).

Mining is another major source of industrial water pollution. The grinding of ores and the subsequent processing with water discharge fine silt with toxic metals into waterways. Lead and zinc ores usually contain the much more toxic cadmium as a minor component. If the cadmium is not retrieved, major water pollution can occur. Other metals, such as copper, nickel, and chromium, are considered essential micronutrients but in high levels can be harmful to health. The presence of copper in water can also arise due to corrosion of drinking water pipes. High levels of copper may make water appear bluish green and give it a metallic taste. Flushing the first water out of the tap can minimize exposure to copper. Similarly, the use of lead pipes and plumbing fixtures may result in high levels of lead in piped water (Kjellstrom et al. 2006).

Mercury can enter waterways from mining and industrial premises. Incineration of medical waste containing broken medical equipment is also a source of environmental contamination with mercury as it is easily transported through the atmosphere due to its highly volatile nature. Furthermore, sulfate-reducing bacteria and certain other microorganisms in lake, river, or coastal underwater sediments can methylate mercury, increasing its toxicity (Murata et al. 2004).

The above discussion shows how the environmental externality is created due to the use of water resource in various economic activities. These externalities have also some impact on health.

1.2.1 Health Effects

Waterborne pollutants kill millions of people worldwide every year, and yet, no published estimates are available of the global burden of disease resulting from the overall effects of chemical pollutants in water (Kjellstrom et al. 2006). The burden in specific local areas may be large, such as arsenic in drinking water in Bangladesh. Other examples include the nervous system diseases of methylmercury poisoning (Minamata disease), the kidney and bone diseases of chronic cadmium poisoning (Itai-itai disease), and the circulatory system diseases of nitrate exposure (methemoglobinemia) and lead exposure (anemia and hypertension) (Murata et al. 2004).

Acute exposure to contaminants in drinking water can cause irritation or inflammation of the eyes and nose, skin, and gastrointestinal system. These adverse health effects are due to chronic exposure (e.g., liver toxicity) to copper, arsenic, or chromium in drinking water. Excretion of chemicals affects kidney through toxic effects such as cadmium, copper, mercury, and chlorobenzene (WHO 2003).

Furthermore, pesticides and other chemical contaminants that enter waterways through agricultural runoff, storm water drains, and industrial discharges may persist in the environment for long periods and be transported by water over long distances. They may disrupt the function of the endocrine system, resulting in reproductive, developmental, and behavioral problems. The endocrine disruptors can reduce fertility and increase the occurrence of stillbirths, birth defects, and hormonally dependent cancers such as breast, testicular, and prostate cancers(WHO 2003).

In addition, solid waste generated by petrochemical processes contains spent caustic and other hazardous chemicals implicated in cancer. Methylmercury accumulates and concentrates in the food chain and can lead to serious neurological disease or more subtle functional damage to the nervous system (Murata et al. 2004). The effects on the developing nervous system can include impaired mental and psychomotor development, as well as cognitive impairment and behavior abnormalities (WHO and International Programme on Chemical Safety 2002). Chemicals in drinking water can also be carcinogenic where disinfectant by-products and arsenic have been a particular concern (International Agency for Research on Cancer 2004).

1.3 Water Pollution in India

Increased population, rapid industrialization, and unplanned urban growth in India are resulting in the generation and discharge of large quantities of wastewater into existing water bodies.

India's 14 major, 55 minor, and several hundred small rivers receive millions of liters of sewage, industrial, and agricultural wastes. The most polluting source for rivers is the city sewage and industrial waste discharge. Presently, only about 10 %

of the wastewater generated is treated; the rest is discharged as it is into our water bodies. Due to this, pollutants enter rivers, lakes, and groundwaters (CAG 2011).

A significant number of industries (livestock, oil refineries, coal and lignite, chemical, distilleries, man-made fiber, paints and dye, leather, textiles, paper, fertilizers, milk and milk products) in India are producing water pollution several times above MINAS (minimum national standard) approved by the Pollution Control Board of India. Agricultural runoff, or the water from the fields that drains into rivers, is another major water pollutant as it contains fertilizers and pesticides. Groundwater accounts for nearly 80 % of the rural domestic water needs and 50 % of the urban water needs in India. It is generally less susceptible to contamination and pollution when compared to surface water bodies.

Furthermore, India has an inadequate treatment of infrastructure. Only 26.8 % of domestic and 60 % of industrial wastewater are treated in India. Sometimes the use of untreated wastewater for irrigation leads to the reduction in agricultural production (e.g., in Hyderabad, wastewater drawn from the river Musi for irrigation has reduced rice output by 40–50 %).[1]

Discharge of untreated wastewater is leading to increased pollution and depletion of clean water resources. This polluted water, which ultimately ends up in our households, is often highly contaminated and carries disease-causing microbes. Health costs incurred owing to water pollution are extremely heavy and sometimes fatal. Water pollution causes many deaths in India every year. The single largest cause of ill health and death among children is diarrhea, which kills nearly half a million children each year in India (WHO and UNICEF 2000). Lack of water, sanitation, and hygiene results in the loss of 0.4 million lives annually in India (WHO 2007). Environmental factors contribute to 60 years of ill health per 1,000 population in India compared to 54 in Russia, 37 in Brazil, and 34 in China. The socioeconomic costs of water pollution are extremely high: 1.5 million children under 5 years die each year due to water-related diseases, 200 million person days of work are lost each year, and the country loses about Rs. 366 billion each year due to water-related diseases (Parikh 2004).

McKenzie and Ray (2004) also observe similar effects of water pollution; however, the magnitude of the effect was modest. The study shows that India loses 90 million days a year due to waterborne diseases with production losses and treatment costs worth Rs. 6 billion. Poor water quality, sanitation, and hygiene result in the loss of 30.5 million disabilities adjusted life years (DALY) in India. Groundwater resources in vast tracts of India are contaminated with fluoride and arsenic. Fluoride problems exist in 150 districts in 17 states in the country, with Orissa and Rajasthan being the most severely affected. High concentration of fluoride in drinking water causes fluorosis resulting in weak bones, weak teeth, and anemia. The presence of arsenic, a poison and a carcinogen, in the groundwater

[1] "Sustainable Technology Options for Reuse of Wastewater," Central Pollution Control Board; "Wastewater Management and Reuse for Agriculture and Aquaculture in India," CSE Conference on Health and Environment 2006.

of the Gangetic delta causes health risks to 35–70 million people in West Bengal and Bihar.

The above analysis presents the water pollution problem and its effect in India. However, water pollution has not been adequately addressed in any policy in India, both at the central and at the state levels. In the absence of a specific water pollution policy which would also incorporate prevention of pollution, treatment of polluted water, and ecological restoration of polluted water bodies, efforts made by the government in these areas would not get the required emphasis and thrust (CAG 2011).

1.4 Water Resources of India

India is rich in water resources, being endowed with a network of rivers and vast alluvial basins to hold groundwater. Besides, India is blessed with snow cover in the Himalayan range which can meet a variety of water requirement of the country. However, with the rapid increase in population and the need to meet the increasing demands for irrigation, human, and industrial consumption, the available water resources in many parts of the country are getting depleted and the water quality has deteriorated. Traditionally, India has been well endowed with large freshwater reserves, but the increasing population and overexploitation of surface and groundwater over the past few decades have resulted in water scarcity in some regions.

1.4.1 Water Resources: Availability and Consumption in India

Water resources can be classified into two broad categories, namely, groundwater resource and surface water resource. The precipitation which does not infiltrate into the ground forms surface water, while deep percolation of water through soil strata eventually becomes a part of groundwater.

India accounts for approximately 2.4 % of land area and 4 % of the water resources of the world but 16 % of the world population (Kaur et al. 2012). It is difficult to prepare an accurate national picture of India's water resources because accurate field data is almost nonexistent. However, the data which are available have been put together and discussed. The main water resource of India consists of the precipitation on the Indian Territory which is estimated to be around 4,000 km^3/year and transboundary flows which it receives in its rivers and aquifers from the upper riparian countries. For the latter, however, no ready quantitative estimate is available.

Out of the total precipitation, including snowfall, the availability from surface water and replenishable groundwater is estimated as 1,869 km^3. Due to various

Table 1.1 Water resources of India

Estimated annual precipitation (including snowfall)	4,000 km^3
Average annual natural flow in rivers and aquifers	1,869 km^3
Estimated utilizable water	1,123 km^3
1. Surface	690 km^3
2. Ground	433 km^3
Water demand = utilization (for the year 2000)	634 km^{3a}/813 km^{3b}/724 km^{3c}
1. Domestic	42 km^{3a}/56 km^{3b}/49 km^{3c}
2. Irrigation	541 km^{3a}/688 km^{3b}/615 km^{3c}
3. Industry, energy, and others	51 km^{3a}/69 km^{3b}/60 km^{3c}

Source: CWC (2010)
[a]Indicates the data for 2000
[b]Refers the data for 2010
[c]Authors' estimates for the year 2006–2007 from the figure of 2000 and 2010

constraints of topography and uneven distribution of resource over space and time, the total utilizable water resource in the country has been estimated to be about 1,123 bcm (690 from surface water and 433 from groundwater resources). This is just 28 % of the water derived from precipitation. Table 1.1 shows the water resources of the country at a glance. It appears from Table 1.1 that water consumption is only 634 km^3 for the year 2000, while for 2010, it increased to 813 km^3 by different sectors of India.

Precipitation over a large part of India is concentrated in the monsoon season (during June, September, and October). Precipitation varies from 100 mm in the western part of Rajasthan to over 11,000 mm at Cherrapunji in Meghalaya (CWC 2010).

1.4.2 Freshwater Scenario in India

The growth of the Indian economy is driving increased water usage across sectors. Wastewater is increasing significantly, and in the absence of proper measures for treatment and management, existing freshwater reserves are being polluted. Increased urbanization is leading to an increase in per capita water consumption in towns and cities as consumption patterns change, with increased demand for water-intensive agricultural crops and industrial products.

Table 1.2 shows the distribution of the use of water by different sectors of India in the year 2006–2007. Agriculture is the major water-consuming sector in India, accounting for 70.09 %.

Table 1.2 Total water availability and consumption of water resources of India for the year 2006–2007 (figures in lakh rupees)

1. Total amount of water resource: 117032[a] + 2,594,660[b] = 3,701,692
2. Consumption of water resources by different sectors
Name of the sector (amount and percentage)
1. Agriculture + irrigation = 211 + 2,594,660 = 2,594,871 (70.09 %)
2. Industry = 514,559 (13.90 %)
3. Electricity = 22,099 (0.60 %)
4. Domestic = 570,163 (15.40 %)
Total = 3,701,692 (100 %)

Sources:
(1) CSO (2011), Input–Output Transaction Table 2006–2007
(2) "a" Input–Output Table (2006–2007)
(3) "b" Actual expenses of Annual Plan 2006–2007, CWC (2010)

1.4.2.1 Water Consumption in Indian Agriculture

India is one of the world's leading crop producers. Rice, wheat, and sugarcane together constitute more than 80 % of India's crop production and are the most water-consuming crops in recent years. India has the highest water footprints among the top rice- and wheat-producing countries.[2]

Wheat production in India has increased from 72.77 million tons in 2000–2001 to 86.87 million tons in 2010–2011, while rice production increased from 93 million tons in 2001–2002 to 95.98 in 2010–2011 and sugarcane production in India has also increased from 29 million tons to 342.38 million tons in 2010–2011 (GOI 2011). Over the years, this has led to an increase in water consumption in the agricultural sector. Consumption of water for irrigation is also rising, which may lead to the overexploitation of available resources. Virtual water consumed for the production of wheat, rice, and sugarcane has increased by 88 Tr liters over the period 2000–2008 – for wheat it increased by 4 Tr liters, for rice it increased by 18 Tr liters, and for sugarcane it increased by 66 Tr liters (Kumar and Jain 2007).

Increased disposable income and urbanization are changing consumption patterns towards more water-intensive products. India's annual domestic per capita consumption (kg) of water-intensive products like poultry meat, egg, cotton, and milk is increasing.

1.4.2.2 Water Consumption by Industries

Industrialization and infrastructure growth are accelerating water consumption and increased discharge of untreated wastewater.

[2] Water footprints of Nations: Water use by people as a function of their consumption pattern, water footprint network.

Steel- and electricity-dependent industries are expected to grow in the coming years. Investment in infrastructure development is increasing in India. The manufacturing sector grew at an average of around 8 % between 2000 and 2010. Thermal power plants, one of the most water-intensive industrial units, constituted more than 65 % of the installed power capacity in India during 2009–2010. Finished steel production in India has increased from 32.3 million tons in 2000–2001 to 59.69 million tons in 2009–2010. Electricity generation in India has increased from 499.5 to 796.3 billion Kwh from 2000–2001 to 2009–2010 (GOI 2010–2011). This industrial growth can explain the increased water consumption followed by increased wastewater generation from Indian industries.

Industrial wastewater discharge contributes to pollution and reduces available freshwater reserves. Increase in wastewater discharge is highest from the agriculture-based industries such as textiles, sugar, and fertilizer. Thermal power plants and steel plants also contribute to industrial wastewater discharge.

In a developing country like India, the link between water consumption and wastewater generation across sectors further complicates water management.

1.5 Overuse and Misuse of Water Resources

The wastage of water is large and overuse of water occurs in all activities. It is very difficult in India to get an estimated wastage of water for different activities. However, one study has estimated wastage of water in various consumptive uses (Briz – Kishore 1992). Accordingly, in domestic use such as drinking, bathing, cooking, washing, cleaning, and gardening, about 16–25 % of water is overused, while in industry and workshop about 20 %, commercial establishments 10 %, transportation including road-rail vehicle and air transport and storage 15–25 %, and public services like government offices, courts, police, etc., 10–25 %.

1.6 A Brief Literature Review

Literatures are not numerous. In this section, we shall make a brief review of the available literature. Several studies have been conducted on water pollution issues in the emerging economies in Southeast Asia. Muyibi et al. (2008) studied the impact of development activities on water pollution in Malaysia. The paper examines the trends of development-induced water pollution in the regions of the country and also indicates the problems and the policy measures taken by the government. It evaluates the probable causative relationship between problems introduced due to technology employed in water pollution control and governmental policy measures. It examines the relationship between development indicators as sources of pollution and polluted rivers over a period of 12 years. The findings of the paper have shown that despite the policy enforcement actions against the identified sources of water pollution, all development indicators still accounted for high percentage of river pollution in Malaysia. The study identified some key reasons for the high pollution. These are (a) the issue of interactive effects between pollutants that many policy makers are not aware of; (b) the financial constraints to invest in appropriate technology especially sewerage systems for controlling human source of water pollution in the country as well as those confronting small polluting industries; and finally (c) the lack of cooperation between government and private business firms to comply with regulatory policies for water pollution control.

Resosudarmo (2003) analyzed the data from global environmental monitoring activities and has shown the alarming environmental conditions in many developing countries. Environmental policies that could improve the environment significantly, while at the same time maintaining the growth of economic activities, are needed. Using an input–output analysis, this paper researches such policies with a view to applying them to Indonesia's river water pollution. The study reviews river water quality and current policies in Indonesia. It also develops future policies to control such pollution. Okadera et al. (2006) evaluate the structures of water demand and water pollutant discharge with socioeconomic activities in the city of Chongqing, the main city upstream of the Three Gorges Dam in China. The study developed a methodology for estimating water demand and water pollutants (carbon, nitrogen, and phosphorus) based on an inter-industry analysis model and then applied it to the city of Chongqing. The study concludes that industry is the largest source of water demand and water pollutants in the city of Chongqing. Water demand from agriculture, forestry, and livestock accounts for 35 % of the total, and about 20 % of water pollutants are discharged from agriculture, forestry, and livestock. Furthermore, water pollutants from households constitute more than 20 % of the total in the city of Chongqing. In addition, about 20 % of the water demand and water pollutant discharge in the city of Chongqing is caused by other provinces and foreign countries, with most of the demand and discharge being industrial.

Recently Kaur et al. (2012), Murty and Kumar (2011), and Barua and Hubacek (2009) have tried to focus on the problems of water pollution in India. Murty and Kumar (2011) provide an overview of the extent, impacts, and control of water pollution in India. They also identify the theoretical and policy issues involved in the abatement and avoidance of water pollution in India. Kaur et al.(2012) discussed the wastewater production treatment and use in India. The overall analysis of water resources indicates that in the coming years, there will be a twin-edged problem to deal with reduced freshwater availability and increased wastewater generation due to increased population and industrialization. They also argue that presently there are no separate regulations/guidelines for safe handling, transport, and disposal of wastewater in the country. The existing policies for regulating wastewater management are based on certain environmental laws and certain policies and legal provisions. In developing countries like India, the problems associated with wastewater reuse arise from its lack of treatment. The challenge thus, as pointed out by them, is to find such low-cost, low-technology, and user-friendly methods, which, on one hand, would avoid threatening substantial wastewater-dependent livelihoods and, on the other hand, protect degradation of valuable natural resources of our nation.

Barua and Hubacek (2009) attempted to explore the EKC relationship for water in India. The study contributes to the EKC debate by using per capita income and water quality indicators for 16 states of India along with a variety of relevant explanatory variables. Using a panel dataset for 20 years (1981–2001), they apply both the generalized least square (GLS) and Arellano-Bond generalized method of moments (GMM A-B). They found no evidence in support of the EKC hypothesis. Population density, livestock population, and literacy are found to have strong effects on the water quality of the rivers of India.

There are a large number of literatures on treatment method for removal of various water pollutant parameters. Vasudevan et al. (2012) reveal the performance of CETP (common effluent treatment plant) for tannery effluent in terms of BOD, COD, TSS, TDS, and by water tracer studies using Rhodamine. CETP showed a removal efficiency of BOD, 66 %; COD, 21 %; TSS, 21 %; and TDS, 5 %. The study suggests that CETP has to be redesigned based on the characteristics of influent wastewater in order to meet the Pollution Control Board prescribed standard limits for CETP. Banu et al. (2007) treat dairy wastewater entirely via anaerobic treatment over a period of 215 days. They used two-stage hybrid upflow anaerobic sludge blanket (HUASB) reactors, which offer the advantages associated both with fixed film and upflow sludge blanket treatments. The two-stage reactor was operated at an organic loading rate that varied from 10.7 to 21.4 kg COD m^3/day for a period of 215 days, including the start-up period. The ideal organic loading rate for the two-stage reactor was 19.2 kg COD/m^3/day. Combined COD removal during the stable operation period (10.7–19.2 kg COD m^3/day) occurred in a range between 97 and 99 %. The two-stage anaerobic treatment using HUASB with PUF and PVC is expected to constitute a better alternative for the complete treatment of dairy wastewater than high-rate anaerobic, anaerobic/aerobic, and two-phase anaerobic treatment methods.

Several studies dealt with the abatement cost of water pollution as well as the impact of fiscal policies on water pollution in India. We review some of them. Rossi et al. (1979), Fraas and Munley (1984), Subrahmanyam (1990), Mehta et al. (1993), James and Murty (1999), Mehta et al. (1997), Roy and Ganguli (1997), Goldar and Panday (1997), Goldar and Mukherjee (1998), Misra (1998), and Pandey (1997) have dealt with the cost of pollution abatement for industries in India in which the cost behavior has been analyzed with the help of an estimated abatement cost function. Some of these studies used Cobb–Douglas functions in their analysis, while others have made an attempt to use the transcendental logarithmic (translog) functional form.

Engineering analysis of wastewater treatment systems suggests that the principal determinants of abatement cost are the volume of wastewater stream and the concentration of pollutants in the effluent stream (Frass and Munley 1984; Subrahmanyam 1990). Subrahmanyam's study provides information about production process and wastewater treatment alternatives in the Indian paper and pulp industry. The study by James and Murty (1999) has estimated marginal abatement cost using plant-level data of 82 firms drawn from 17 major polluting industries identified by the Central Pollution Control Board (CPCB) of India. This study has used the ratio of influent and effluent concentrations in the cost function. Pandey (1997) has made an attempt to estimate abatement costs by analyzing plant-level data on costs of water pollution abatement in sugar industry for 53 firms using the Cobb–Douglas functional forms. The analysis points out the loophole in the existing legislation (MINAS) and suggests the pricing of water be rationalized. Further, pollution tax would require periodic revision based on consideration such as firms, response, and inflation advent of new technology. Also, as pollution-causing activity rises and source-specific standards are more stringent in order to maintain the same ambient standards, pollution tax will have to be revised from time to time. A study by Roy and Ganguli (1997) attempts to evaluate the efficiency of the standards for controlling BOD and COD effluents to maintain water quality of large pulp and paper mill. Using secondary data on water pollution audit by BICP for large pulp and paper mills, they have estimated the marginal cost of abatement curves of BOD-5 and COD of different firms. An engineering cost function has been used. The focus of Goldar and Mukherjee's (1998) paper is on methodological and estimation issues for water pollution abatement cost function. They have also suggested an alternative approach to specifying the production function for abatement activity that avoids all these problems.

The study by Misra (1998) provides empirical evidence on economies of scale in water pollution abatement activity at Nandesari Industrial Estate comprising 250 small-scale factories. The study shows that the cost burden of water pollution abatement is much higher for small factories providing greater cost advantage to treat effluents jointly in a common effluent treatment plant (CETP).

Dasgupta and Murty (1985) explore some problems related to the control of external diseconomies (damages) inflicted on water resources by various developmental activities. Their study has shown that paper and pulp industry in India contributes significant environmental pollution which requires additional resources to abate it. Estimates of costs of water pollution abatement for big and small paper mills show that the comparative capital and operation costs per ton of paper for the small paper mill is more than double that for the big mill. Pollution abatement costs for big and small paper mills at shadow prices are significantly higher than those at market prices. James and Murty (1999) have suggested the use of incentives-based policies as the most efficient technique for the control of environmental pollution.

Recently Tare et al. (2012) present a comparative assessment of the cost and quality of treatment of tannery wastewater in India by two CETPs constructed for two tannery clusters, at Jajmau and Unnao in Uttar Pradesh, India. The Jajmau plant is upflow anaerobic sludge blanket (UASB) process based, while the Unnao plant is activated sludge process (ASP) based. Investigations indicated that the ASP-based plant was superior in all respects. Total annualized costs, including capital and operation and maintenance costs, for the UASB and ASP plants were Rs. 4.24 million/million liters per day (MLD) and Rs. 3.36 million/MLD, respectively. The results of this study do not support the conventional view of the superiority of anaerobic processes for tannery wastewater treatment in tropical developing countries like India.

An economy consists of a large number of industries. These industries do not exist in isolation from each other, rather are interdependent. This interdependence arises from the fact that the output of an industry is generally required as an input by another industry. Though some industries do not produce pollution directly, they produce pollution indirectly in a very significant way. Only limited numbers of industries in India have been compelled to minimize the generation of pollution. Even if a single industry, for example, the chemical industry, tries to control the pollution it generates, production cost is bound to increase. Such an increase in production cost will affect the market price of the product of chemical industries. Since the product of this industry is used by other industries, they will also be impacted. In this way, the prices of all the sectors will also be affected. Thus, pollution control schemes will also influence the demand for output of different products which are used as inputs.

However, quantitative analysis involving interdependence between water pollution and all branches of production and consumption of an economy is few. In this respect, we can refer the work of Sanchez-Choliz and Duarte (2005) who discuss the relationships between production processes and water pollution based on the recent Satellite Water Accounts (SWA) and the 1997 input–output table for the Spanish economy. The study focuses on four pollutants (BOD, metals, nitrogen, and phosphorus) and seven sector blocks. They have identified the roles of the various sectors as generators and consumers of each type of pollution. Furthermore, they examined how pollution responds to changes in the unit coefficients of pollution and final demand patterns to obtain the shadow prices for the different pollutants. The results obtained provide a sound basis for the design of improvements in environmental policy.

Maiti and Chakraborty (1999) and Chakraborty et al. (2001) have contributed to this field for India. They have studied different types of water pollutant generated directly and indirectly in different industries. In addition, they have also analyzed the effect of pollution control cost on the economy. This study makes an attempt in that direction.

1.7 Objective

The objective of the book is to:

(a) Evaluate the status of water pollution in developed and developing Asia
(b) Estimate the total amount of water pollution generation directly and indirectly from different sectors/activities of India
(c) Study the effect of pollution abatement scheme on the output and prices of different goods and services and also on the final consumers of the Indian economy

(d) Estimate the water pollution content in India's foreign trade sector
(e) Account for defensive expenditure arising from water pollution and also estimate Green GDP
(f) Assess the different case studies focused on water pollution-intensive industries in India
(g) Suggest a portfolio of policies and also assess the implications of such policies on pollution generation in India

1.8 Arrangement of the Chapters

This chapter provides a discussion on the link between environment and development. It covers the problem of water pollution and development. A brief review of literatures primarily focusing on water pollution, its effect, on quality indices and wastewater treatment is also presented.

Chapter 2 describes the status of water pollution in different countries of Asia including India. What are the major sources of water pollution and impacts in these countries? It also reviews the measures/acts/policies adopted and implemented so far by the respective governments.

Chapter 3 formulates the model based on input–output framework. A pollution model is developed to capture the generation of water pollution from different industrial activities. It estimates both direct and indirect water pollution content of different economic activities. The model is further extended to incorporate pollution abatement cost and its impacts on output and prices of the economy.

Chapter 4 provides the data from various sources and discusses the processing of data.

Experiments with the models and discussion on the results are presented in Chap. 5. This chapter analyzes the results on direct and indirect water pollution requirement, water pollution content of the total final demand of different sectors of India, and effects of pollution abatement costs on output and prices of different goods and services.

With economic reform and ambitious export policies, the Indian economy is now expanding and diversifying its exports. This might have some implications on generation of water pollution. This is the focus of Chap. 6 which measures the water pollution content in trade.

Certain policy simulation exercises on the basis of alternative pollution control schemes are carried out in Chap. 7. It suggests some policies and also evaluates the implications of such policies on pollution generation as well as output and prices.

Chapter 8 calculates the green GDP considering the defensive expenditure arising from water pollution in economic activity. It measures green GDP of India to find out the Environmentally Adjusted National Income Accounts for the study period. It also estimates the impacts of different policy simulation exercises as carried out in Chap. 7 on green GDP measure.

Chapter 9 reviews a number of case studies on various industries conducted across different states in India.

Chapter 10 summarizes and concludes the study.

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Chapter 2
Status of Water Pollution in India and Other Countries of Asia

2.1 Introduction

During the last 50 years or more, increasing population, industrialization, and agricultural development have profoundly impacted on natural ecosystems and water quality (Khan and Hanjra 2009; Park et al. 2010).

Water resources are coming under intense pressure in Asia. The Asia Pacific region has the highest annual water withdrawal and return flows among the world's regions due to its geographic size, population, and extensive and intensive irrigation practices. More than half of global irrigation is taking place in Asia and results in a high level of agrochemical consumption, which is nonpoint source pollution. Another form of nonpoint source pollution comes from the topography of the region, resulting in high sediment loads (Evans et al. 2012).

The domestic pollution problems are a factor not only of the wastewater generated but also of inadequate treatment and management measures. The volume of wastewater generated annually across Asia is nearly 144 km^3, of which 37 % is generated in China, 27 % in South Asia, 20 % in Japan, 6 % in Southeast Asia, and 3 % in Central Asia (AQUASTAT 2011; Evans et al. 2012). Only an estimated 33–35 % of all wastewater in Asia is treated, with the lowest treatment rates in South Asia (7 %) and Southeast Asia (14 %) (Table 2.1).

Increasing water pollution from accelerating domestic, industrial, and agricultural activities is a major issue for nearly all Asian developing countries.

Table 2.2 gives an overview of the level of BOD pollutions among the developing countries in Asia. China, as the largest economy among the regions observed, reported the most pollution, at 8.82 million kg/day in 2006, eclipsing BOD emissions from the other regions. This is compared to a combined total BOD emission of 1.96 million kg/day from Indonesia, Thailand, and Vietnam, the major polluting countries in the Southeast Asian region. These levels were not surprising when viewed in context of the countries' GDP, as in 2006, China's GDP was about 4.6 times of that of the three countries combined.

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Table 2.1 Wastewater generation and treatment in Asia

Country	Wastewater generated		Wastewater treated	
	Reporting year	Volume (km^3 year^{-1})	Reporting year	Volume (km^3 year^{-1})
Bangladesh	2000	0.725	–	n/a
Bhutan	2000	0.004	–	n/a
Cambodia	2000	1.184	1994	0.0002
China	2006	53.700	2004	22.100
India	1996	25.410	2004	2.555
Japan	2007	28.500	2008	14.250
Laos	2000	0.546	–	n/a
Malaysia	1995	2.690	1995	0.398
Maldives	2000	0.004	–	NA
Mongolia	2002	0.126	2002	0.083
Myanmar	2000	0.017	–	n/a
Nepal	2006	0.135	2006	0.006
Pakistan	2000	12.330	2000	0.145
Philippines	1993	0.074	1993	0.010
Republic of Korea	1996	7.947	1996	4.180
Singapore	2000	0.470	–	n/a
Sri Lanka	2000	0.950	–	n/a
Thailand	2007	2.191	2007	0.523
Viet Nam	2003	1.100	2003	0.250
Kazakhstan	1993	1.833	1993	0.274
Kyrgyzstan	2006	0.701	2006	0.148
Tajikistan	1999	0.026	1998	0.061
Turkmenistan	2000	1.181	1994	0.025
Uzbekistan	2001	2.200	2001	2.069

Source: Evans et al. (2012)
Note: – indicates that data are not available for that year

Most of the countries also reported a significant growth in BOD pollution that seemed to accompany economic development in the region. This is especially true for Thailand and Vietnam which saw their BOD emissions increased by 86.5 % and 254.9 %, respectively, from 1998 to 2006. This is alarming since GDP grew at a much slower rate in these two countries over the same period. Between 1998 and 2006, GDP in Thailand and Vietnam only grew by 47.5 and 73.9 %.

The situation is even more serious and complex with the inclusion of industrial wastewater discharges. These receive mostly inadequate treatment in nearly all Asian developing countries. Few Asian urban centers have functional secondary and tertiary waste treatment plants. Many primary waste treatment plants are nonfunctional for significant periods of time because of poor design, inadequate management, poor infrastructure facilities, and lack of public awareness. Most of these plants operate with low efficiency. Since the domestic wastes are primarily organic, they degrade over a limited time. However, the situation is more complex

Table 2.2 BOD emissions in selected developing countries in Asia (kg/day)

	1998	2003	2006
Bangladesh	303,022	N/A	N/A
China	N/A	7,066,070	8,823,750
Indonesia	721,774	731,009	882,985
Malaysia	N/A	181,715	208,312
Pakistan	N/A	N/A	153,680
Philippines	179,901	143,262	N/A
Sri Lanka	N/A	N/A	266,109
Thailand	311,822	N/A	581,425
Vietnam	141,036	399,522	500,482

Source: WDI (2012)

and serious for industrial wastes, because they contain significant amounts of conservative elements. These elements may be toxic to human beings and ecosystems and are not easily biodegradable.

With rapid industrial and urban growth, environmentally sound wastewater disposal in all Asian developing countries is increasingly becoming a serious social and human health issue. Surface water and groundwater sources for urban centers are being contaminated with domestic and industrial wastes and require higher levels of treatment before they can be used safely as potable water. However, the treatment processes need sophisticated technologies which are too expensive for most of the developing countries. In practice, collection and disposal are done in nearby rivers, lakes, and water bodies within and around urban centers. This leads to contamination of the water bodies. Land disposal of wastewater is also contaminating groundwater, which is often an important source of drinking water. These are considered to be point sources of contamination from domestic and industrial users. However, nonpoint sources cannot be ignored because the use of agricultural chemicals is likely to increase in the future for improving crop production to enhance both farmers' incomes and food security. This will further aggravate the water quality situation because control and management of nonpoint sources of pollution are very complex and difficult tasks as experienced by even the most developed countries like Japan and the United States (ADB 2007).

In a macro sense, one major challenge facing Asian developing countries is how quickly and efficiently current wastewater management practices and processes can be substantially improved. Considering the cost of construction and efficient operation of wastewater management systems together with the lack of trained and skilled personnel needed to manage them – this problem is likely to continue in the foreseeable future (ADB 2007). Thus, over the years, water pollution has emerged as a major issue. South Asia – particularly India – and Southeast Asia are facing severe water pollution problems. Rivers such as the Yellow (China), Ganges (India), and Amu and Syr Darya (Central Asia) top the list of the world's most polluted rivers (World Commission on Water 1999). Most water bodies in cities in the developing countries of the region are now heavily polluted with domestic sewage, industrial effluents, chemicals, and solid wastes.

Water pollution has affected human health adversely. In the Pacific Islands, especially in some communities, the use of polluted groundwater for drinking and cooking has led to health problems such as diarrhea, hepatitis, and occasional outbreaks of typhoid and cholera. Groundwater in districts of West Bengal, India, and in some villages in Bangladesh, for example, is contaminated with arsenic at levels as much as 70 times higher than the national drinking water standard of 0.05 mg/L (UNEP 2002).

During the past decade, several countries have started to address their water quality problem by implementing large-scale programs and action plans to rehabilitate degraded streams and depleted aquifers. These programs are given legislative or statutory authority such as that provided by Thailand's National Water Quality Act, the Philippine Water Quality Code, India's Environment Protection Act, China's Water Law, and the Republic of Korea's Water Quality Preservation Act (UNESCAP 1999). Success has been achieved where water policies adopted a multisectoral and multidisciplinary approach to the management of water resources.

2.1.1 Agricultural Pollution

Agriculture is the major contributor of nonpoint source pollution of surface water and groundwater worldwide (Chhabra et al. 2010). Fertilizers are a major pollutant. Due to the increased use of fertilizer, rice-producing and vegetable-cultivating areas have the most impact of groundwater quality (Chowdary et al. 2005). The excessive use of fertilizers, herbicides, pesticides, and defoliants and the resulting water quality degradation are responsible for health problems (ESCAP 2000). While some countries in the region are trying to reduce fertilizer use, others, including India, Pakistan, Sri Lanka, and Bangladesh, are increasing its use and this will likely aggravate the nonpoint source pollution in those countries (ESCAP 2005).

2.1.2 Industrial Pollution

Many Asian countries have undergone a structural change from agriculture to a more industry-based economy. More than 20 % of the total GDP is coming from industrial activity (ESCAP 2005). For example, food and beverages, electrical equipment, cement, metals, chemicals, plastic and rubber products, and textiles have expanded their production activity extensively. Table 2.3 lists sectoral shares of BOD in selected countries in Asia.

A breakdown of the sources of BOD emissions in the developing countries in Asia showed that in the majority of them, the largest contributor of BOD emission is the textile industry followed by the food industry. The former is especially

Table 2.3 Sectoral share of BOD emissions in selected countries in 2006 (%)

	Chemical industry	Clay and glass industry	Food industry	Metal industry	Other industry	Paper and pulp industry	Textile industry	Wood industry
China	13	6.5	7.4	7.2	38.7	4.1	21.4	1.7
Indonesia	12	4	23.1	1.4	19.9	4.1	29.2	6.3
Malaysia	16.5	3.8	9.1	2.8	48.5	4.9	6.6	7.8
Pakistan	9.1	4.3	15.1	2.2	11.2	1.9	55.6	0.4
Sri Lanka	9	6.3	22.4	2.6	9.3	4.3	43.6	2.5
Thailand	12.4	4.7	16.4	1.9	37.2	4.2	20.5	2.8
Vietnam	6.8	6.7	13.3	1.4	24.7	3.5	40.3	3.3
Bangladesh[a]	3.5	0.1	34.2	2.8	1.1	6.8	50.9	0.6
Iran[a]	8	0.5	39.7	20.6	5.4	8	17.3	0.7
Nepal[a]	3.9	1.2	43.3	1.5	1	8.1	39.3	1.7
India[a]	8.2	0.2	51.5	15.5	5.2	7.5	11.6	0.3

Source: WDI (2012)
[a]ESCAP (2000) cited in Evans et al. (2012)

important in the case of India because textile is one of the major export industries in the country.

Although environmental awareness in the industrial sector has increased, enforcement of regulations is difficult and pollution continues to rise as the region is dominated by small- and medium-scale industries. There is a wide variation between pollutants and across the region.

2.2 Status of Water Pollution in India

According to the Ministry of Water Resources (MOWR), the Government of India (MoEF 2009), almost 70 % of India's surface water resources and a growing percentage of its groundwater reserves are contaminated by biological, toxic, organic, and inorganic pollutants. In many cases, these sources have been rendered unsafe for human consumption as well as for other activities, such as irrigation and industrial needs.

Industrial, agricultural, and domestic activities contribute in terms of overall impact on water quality. Besides, a rapidly depleting groundwater table in different parts of the country results in groundwater contamination – affecting as many as 19 states. Geogenic contaminants, including salinity, iron, fluoride, and arsenic, have affected groundwater in over 200 districts and spread across 19 states in India (Murty and Kumar 2011).

The level of water pollution in the country can be gauged by the status of water quality. Water quality monitoring carried out by the Central Pollution Control Board (CPCB), particularly with respect to the indicator of oxygen-consuming substances (BOD) and pathogenic bacteria (total coliform and fecal coliform), shows a gradual degradation in water quality (CPCB 2009). The worrying aspect of poor water quality arises because of high levels of BOD. This might be due to the fact that discharge sources are not complying with the standards, or even after their compliance, their high quantity of discharge contributes to elevated levels of contaminants (Rajaram and Das 2008). However, the status of water quality cannot be adequately assessed as there is currently inadequate number of sampling stations to monitor basic parameters.

Another aspect of water pollution in India is the inadequate infrastructure, comprising monitoring stations and frequency of monitoring pollution. Monitoring is conducted for 62 parameters by the CPCB at 1,700 stations; under a Global Environment Monitoring System (GEMS) and Monitoring of Indian National Aquatic Resources (MINARS) programs, there has been a significant increase from the 18 locations when monitoring started in 1977 (CPCB 2009). The results for 2009 indicate that organic pollution continues to dominate. Almost 36 % of the observations have BOD level of more than the standard for bathing water of 3 mg/L, 19 % between 3 and 6 mg/L, and 17 % above 6 mg/L, with 6 of the 50 rivers exceeding 100 mg/L. The desired total coliform (TC) standard for bathing water is 500 MPN/100 million liter, which is exceeded in 51 % of sample sites. Fecal coliform (FC) counts also exceed this figure in 30 % of sites (CPCB 2010). This represents a slight improvement since 1995. Progress has been made in wastewater collection. This is an important step but does not necessarily result in treatment and does not translate into “clean” rivers. Observations from 1995 to 2009 suggest only a slight decline in overall water quality in Indian rivers (CPCB 2010).

CPCB (2009) also reports the frequency of monitoring in the country. It is observed that 32 % of the stations have frequency of monitoring on a monthly basis, 28.82 % on a half-yearly basis, and 38.64 % on a quarterly basis. This indicates the need for increasing the frequency of monitoring. The water quality monitoring results obtained by the CPCB during 1995 to 2009 indicate that organic and bacterial contamination was critical in the water bodies. The main cause for such contamination is the discharge of domestic and industrial wastewater in water bodies mostly in an untreated form. Secondly, the receiving water bodies also do not have adequate water flow for dilution. Therefore, the biological oxygen demand and bacterial pollution are increasing. Household-borne effluents contribute a substantial proportion of water pollution in India for both surface and groundwater sources as about 70 % of them are disposed off into the environment untreated.

Agricultural runoffs affect groundwater and surface water sources as they contain pesticide and fertilizer residues. Fertilizers have an indirect adverse impact on water resources. Indeed, by increasing the nutritional content of water sources, fertilizers allow organisms that may be a disease vector or algae to multiply more. The proliferation of algae may slow the flow in watercourse, thus increasing the spread of organisms and sedimentation. The WHO has defined a permissible limit of concentration of nitrates of 45 mg/L of NO3, which is also accepted by the Indian Council of Medical Research (ICMR). In the agricultural sector, fertilizer use increased from 7.7 MT in 1984 to 13.4 MT in 1996 and pesticide use increased from 24 MT in 1971 to 85 MT in 1995 (Bhalla et al. 1999). It has been observed that in states, such as Haryana, the NO3 concentration has exceeded the permissible limits (Maria 2003). Water quality data suggest that agriculture is the largest polluter of water bodies in India (MoEF 2009). This is due to the increase in pesticide use, which grew by 750 % over the second half of the twentieth century, and fertilizer application, which rose from 70 kg/ha in 1991–1992 to 113 kg/ha in 2006–2007 (MoEF 2009).

Industry is a relatively small water consumer in India (3 % of annual water withdrawals), but its contribution to water pollution is considerable. As per the inventory of the CPCB (CPCB 2002–2003), there are about 8,432 large and medium industries in India. The Central and State Pollution Control Boards have identified 1,532 “grossly polluting” industries across the country (MoEF 2009). However, the number of small-scale polluting industries could not be ascertained because many of them are not registered. CPCB has estimated the pollution load. Their estimation is based on average generation of wastewater per unit of product, though it is difficult to estimate due to large variation in volume of wastewater generation per unit of product as explained by the CPCB.

It has been estimated by CPCB (2002–2003) that total wastewater generated from all major industrial sources is 82,446 MLD which includes 68,977 MLD of cooling water generated from thermal power plants. Out of the remaining 13,469 MLD of wastewater, thermal power plants generate another 3,242 MLD as boiler blow down water and wastewater from ash disposal. The data on wastewater generated in India in terms of process water and cooling water show that 16 % comes from process water and 84 % from cooling water. Share of industrial wastewater varies across industries. Process wastewater by different categories of industries shows that the steel industry has 8 %, engineering 32 %, thermal power plants 24 %, textile cotton 13 %, pulp and paper 14 %, and others 9 %. The shares of small-scale and large-scale industries in wastewater generation are 38 % and 62 %, respectively. Under the small-scale category, the significant polluting industries are electroplaters. The control of pollution from small-scale category is not very effective as many of them are located in congested residential areas where land is not available for treatment of wastewater.

From pollution point of view, the major polluter in terms of organic load is the distilleries, followed by paper mills. Since the distilleries generate very concentrated wastewater, it is difficult to treat them. Paper and board mills also generate heavy organic pollution load. A large number of paper mills are also in small-scale sector, making it difficult to manage the effluent. As a result, these mills can create heavy pollution in many areas.

The industries that generate chemical pollution can be divided into two categories: (a) those which generate high TDS bearing wastes such as pharmaceuticals, rayon fibers, chemicals, caustic soda, soap and detergents, smelters, etc., and (b) those which generate toxic wastes, for example, pesticides, smelters, inorganic chemicals, organic chemicals, steel plants, pharmaceuticals, and tanneries (CPCB 2002–2003).

Total dissolved solid loads are primarily generated from distilleries, followed by pharmaceuticals, sugar, and viscose rayon. Suspended solid comes mainly from thermal power plants, followed by cotton textile, paper, steel, tanneries, sugar, edible oil and vanaspati, dye and dye intermediates, pesticides, oil refinery, and paints and varnishes. Oil and grease loads generally originate from engineering, followed by edible oil and vanaspati, sugar, oil refineries, and paints and varnishes (CPCB 2002–2003).

For the small-scale industries, it is observed that polluting industries are mostly in engineering, textile, paper and paper board mills, pharmaceuticals, edible oil and vanaspati, dye and dye intermediates, soap and detergent, paints and varnishes, petrochemicals, organic chemicals, and tannery categories. Total volume of wastewater generation from small-scale industries amount to 5,084 MLD (CPCB 2002–2003).

Household-borne effluents contribute a substantial proportion of water pollution in India. A 2007 study finds that discharge of untreated sewage is the single most important cause for pollution of surface and groundwater in India. Nearly 12.47 million (18.5 %) households do not have access to a drainage network, while 26.83 million (39.8 %) households are connected to open drains. With respect to underground sewerage, the availability is 30 and 15 % in notified and non-notified slums, respectively (Sridhar and Kumar 2012).

2.2.1 Wastewater Production and Treatment

With rapid expansion of cities and domestic water supply, quantity of gray/wastewater is increasing in the same proportion. City corporations, municipalities, and panchayats having the responsibility of water supply and sanitation are supposed to treat the effluents as per the national water pollution standards or MINAS standards. However, a major portion of effluents, about 70 %, goes untreated. Table 2.4 provides the summary statistics of wastewater generation and treatment in Urban India in 2008. The wastewater generation was 38,254 million liters/day in 2008, out of which 26,467 million liters/day was untreated (CPCB 2008). Wastewater management plants in cities have a capacity of approximately 11,787.38 L/day. Delhi, the national capital, treats less than half of the 3,267 MM liters of wastewater it generates every day. As per the CPCB estimates, the total wastewater generation from Class I cities (498) and Class II (410) towns in the country is around 35,558 and 2,696 MLD, respectively. Class I treats only about 32 % of the wastewater generated in India in 2008. Maharashtra, Delhi, Uttar Pradesh, West Bengal, and Gujarat are the major contributors of wastewater (63 %; CPCB 2008; Kaur et al. 2012). Metropolitan cities treat about 52 % of their wastewater, but Delhi and Mumbai account for about 69 % of the treatment capacity of metropolitan cities, indicating that smaller towns and cities have very little wastewater treatment capacity.

Due to strict impositions of pollution control regulation and involvement of judiciary in implementing pollution control law and also NGO and public, a number of effluent treatment plants have been set up (CPCB 2002–2003). In this regard, the state of Gujarat and Karnataka had taken initiatives in the installation of pollution

Table 2.4 Wastewater treatment capacity in urban areas in India in 2008

Category	Number of cities	Total water supply (in MLD)	Wastewater generation (in MLD)	Treatment capacity (in MLD)
Class I city	498	44,769.09	35,558.12	11,553.68 (32 %)
Class II town	410	3,324.83	2,696.7	233.7 (8 %)
Total	908	48,093.88	38,254.82	11,787.38 (31 %)

Source: CPCB (2008)

Table 2.5 Status of pollution control and defaulters in highly polluting industries under the program of industrial pollution control in India

	Number of units identified	Units with adequate facilities to comply with standards, December 1995	Units with adequate facilities to comply with standards, December 2000	Defaulters, August 1997	Closed since	Acquired requisite treatment/ disposal facilities	Defaulters, December 2000
India	1,551	252	24	851	233	596	22

Source: Evans et al. (2012)

control system for large and medium industries. Since 1995, the situation has improved to some extent with an increase in the number of installations of pollution control systems resulting in significant reduction in pollution loads in many areas. However, the net result is not visible due to ever-increasing pollution loads (CPCB 2003). Table 2.5 presents the status of pollution control and defaulters in India.

2.2.2 Legislations and Policies for Water Pollution in India

Since the 1970s, there have been policy responses for the prevention and control of environmental degradation in India. There are several laws for water quality protection in India.

> Water (Prevention and Control of Pollution) Act was enacted in 1974 under article 252 of Constitution which provides power to the Parliament to legislate for two or more States by consent and adoption of such legislation by any other State. The Act provides for the prevention and control of water pollution and for the maintaining or restoring of wholesomeness of water in the country.
>
> To achieve this objective, the Act provided for establishing Boards at the Central and State level for the prevention and control of water pollution and conferred and assigned powers and functions relating this to these Boards. It lays down a system of consent whereby no industry or operator process or any treatment and disposal system can be established without the previous consent of the State Board. Similarly, no industry or process can discharge sewage or trade effluent into a stream or well or sewer or land in

> excess of the standards. Contravention of the provisions of this Act is punishable in monetary as well non-monetary terms.
>
> The Water (Prevention and Control of Pollution) Cess Act, 1977 provides for the levy of cess on use of water by various users of water i.e. industry and local authorities which are entrusted with duty of supplying of water under the law. This cess was meant to augment the funds required by State pollution Boards for their effective functioning in discharge of duties under the Water (Prevention and Control of Pollution) Act, 1974 (CAG 2011).

The Cess is collected by the State Government concerned and paid to the Central Government.

> Environment (Protection) Act, 1986 provides for the protection and improvement of environment and for matters connected there with. The definition of "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 (CAG 2011).

The Central Government has the power to take all such measures as it deems necessary or expedient for the purpose of protecting and improving the quality of the environment and preventing controlling and abating environmental pollution. Thus, MOEF has the responsibility of controlling water pollution under Environment (Protection) Act, 1986 (CAG 2011). The penalty provisions under various Acts relating to control and prevention of water pollution are documented in Table 2.6.

It should be reported that Water (Prevention and Control of Pollution) Act, 1974 was adopted by all the 25 states of India, and states pollution control board/committee were framed in these states (CAG 2011).

2.2.3 Policy Framework

Strong policy framework is an essential first step in effectively regulating water quality. With respect to policy formulation by the government, two policies were formulated: The National Water Policy 1987 and National Environment Policy 2006.

1. The National Water Policy was adopted in 1987 and was reviewed and updated by National Water Policy 2002 by the Ministry of Water Resources in 2002. This policy aimed at meeting the challenges that have emerged in the development and management of water resources, including water pollution.

   Some of the salient features of National Water Policy relating to water pollution are as follows:

   (a) Both surface water and groundwater should be regularly monitored for quality. A phased program should be undertaken for improvements in water quality.
   (b) Effluents should be treated to acceptable levels and standards before discharging them into natural streams.

Table 2.6 Penalty provisions

Name of the act/provision	The Water (Prevention and Control of Pollution) Act, 1974	The Water (Prevention and Control of Pollution) Cess Act, 1977	The Environment (Protection) Act, 1986
Provision relating to penalty	Failure to comply with provisions or for contravention of the provisions of the act and the rules, orders, and directions shall, in respect of each such failure or contravention, be punishable with	Failure to comply with provisions or for contravention of the provisions of the act and the rules, orders, and directions shall, in respect of each such failure or contravention, be punishable with	Failure to comply with provisions or for contravention of the provisions of the act and the rules, orders, and directions shall, in respect of each such failure or contravention, be punishable with
	Imprisonment for a term which may extend to 3 months to 6 years	Imprisonment which may extend to 6 months	Imprisonment for a term which may extend to 5/7 years
	Fine which may extend to 10,000 and in case failure continues, with an additional fine which may extend to 5,000 for every day during which such failure continues after the conviction for the first such failure	Fine which may extend to one thousand or with both	Fine which may extend to one lakh, continued failure or contravention, with additional fine which may extend to five thousand for every day during which such failure or contravention continues after the conviction for the first such failure or contravention
			Or with both

Source: CAG (2011)

(c) Principle of "polluter pays" should be followed in management of polluted water.
(d) Necessary legislation is to be made for the preservation of existing water bodies by preventing encroachment and deterioration of water quality.

2. National Environment Policy 2006 has outlined an action plan to address the water pollution. Some of the elements of the action plan are to:

(a) Develop and implement, initially on a pilot scale, public–private partnership models for setting up and operating effluent and sewage treatment plants.
(b) Prepare and implement action plans for major cities for addressing water pollution, comprising regulatory systems.
(c) Implement the projects through public agencies as well as public–private partnerships for treatment, reuse, and recycle of sewage and wastewater

from municipal and industrial sources, before final discharge to water bodies.

(d) Prevent pollution of water bodies from other sources, especially waste disposal on lands.

(e) Enhance capacities for spatial planning among the state and local governments, with adequate participation by local communities.

(f) Ensure clustering of polluting industries to facilitate setting up of common effluent treatment plants to be operated on cost recovery basis.

(g) Ensure that legal entity status is available for common effluent treatment plants to facilitate investments and enable enforcement of standards.

(h) Promote R&D in the development of low-cost technologies for sewage treatment at different scales.

(i) Take explicit account of groundwater pollution in pricing policies of agricultural inputs, especially pesticides, and dissemination of agronomy practices.

National Water Policy 2002 envisages that within a time-bound manner, states would frame and adopt state water policy. With respect to state water policy formulation, most of the states in India have framed water policy. Thus, to address water pollution is one of the thrust areas of national water and environmental policy.

2.3 Status of Water Pollution in Other Countries in Asia

This section briefly presents the status of water pollution across Asia. Due to paucity of information, we could only focus briefly on few countries.

2.3.1 Pakistan

Despite irrigation being the largest water consumption (96 % of total withdrawals), the pollution caused by agriculture, particularly in relation to fertilizer use, is marginal compared to industrial and domestic sources in Pakistan (Pak-EPA 2005). Industrial growth is putting considerable pressure on water resources (ADB 2008). Tanneries, food processing industries, pharmaceuticals, and textiles are all major contributors of pollutants, including high BOD levels, acids, ammonia, heavy metals, and hydrocarbons (Pak-EPA 2005). Despite legislation, only 5 % of national (compared with 91 % of multinational) industries provide environmental assessments, and many do not adhere to the permissible limits for pollution loads (Pak-EPA 2005). Only 1 % of wastewater is treated before being discharged into rivers and drains.

According to the National Environmental Quality Standard, the pollutant level in rivers, lakes, and groundwater in Pakistan is exceeding the standards since last decade. It has not experienced appreciable improvement in recent years (Pak-EPA 2005).

2.3.2 Bangladesh

Another country with major concerns about chemicals (arsenic) in water is Bangladesh. Estimates indicate that 28–35 million people of Bangladesh's population of 130 million are exposed to arsenic levels exceeding 50 μg/L, the prescribed limit for drinking water in Bangladesh (Kinniburgh and Smedley 2001). This number increases to 46–57 million if the WHO guideline level of 10 μg/L is used. The most common sign of arsenic poisoning in Bangladesh is skin lesions characterized by hyperkeratosis and melanosis.

The arsenic mitigation programs have applied various arsenic removal technologies, but the costs and benefits are not well established. Bangladesh has adopted a drinking water standard of 50 μg/L for arsenic in drinking water. The cost of achieving the lower WHO guideline value of 10 μg/L would be significant. An evaluation of the cost of lowering arsenic levels in drinking water predicts that a reduction from 50 to 10 μg/L would prevent a limited number of deaths from bladder and lung cancer at a cost of several million dollars per death prevented (Frost et al. 2002).

2.3.3 Sri Lanka

Water quality is a major issue in Sri Lanka. Pollution and waste dumping contaminate water supplies, leading to serious health impacts for nearby water users. In one of the country's most serious cases of water pollution, 300,000 people in Gampola were at risk when an epidemic of viral hepatitis broke out (Global Water Partnership 2011).

Industrial pollution is also an issue. The Maha Oya, one of Sri Lanka's largest rivers, was affected by factories discharging effluents, dyes, and chemicals into its waters. In the town of Alawa, many people suffered from skin diseases and other health issues due to contaminated water. GWP experts gave evidence to local authorities and provided data about the impacts of the pollution. In response, the authorities introduced regulations forcing the factories to treat the effluent. Now, 15,000 people have access to better quality water (Global Water Partnership 2011).

2.3.4 Malaysia

Water pollution in Malaysia originates from both point and nonpoint sources. Point sources that have been identified include sewage treatment plants, manufacturing, agro-based industries, and animal farms. Nonpoint sources are mainly diffused ones such as agricultural activities and surface runoffs. According to Malaysia Environment Quality Report 2004, the Department of Environment has recorded 17,991 water pollution point sources in 2004 comprising mainly sewage treatment plants (54 %), manufacturing industries (38 %), animal farms (5 %), and agro-based industries (3 %). Furthermore, according to the Department of Environment (DOE) of Malaysia, approximately 2,292 industries have been identified as significant water pollutant sources in Peninsular Malaysia. The major potentially polluting industries were 928 (40 %) food and beverage factories, 324 (14.1 %) rubber producing premises, and 270 (11.4 %) chemical producers. In terms of organic water pollution load, sewage and animal wastes were the major contributors of water pollution followed by manufacturing and agro-based industries in the country (WEPA 2011a).

Suspended solids, as an indicator of soil erosion that resulted in river siltation, continued to pose major environmental problems in the country's water resources. Soil erosion from construction sites has been excessive in Peninsular Malaysia. In 1998, 43 % of the total rivers monitored by DOE were polluted by ammoniacal nitrogen discharged from both sewage and animal husbandry wastes into the water resources. Suspended solid pollutants have accounted for 3.4–21 % by BOD from both agro-based and manufacturing industries (WEPA 2011a).

Between the year 2000 and 2004, the major contributors of water pollution were effluents from manufacturing industries with an estimate of 37.9 % and urban domestic sewage facilities, which amounted to 52.6 % of the total water pollutants in the country. The pollution loads contributed by these pollutants significantly affected the river quality. Analysis of manufacturing industries in 2000 showed that the food and beverage industry constituted 23.7 % of the total sources of industrial water pollution, while electrical and electronic industries accounted for 11.4 %. The chemical industry was found to contribute 11.2 % and the paper industry generated 8.8 % of the total pollution. The textile and finishing/electroplating industry accounted for 7.4 % and 5.3 % water pollution source, respectively. The effluents from palm oil and rubber factories generated into water resources amounted to 5.3 % and 2 %, respectively.

The Department of Environment (DOE) used Water Quality Index (WQI) to evaluate the status of the river water quality. The WQI serves as the basis for environment assessment of a watercourse in relation to pollution load categorization and designation of classes of beneficial uses as provided for under the National Water Quality Standards for Malaysia (NWQS). In 2006, a total of 1,064 water quality monitoring stations located within 146 river basins were monitored. Out of these 1,064 monitoring stations, 619 (58 %) were found to be clean, 359 (34 %) slightly polluted, and 86 (8 %) polluted. Stations located upstream were generally clean, while those downstream were either slightly polluted or polluted. In terms of river basin water quality, 80 river basins (55 %) were clean, 59 (40 %) slightly polluted, and 7 (5 %) were polluted. The major pollutants were biochemical oxygen demand (BOD), ammoniacal nitrogen (NH3-N), and suspended solids (SS). In 2006, 22 river basins were categorized as being polluted by BOD, 41 river basins by NH3-N, and 42 river basins by SS. High BOD was caused largely by untreated or partially treated sewage and discharges from agro-based and manufacturing industries. The main sources of NH3-N were domestic sewage and livestock farming, while the sources for SS were mostly earthworks and land-clearing activities (WEPA 2011a).

Analysis of heavy metals in 5,613 water samples revealed that almost all samples complied with Class III, National Water Quality Standards for arsenic (As), mercury (Hg), cadmium (Cd), chromium (Cr), lead (Pb), and zinc (Zn), except iron (Fe) with 83 % compliance. Intensified enforcement efforts and good environmental management practices could also have contributed to the water quality improvement (WEPA 2011a).

2.3.5 The Philippines

There are about 85,000 manufacturing industries in the Philippines, with Metro Manila as the prime industrial region accounting for about 52 % of the total manufacturing establishments. These establishments are classified into 30 major industrial groups. Food manufacturing constitutes the biggest number of manufacturing establishments in the country. Only 5 % of the total population is connected to a sewer network, while the vast majority uses flush toilets connected to septic tanks. Since sludge treatment and disposal facilities are rare, most effluents are discharged without treatment (World Bank 2005). According to the Asian Development Bank, the Pasig River is one of the world's most polluted rivers (ADB 2007). Over 36 % of the country's river systems are classified as sources of public water supply. It is found that up to 58 % of groundwater sampled is contaminated with coliform and it needs treatment (ADB 2007).

The main sources of organic water pollution are domestic and industrial sewage, effluent from palm oil mills, rubber factories, and animal husbandry. On the other hand, mining operations, housing and road development, logging, and clearing of forest are major causes of high concentration of suspended sediments in the rivers. In several urban and industrial areas, organic pollution of water has resulted in environmental problems and adversely affected aquatic life. In addition to organic wastes, rivers remain a convenient means of solid waste disposal. A major portion of household refuse, which is not collected, burnt, or buried, is thrown into drains and rivers.

Nearly 2.2 million metric tons of organic pollution are produced annually by domestic (48 %), agricultural (37 %), and industrial (15 %) sectors. In the four water-critical regions, water pollution is dominated by domestic and industrial sources. Untreated wastewater affects health by spreading disease-causing bacteria and viruses, makes water unfit for drinking and recreational use, threatens biodiversity, and deteriorates overall quality of life. The annual economic losses caused by water pollution are estimated at Php67 billion (US$1.3 billion). These include Php3 billion for health, Php17 billion for fisheries production, and Php47 for tourism (World Bank 2005). Despite the presence of many water-related laws in the Philippines, their enforcement is weak and beset with problems that include inadequate resources, poor database, and weak cooperation among different agencies and local government units (LGUs). In the last few years, the government has employed economic instruments such as pollution fines and environmental taxes. In addition, the Philippines implemented Water Quality Code for the Local Government, under which local governments were given increased autonomy (World Bank 2005; ADB 2007).

2.3.6 Vietnam

Rapid urbanization and industrialization in coastal areas, port and marine transport development, expansion in coastal tourism, and an increase in the number of oil spills contribute to the deterioration of coastal water quality in Vietnam. Data on surface water quality are poor in this country. However, limited testing reveals rising pollution levels in downstream sections of the major rivers. The upstream water quality of most rivers remains good, while downstream pollution mainly from urban areas and industries affects the water quality.

Trends indicate that the levels of two primary pollution indicators, ammonia-nitrogen (NH4-N) and biochemical oxygen demand (BOD5) vary considerably and exceed national water quality class A standards by severalfold. Industrial and other pollution add to the human waste from the population. Around 70 industrial parks have been developed, and with more than 1,000 hospitals nationwide, some million cubic meters of untreated wastewater is discharged from these sources alone per day. According to MoNRE, there are about 4,000 enterprises discharging wastewater, of which 439 enterprises are the most serious. These enterprises need to be reallocated or closed or will have to adapt cleaner technologies and treatment of their wastewater (Aquastat 2011).

Rivers in Vietnam's urban areas, especially major cities, are seriously polluted by untreated industrial wastewater. Surveys conducted by the Institute of Tropical Techniques and Environmental Protection show that the content of contaminants in rivers in Hanoi, Ho Chi Minh City, Hai Phong, Hai Duong, Bac Giang, Hue, Da Nang, Quang Nam, and Dong Nai are much higher than permissible levels (Aquastat 2011). Untreated industrial wastewater discharging into rivers is the main source of the pollution. According to the institute, industrial parks (IPs) and export processing zones (EPZs) in the Southern Key Economic Zone discharge over 137,000 m^3 of wastewater containing nearly 93 tons of waste into the Dong Nai, Thi Vai, and Saigon Rivers each day. Meanwhile, 2 out of 12 IPs and EPZs in Ho Chi

Minh City, 3 out of 17 in Dong Nai, 2 out of 13 in Binh Duong, and none of the IPs and EPZs in Ba Ria-Vung Tau have wastewater treatment facilities. According to environmentalists, the Southern Key Economic Zone needs investment of 5.7 trillion VND (380 million USD) in 2005 and 13 trillion VND (867 million USD) in 2010 to deal with environmental pollution (WEPA 2011b).

Within cities, lakes, streams, and canals increasingly serve as sinks for domestic sewage and municipal and industrial wastes. Most of the lakes in Hanoi are seriously polluted with high BOD levels. Similarly, 4 small rivers in Hanoi and 5 canals in HCM City have levels of DO as low as 0–2 mg/L and BOD levels as high as 50–200 mg/L.

In early 2000, about six million cases of six varieties of waterborne diseases were registered and incurred direct costs of at least 400 billion VND. In addition to the health costs, there are significant costs associated with the treatment of water resources and the cleanup after oil spills. Total financial losses caused by a major oil spill in 2001 were estimated at 250 billion VND (17 million USD), while costs for cleaning up polluted waters and beaches reached 60 billion VND (4 million USD) (WEPA 2011b).

2.3.7 Singapore

Given Singapore's limited water resources, it is critical that water pollution and quality are carefully monitored and regulated. The responsibility for this belongs to the National Environment Agency (NEA), which regulates water pollution and quality in Singapore's sewerage system, as well as inland water bodies and coastal areas. The control of soil pollution is also an important aspect in this regard, given that pollutants in the soil are likely to make their way into the water system as runoff or groundwater. Soil pollution control in Singapore primarily focuses on the use of approved pesticides to combat termites in soil. Over the past 20 years, Singapore has maintained an impressive environmental record, despite an increase in industrialization and urbanization.

2.3.8 Central Asia

In Central Asia, compared with agriculture, water use by industry is low, but it is considered the largest source of water pollution. The most highly polluting industries are construction, mining, and petroleum refining. The volume of industrial waste was 168 million tons in 1998, of which more than half was generated in Kazakhstan and one-third in Kyrgyzstan. Fortunately this waste is declining. The mining industry has been the largest generator of industrial and toxic waste throughout the subregion, which has more than 130 mining waste sites (ESCAP 2005).

The major pollution sources in the region are agrochemicals and insufficiently treated effluents from municipal and industrial sewers. National reports also note increased contamination of groundwater due to substandard management of municipal and industrial waste sites, especially in the mining industry. On average, from 1995 to 2001, 8–15 % of water samples failed to satisfy bacteriological requirements and 20–40 % fell short of physical and chemical standards (UNECE/UNESCAP 2004). Salinity and chemical contamination from agricultural drainage water are also of significant concern in many parts of Central Asia, including Kazakhstan and Uzbekistan.

2.3.9 China

China's per capita water supply is 70 % lower than the global average, but its demand for water is astronomical. Both industry and agriculture use large volume of water – and create massive water pollution. According to a long-term study completed in 2011 by the Ministry of Environment Protection and the Chinese Academy of Engineering, over 90 % of the groundwater in cities was polluted to different degrees. This is highly alarming, as 70 % of China's population relies on groundwater for their drinking water. In China, 320 million people are without access to clean drinking water. Of 118 major cities, 64 had seriously contaminated groundwater supplies and 190 million people are drinking water severely contaminated with hazardous chemicals (UNDP 2013; Burkhardt 2013).

Water quality trends in China suggest that poor water quality caused by pollution is exacerbating the existing water scarcity problem in some areas and threatening food security, economic development, and quality of life (Liu and Diamond 2005; CAS 2007; World Bank 2007; Jiang 2009). Monitoring from 1991 to 2008 by the State Environmental Protection Administration (SEPA) showed that the water quality in the rivers in Northern China, especially the Hai and Liao, was significantly lower than those in the south (MEP 2009, 2010; World Bank 2001, 2006). Water quality monitoring revealed an improvement from 1990 to 2008 in the south, in the Yangtze and Pearl Rivers, although they still contain areas of very poor water quality. The Yangtze River is one of China's most legendary rivers, but today it is known for its pollution. In 2008, over 21 billion tons of wastewater – 70 % of which came from industrial sources – were dumped into the Yangtze. The Yellow River, China's iconic "mother river," is severely overexploited. Parts of the river have run dry, while the water is polluted and underground aquifers are severely stressed out. Industrial pollution is the main threat to the Pearl River, which runs through Guangdong province, the site of China's earliest factories. Industrial waste makes up 60 % of all water emptied into the Pearl River, and clean drinking water is a critical issue for this densely populated region. It is estimated that 13,000 petrochemical factories (out of a national total of 21,000) are located along the Yangtze and Yellow rivers. Many of these freely dump their wastewater into the Yangtze, threatening lives and health in villages such as Taicang.

Deterioration was also noted in the north from 1991 to 2005 (World Bank 2006; Xie 2009; MEP 2009, 2010). Monitoring of 204 rivers in seven major river basins in 2009 found that 60 % of the river sections meet the SEPA national standards for "good" (Class I, II, and III) water, meaning that they are suitable for aquaculture; 24 % can be classified as "poor" (Class IV and V), only suitable for agriculture; and the remainder are highly polluted (below Class V) in terms of nitrates and BOD.

In 2010, among the 26 key state-controlled lakes and reservoirs, none of them met Class I standards and only 21 % met Class II or III, while 38 % were inferior to Class V. The major pollutants were nitrogen and phosphorus; more than half the lakes suffered from eutrophication. Over the period from 2005 to 2009, water quality in the rivers has improved (ESCAP 1999, 2000).

Poor environmental regulations, weak enforcement, and local corruption mean that factories can discharge their wastewater directly into rivers and lakes. According to Environment magazine, there are over 450 cancer villages in 29 out of 31 provinces. Though industrial pollution cannot be absolutely confirmed as the cause, there is a close link between the locations of cancer villages, factories, and polluted rivers. Moreover, many hazardous chemicals that are restricted or banned completely in Europe and elsewhere are not regulated in China. These chemicals have already been recognized as having serious threats to the environment and health, but in China they can still be used in large quantities and without oversight (Burkhardt 2013).

2.3.10 Indonesia

The results of water quality monitoring in 30 rivers in Indonesia indicate that based on national standards, most rivers cannot be considered sources of drinking water. On the basis of BOD, only 21 % of samples meet the criteria for Class 1, with most samples above 10 ppm and some as high as 100 ppm. The figures are similar for COD and dissolved oxygen (DO), and the same applies to lake water quality (WEPA 2011c).

2.3.11 Thailand

In Thailand, monitoring by the Pollution Control Department (PCD) revealed that 68 % of water bodies were suitable for agriculture and general consumption ("good" and "moderate" quality), but no surface water was categorized as "very good" quality (extra clean, suitable for aquatic animals and human consumption after normal treatment). The variation between regions was wide. The surface water bodies in the northern-central and southern regions are of particularly poor quality, while water in the eastern region was fair and that in the northeastern region was good. Concentration of BOD is almost higher than the standard. In a study of

15 waste disposal sites, 11 were found to have heavy metal (nickel, lead, and mercury) contamination exceeding standard values. It is estimated that more than 200,000 tons of waste (BOD) is discharged into the gulf of Thailand annually. Industrial pollution discharges to coastal waters, the heavy metal count, especially mercury, have exceeded Thai water quality guidelines. In general, the implementation of regulations on the environment has suffered from lack of monitoring activities and weak enforcement (Mukhopadhyay 2007).

The above discussion on the status of water pollution in India and other countries in Asia clearly reflects that there is a great diversity in water pollution issues across the region and it is difficult to identify a particular problem only in a certain subregion (ESCAP 2000). Demographic changes, industrialization, and increased use of agrochemicals have serious implications for water quality across Asia. Appropriate monitoring program is required to manage these challenges.

Proactive policies for water quality improvement are emerging across Asia, although many are in their premature level, and a unified framework has yet to evolve. Many Asian countries are making major moves to achieve the Millennium Development Goals, though the achievement is far from goals. Several countries have already taken water quality monitoring measures; there experience could guide the other nations in the region. Most countries have legislation that controls water quality and the emission of pollutants to water bodies, based on concentrations of specific pollutants and dilution requirements.

Several countries are implementing large-scale and ambitious programs to restore degraded water resources. The enforcement of water quality is particularly difficult in emerging economies, where institutional capacities do not keep pace with rapid industrialization (Kathuria and Sterner 2006). Economic instruments, like taxation and reduction of subsidies, are in conflict with other development goals. Moreover, monitoring is expensive and voluntary compliance is poor. Many regulatory and economic options exist to address the problems; however, the constraints like low institutional capacities, social pressure, political will, and inadequate financial resources cannot be ignored (Jiang et al. 2011; Carr and Neary 2008).

In this context, we should mention the most urgent challenges stated in a comprehensive report for the Asian Development Bank. “A major issue in preparing the Asian Water Development Outlook has been the paucity of data on all aspects of water-related issues. Even when data were available, their reliability was often unknown. The problem was further compounded by the presence of either inconsistent national datasets or different data from various national sources on the same parameters, and/or significant differences in many cases between national and international datasets (Biswas and Seetharam 2008).” Keeping these constraints in mind, we have attempted to piece together the scattered information available from different sources and documents to present a status of water pollution in Asia, however.

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Chapter 3
The Methodology

In this chapter, we shall present the methodology which will be used in this work. The framework is an extension of the basic input–output model of Leontief (1951). Input–output model primarily deals with the methodology of analyzing interdependence among the different sectors of the economy. Thus, it becomes a tool to measure inter-sectoral and interrelationship. In input–output analysis, the economy is broken up into sectors and flows of goods and services among these sectors are recorded to study the relationship among them in a systematic and quantitative manner.

3.1 The Basic Input–Output Model

The basic input–output model can be explained by considering a simple hypothetical economy consisting of "*n*" sectors. These "*n*" sectors would be interdependent in so far as they would purchase inputs from and sell outputs to each other.

The input–output matrix presents inter-industry flows of intermediate inputs among the various sectors of the economy. A column records all the inputs required from the various sectors in the production process of a particular activity, while a row describes the flows from a particular sector to different sectors. A technology coefficient matrix is derived from the input–output transaction matrix by dividing all elements in the input column by the output level of a sector represented by the column. Thus, if $A = (\mathrm{aij})$ is the input–output coefficient matrix, then a typical element "aij" represents the amount of input i required to produce one unit of output j. The direct input–output coefficient matrix is, of course, the core of the model. Since total output is equal to inter-industry sales plus final demand, we have

$$X = AX + Y \tag{3.1}$$

This gives the solution for the output vector X given the final demand vector Y and the technical matrix A.

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Here

$A = n \times$ n matrix of input–output coefficient matrix
$X = n \times 1$ vector of output
$Y = n \times 1$ vector of final demand
$I = n \times n$ identity matrix

From (3.1) we derived Eq. (3.2):

$$X = (I - A)^{-1} Y \tag{3.2}$$

$(I - A)^{-1}$ is the Leontief inverse. Leontief inverse is the total (direct and indirect) input requirements.

3.2 Model I

3.2.1 Pollution Model

The input–output framework has been extended here to account for water pollution generation.

To study water pollution generation associated with inter-industry activity, let us consider a matrix of pollution output coefficient, denoted by, W [Wkj], each element of which is the amount of water pollutant type k, (e.g., chloride, sulfide) generated per rupee's worth of industry "j's" output. Hence, the level of water pollution associated with a given vector of total outputs can be expressed as

$$R = WX \tag{3.3}$$

where R is the vector of pollution level. Hence, by multiplying the traditional Leontief's inverse matrix $(I - A)^{-1}$, we can compute R', that is, the total pollution of each type generated by the economy directly and indirectly by different sectors.

$$R' = W(I - A)^{-1} \tag{3.4}$$

Here

R' is the direct and indirect water pollution coefficient matrix of different sectors $(k \times n)$
W is the direct water pollution coefficient matrix of different sectors $(k \times n)$
$(I - A)^{-1}$ is the Leontief matrix multiplier of different sectors $(n \times n)$

3.3 Model II

3.3.1 Model II A

The model has further being extended to incorporate pollution abatement cost. Incorporating the cost data into the input–output framework applied in our present work, for assessment of abatement cost of direct and indirect pollution and its impacts on output and prices of the economy, is the problem dealt herein.

As first step towards solving the problem, attempts have been made to extend the conventional input–output framework to cover not only production and consumption of ordinary goods and services but also generation and elimination of water pollution based on Leontief's work in 1970 (Leontief 1970). It has been achieved by introducing an additional row for water pollutants giving the amount of pollution produced by each sector per unit of output and a column for pollution abatement giving the amount of input required from each sector. And this can be presented in the matrix form as formally described below:

$$\left[\begin{array}{c|c} I - A_{11} & -A_{12} \\ \hline -A_{21} & I - A_{22} \end{array}\right] * \left[\begin{array}{c} X_1 \\ \hline X_2 \end{array}\right] = \left[\begin{array}{c} Y_1 \\ \hline Y_2 \end{array}\right] \tag{3.5}$$

$$\left[\begin{array}{c} X_1 \\ \hline X_2 \end{array}\right] = \left[\begin{array}{c|c} I - A_{11} & -A_{12} \\ \hline -A_{21} & I - A_{22} \end{array}\right]^{-1} * \left[\begin{array}{c} Y_1 \\ \hline Y_2 \end{array}\right] \tag{3.6}$$

where:

A_{11} is the original input–output matrix (without abatement).
A_{12} is the input structure coefficients of pollution abatement activities.
A_{21} is the matrix of direct pollution output coefficients.
A_{22} is the pollution output coefficients matrix for the pollution abatement activities.
X_1, Y_1 are respectively the original output and final demand vectors (without abatement).
X_2, Y_2 are respectively the total output and final demand for the abatement sector.

A point of discrepancy relating to a negative sign in the last row led to the formulation of the model from different perspectives (Qayum 1991). The discrepancy arises because

$$-A_{21}X_1 + [I - A_{22}]X_2$$

should have resulted in $-Y_2$. As $[I - A_{22}]X_2$ denote the total amount of pollution eliminated and sum of $[A_{21}\ X_1]$ denote the total amount of water pollutants generated by the economy, the total amount tolerated, that is, Y_2, given by the difference between the former two should have a negative sign.

The model thus formulated can be dealt with in a straightforward manner by introducing a sector of clean water instead of a pollution-producing sector with negative entries and a pollution abatement sector. With this alternative designation, X_2 will be the total amount of clean water produced through pollution abatement activities. This X_2 is the same as in the previous treatment, because the amount of water pollution eliminated is equivalent to the amount of clean water produced. And the amount of final delivery of clean water, however, is the opposite of the amount of pollution tolerated by final consumers. That is, if we denote the amount of final delivery of clean water by Y_2*, it will be equivalent to $-Y_2$ of the earlier case.

With this slight reformulation, the discrepancy arising due to the negative sign gets solved and the model stands at the same place, as in Eq. (3.6), and the interpretation of A_{11}, A_{12}, A_{21}, A_{22}, X_2, and Y_2 becomes as follows:

A_{11} is the original input–output matrix (without abatement).
A_{12} is the input structure coefficients of "clean water" sector.
A_{21} is the matrix of direct clean water output coefficients.
A_{22} is the clean water output coefficient matrix for clean water production and X_2, Y_2 are respectively the total output and final demand for the clean water sector.

Then from the model, the impact of the abatement cost on the output can be studied.

3.3.2 Model II B

For expressing the effect of pollution abatement cost on prices of different goods and services, the original input–output model has similarly been extended to account for the "clean water" sector, as described above in case of output model, and formally presented below:

$$\left[\frac{P_1}{P_2}\right] = \left[\begin{array}{c|c} I - A_{11} & -A_{21} \\ \hline -A_{12} & I - A_{22} \end{array}\right]^{-1} * \left[\frac{v_1}{v_2}\right] \tag{3.7}$$

where:

P_1 is the prices of different goods and services.
P_2 is the prices of producing one unit of clean water.
V_1 is the value added coefficients of different products.
V_2 is the value added in clean water sector per unit of clean water produced.
A_{11}, A_{12}, A_{21}, A_{22} has the same interpretation as discussed earlier in case of output model.

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Chapter 4
Data Sources and Processing

To work with the various types of water pollutants generated by the different industries of India using the methodology as developed in Chap. 3, we need the appropriate data. The main focus of this chapter is to discuss the available data. Most data are not available in the required form, and therefore, necessary adjustments have to be made to suit the purpose of the work. The major data required for the work are:

(a) The input–output table of India
(b) The different types of water pollutants generated by the different industries of India
(c) The abatement cost for various water-polluting industries

4.1 Input–Output Data

The study has used the input–output table of India for the year 2006–2007 recently prepared by the CSO (2011). The input–output table of 2006–2007 consists of 130*130 sectors. For our study, the input–output table has been aggregated into 38 sectors. The list of the sectors is shown in Table 4.1. Sectors which have relatively high level of water pollution generation (agriculture, livestock, milk and milk products, leather, paper, textiles, chemicals, food products, etc.) are presented as separate sectors. But the other sectors have been aggregated. The aggregation scheme is presented in Appendix 4.A.1.

4.2 Water Pollution Data

Data on water pollution are scanty and are not available in the required form. However, the Central Pollution Control Board (CPCB), India, and the Bureau of Indian Standard (BIS) publish certain documents which have been of great use in

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Table 4.1 List of the sectors for the year 2006–2007

1. Agriculture	20. Plastic products
2. Other agriculture	21. Petroleum and coal tar products
3. Milk and milk products	22. Inorganic heavy chemicals
4. Livestock	23. Organic heavy chemicals
5. Fishing	24. Fertilizers
6. Coal and lignite	25. Pesticides
7. Mining and quarrying	26. Paints, varnishes, and lacquers
8. Sugar	27. Other chemicals
9. Oil and vanaspati	28. Synthetic fibers, resin
10. Tea, coffee, and beverages	29. Other nonmetallic mineral products
11. Food product	30. Iron and steel
12. Cotton textile	31. Machinery and metal products
13. Woolen and silk textiles	32. Electrical machinery
14. Jute, hemp, and mesta textiles	33. Transport equipment
15. Miscellaneous textile products	34. Other machinery
16. Wood and wood products	35. Construction
17. Paper and paper products	36. Electricity gas and water supply
18. Leather and leather products	37. Transport service and communication
19. Rubber products	38. Other services

Source: CSO (2011)

attaining the different types of water pollutants generated from different industries. We have obtained 10 types of water pollution data from this source (CPCB 2006a). The work is constrained by the fact that the sectors mentioned in these documents have to be matched to the corresponding input–output classification. The water pollutants generated by the different Indian industries are mentioned below.

1. Suspended solids (SS)
2. Dissolved solids (DS)
3. Chloride
4. Sulfide
5. Zinc
6. Phenol
7. Oil and grease
8. Biochemical oxygen demand (BOD)
9. Chemical oxygen demand (COD)
10. Other pollutants such as nitrogen, chromium, cyanide, alkalinity

Although data for the 38 sectors were not available, the 38 sectors classification will give us not only direct pollution status but also indirect pollution. Moreover, it is quite likely that water pollution is also not directly generated from all 38 sectors (e.g., service sectors, communication, etc.). In that case, the 38 sector classifications will provide a good view of the indirect contribution.

4.2.1 *Derivation of Different Types of Water Pollutants*

We have used the water pollutant data for a number of sectors directly from the documents published by the Central Pollution Control Board. But for some sectors, these data have been calculated on the basis of available information following the procedure mentioned below (Chakraborty et al. 2001). For each sector, the following information of pollution generation has been collected.

(a) Flow of wastewater $(F) = \frac{\text{Amount of wastewater in liter}}{\text{ton of production}}$

(b) Amount of different types of water pollutants (W) per liter $=$ Amount of $\frac{\text{different types of pollutants (in mg)}}{\text{liter of wastewater}}$

(c) Total amount of production of each sectors (P) in tons

From these parameters, we have been able to derive the total amount of different types of water pollution generation by different sectors, using the following steps:

1. Total amount of wastewater flow in liters (F) $F = F{*}P$
2. Total amount of each types of water pollutants (W) $W = F{*}W$

To illustrate the method of calculation of pollution generation of a composite industry, we can use the beverage industry as an example. Beverage industry is a composite industry comprising many units, but due to the limited availability of data, we have used soft drinks, breweries, and distilleries industries as representative of the sector. Here, the combined wastewater characteristics have been derived by giving weights, with respect to their production level and then arriving at an average for the three industries considered. It has been so done due to the nonavailability of data of the other industries (Table 4.2).

With this in mind, we present the construction of the dataset required for the study.

4.2.1.1 Agriculture

Agriculture is the backbone of the Indian economy. Although agriculture contributes only 21 % of India's GDP, its importance in the country's economic, social, and political fabric goes well beyond this indicator (World Bank 2011). The sector plays a vital role in the development of India with over 60 % of the country's population deriving their living from it. Most of the industries also depend upon the agriculture sector for their raw materials (IBEF 2013).

We have considered rice, wheat, and pulse in agriculture sector. The rice obtained from milling pretreated paddy is considered as parboiled rice, whereas rice obtained from milling of untreated paddy is considered as raw rice or white rice. About 60 % of total production of paddy is parboiled in India. Parboiling is thus an important industry (CPCB 2008–2009).

Table 4.2 Volume of the different types of water pollutants across industries in India during 2006–2007 (thousand tons)

		SS	DS	Chloride	Sufide	Oil/grease	Phenol	Zinc	Others	BOD	COD
1	Agriculture	21,456.933	0.000	0.000	0.000	1,547.418	0.000	0.000	7,012.000	57,350.160	89,822.409
2	Other agriculture	6.940	1.160	0.000	0.000	0.940	0.000	0.000	0.007	6.260	15.100
3	Milk and milk products	1,971.864	3,049.51	276.710	0.000	763.300	0.000	0.000	1,833.610	11,256.771	24,779.727
4	Livestock	1,798.830	535.660	0.000	0.000	146.280	0.000	0.000	2,721.920	5,364.681	29,548.974
5	Fishing	8.410	0.000	0.000	0.000	3.670	0.000	0.000	2.320	16.300	34.840
6	Coal and lignite	0.000	0.439	0.036	0.073	0.000	0.000	0.000	0.082	0.000	0.000
7	Mining and quarrying	113.270	240.910	0.000	0.000	23.720	0.792	0.000	0.000	6.270	0.000
8	Sugar	37.290	148.500	0.000	0.000	12.963	0.000	0.000	15.120	87.780	175.560
9	Oil and vanaspati	32.055	0.000	0.000	0.000	33.000	0.000	0.000	0.000	186.000	275.675
10	Tea, coffee, and beverages	154.139	3,734.09	0.000	0.000	0.000	1.620	0.000	0.000	2,105.471	4,580.545
11	Food products	68.323	0.000	0.000	0.000	91.297	0.000	0.000	0.000	57.631	98.703
12	Cotton textile	3,882.613	54,651.42	0.000	0.000	0.000	0.000	0.000	179.388	302.000	17,274.733
13	Woolen and silk textile	211.370	518.570	500.000	230.000	15.290	2.000	0.000	11.552	180.600	666.200
14	Jute, hemp, and mesta textiles	275.000	0.123	643.000	376.000	5.004	1.400	0.000	5.006	350.000	690.000
15	Miscellaneous textile products	360.000	77.460	900.150	490.000	6.900	0.500	1.700	749.470	580.000	1,278.000
16	Wood and wood products	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	Paper and paper products	653.400	0.000	0.000	0.000	0.000	0.000	0.000	967.770	498.300	682.110
18	Leather and leather products	387.000	558.750	562.500	4.450	0.000	0.000	0.000	250.725	116.427	465.000
19	Rubber products	81.720	649.120	0.000	10.168	12.900	0.000	0.000	25.190	512.750	982.530
20	Plastic products	0.000	81.000	0.000	0.000	0.000	0.000	0.000	0.000	27.000	67.500
21	Petroleum and coal tar products	302.410	863.760	0.000	110.770	880.380	10.330	0.000	0.000	100.540	251.630
22	Inorganic heavy chemicals	15.900	580.750	0.000	0.000	0.000	0.000	0.000	93.315	90.000	267.000
23	Organic heavy chemicals	160.770	0.000	0.000	0.000	170.82	50.660	0.000	20.460	735.000	216.900
24	Fertilizers	330.200	0.000	0.000	0.000	0.000	0.000	0.000	228.900	0.000	0.000
25	Pesticides	90.000	0.000	91.200	0.000	0.000	0.000	0.000	30.780	87.000	396.000
26	Paints, varnishes, and lacquers	20.700	0.000	0.000	0.000	23.400	10.800	0.000	0.000	70.500	8.820
27	Other chemicals	0.001	510.000	0.004	0.005	0.000	0.000	0.000	0.000	174.000	993.000
28	Synthetic fibers, resin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

29	Other nonmetallic mineral products	50.130	0.000	0.000	0.000	0.000	0.000	37.37	20.002	0.000	30.044
30	Iron and steel	978.000	0.000	170.810	6.065	0.000	32.258	0.000	123.000	327.000	816.000
31	Machinery and metal products	0.000	0.000	0.000	0.000	0.000	106.20	0.000	0.000	360.000	112.020
32	Electrical machinery	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33	Transport equipment	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
34	Other machinery	0.000	0.000	0.000	0.000	0.000	211.98	0.000	0.000	720.000	224.010
35	Construction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
36	Electricity gas and water supply	169,781.57	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	50.100
37	Transport services and communication	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
38	Other services	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Source: Authors' estimate from various sources

Table 4.3 Total volume of pollutants for agriculture sector (thousand tons)

	BOD	COD	TSS	Oil and grease
Wheat	9.918	24.370	5.100	0.141
Pulse	0.004	0.006	0.003	0.0003
Rice revised	57,340.23	89,798.03	21,451.83	1,547.27
Total agriculture	57,350.15	89,822.40	21,456.93	1,547.41

Source: Authors' estimate

To calculate the total volume of pollution from these sectors, we have collected the information on total area and water requirements under rice, pulse, and wheat production. We assumed that parboiled rice makes up 60 % of the total rice production. Total rice and wheat production in India was 93.45 million tons in 2006 (milled rice production, GOI 2011a) and 70 million tons in 2004 (GOI 2011a), respectively. The wastewater calculation was then calculated based on the 60 % of total rice production, that is, 56.01 million ton. On the other hand, pulse production in India was 14 million tons in 2006–2007 (GOI 2011a), and its water requirement (assuming a 1/5 water requirement that of cereals) was 31,055.34 L. Lastly, total water requirement in wheat production in India was 51,758.90 L (CPCB 2008–2009). On the basis of all these information, we have estimated the volume of pollutants for the agriculture sector which is given in Table 4.3.

4.2.1.2 Other Agriculture

In this sector, we consider only cashew nut and cocoa production only. Cashew nut processing industries are one of the promising sectors that produce a valuable commodity exported to Gulf, European, and Western countries. There are two commonly followed methods of cashew nut processing: roasting process and steam (roasting) cooking process. Since these industries are small with cottage category units, there is no conventional and techno-economically cost-effective pollution abatement systems like those in operation elsewhere (CPCB 2007a).

Since the cashew nut cooking process is a batch process, the quantity of the water discharge from the cooker per batch was collected and measured in liter per batch. The wastewater discharge from the quenching of cashew nut in the roasting process was collected over a specific period using a stopwatch and the discharge rate was then calculated in liter/h. Since the cashew nut process was limited only for few hours in a day, the total wastewater generation load per 100 kg of cashew nut cooked was calculated (CPCB 2007a).

Groundwater samples in and around the cashew nut processing units were also collected and analyzed to study the influence of wastewater discharges by the units on the ground. All the wastewater samples were analyzed for pH, TSS, TDS, oil and grease, BOD, COD, and phenolic compounds (represented as phenols). The actual domestic water consumption by the units was assessed with the help of the information by the respective unit management.

Table 4.4 Rate of pollution from processing units of cashew nut

	Quench mg/L	Cooker mg/L
pH	7.7	6.3
TSS	1,645	535
TDS	3,262	9,722
OG	1,734	38
BOD	7,812	3,900
COD	16,195	12,040

Source: CPCB (2007a)

We have estimated the volume of water pollution on the basis of production. In 2003–2004, the cashew nut production was 5,350,000 metric tons (DCCD 2011). The pollution generation is from the two processing unit of cashew nut which are quenching and cooker. Table 4.4 shows the rate of pollution release per liter. Using this dataset we have calculated the total volume of pollution given in Table 4.2.

4.2.1.3 Milk and Milk Products

According to the National Dairy Development Board, India is probably the only country which has had a steady increase in milk production and emerged as the largest milk-producing country among all the tropical countries in the world. India is the world's largest producer of dairy products by volume and has the world's largest dairy herd. The country accounts for more than 13 % of the world's total milk production and is also the world's largest consumer of dairy products, consuming almost all of its own milk production. As the country consumes almost all of its own milk production, India was neither an active importer nor an exporter of dairy products prior to year 2000. However, since the implementation of Operation Flood program, the situation changed significantly, and imports of dairy products are reduced to very small quantities. From 2001, India has become a net exporter of dairy products (IUF 2011).

Dairy industrial facilities are responsible for the release of huge quantities of wastewater, often in the order of thousands of cubic meters/day (Banu et al. 2007). The principal components of dairy wastewater are milk, milk fractions, and milk products. About 90 % of BOD in dairy processing waste comes from these materials (CPCB 1992–1993). The relatively high concentrations of organic matter contained in dairy wastewater have been implicated in a number of pollution issues (Banu et al. 2007). We have collected the information of BOD, COD, and SS for the dairy industry from the CPCB document (CPCB 1992–1993). It provides the estimates by CPCB experts and other experts in India (Table 4.5). The rate of generation of BOD, COD, and SS released from the dairy plant is at the higher end according to the CPCB estimates compared to that of other literatures in India.

To estimate the total amount of BOD, COD, and SS, we have used the data for milk production in India for the year 2006–2007. The amount of milk production in India was 102.86 million tons for the year 2006–2007 (GOI 2013). The total amount of pollution is calculated on the basis of the rate of the water pollutants parameters and milk production given in Table 4.6.

Table 4.5 Average generation of water pollutants from the dairy plant in India (mg/L)

	BOD	COD	SS	Others
Literature	10,483	18,892	6,788	60.85
CPCB	110,360.5	242,938.5	19,332	80.5

Source: CPCB (1992–1993)

Table 4.6 Water pollution from milk and milk products in 2006–2007 (thousand tons)

	BOD	COD	SS	Others
CPCB	11,256.771	24,779.727	1,971.864	8.211

Source: Authors' estimate

4.2.1.4 Rubber and Rubber Products

Since the establishment of the first rubber products manufacturing unit in 1921, the rubber products manufacturing industry of India has experienced dramatic growth and expansion, particularly during the post-independence era. It has achieved overall development by expanding its size, spatial distribution, technological improvement, and more prominently the wide range of products manufactured (CPCB 2007b).

The rubber industry plays an important sector role in the Indian national economy with around 6,000 unit comprising 30 large-scale, 300 medium-scale, and around 5,600 SSI/tiny sector units. It manufactures 35,000 rubber products and employs 400 hundred thousand people, including around 22,000 technically qualified support personnel. It has a turnover of Rs. 200 billions and contributes Rs. 40 billions to the national exchequer through taxes, duties, and other levies. India is the third largest producer, fourth largest consumer of natural rubber, and fifth largest consumer of natural and synthetic rubber in the world. In addition, India is the world's largest manufacturer of reclaimed rubber (India Finance and Investment Guide 2013).

The rubber products in India according to the end products for the year 2004–2005 are shown in Table 4.7. The wastewater generation from these end products is categorized into four components: tire and tube industry, latex based, molded and extruded, and reclaimed.

Rubber processing industry consumes large volumes of water and chemicals, producing enormous amounts of wastewater. The discharge of this wastewater to the environment without proper treatment causes serious consequences. The industrial water consumption varies widely mainly due to different cooling water systems adopted by tire and tube industry. The consumption variations are mainly due to the use of the once-through cooling water in certain plants as compared to the recirculation cooling in others. The wastewater from the process areas includes water and steam leakages, overflows, runoff from oil storage areas, soapstone solution spillages, and wash down and runoff from process or storage areas. Water leakages occur at various water-cooled machinery units including mills, banburies, extruders, and tread cooling tanks. In general, wastewater problems arising from compounding, extrusion, molding, and curing operations in tube manufacturing are very similar to that of the tire manufacturing (CPCB 2007b). The wastewater generation in per kg of raw materials according to each stage of rubber production is given in Table 4.8.

Table 4.7 Rubber products in metric tons (2004–2005)

Broad categories	Total
Tire and tube industry	
Auto tires and tubes	443,894.93
Cycle tires and tube	116,368.23
Molded and extruded	
Camel back	49,415.85
Footwear	97,377.775
Belts and hoses	50,266.599
Latex based	
Latex foam	32,722.452
Reclaimed	
Cables and wires	3,463.505
Battery boxes	13,177.669
Dipped goods	33,641.415
Others	76,250.558
Total	916,579

Source: CPCB document (2007b)

Table 4.8 Generation of wastewater from rubber products (L)

Tire and tube industry	3.5
Molded and extruded	1.25
Latex based	20
Reclaimed	0.3

Source: CPCB (2007b)

Table 4.9 Types of water pollutant from rubber product (mg/L)

Rubber products	pH	SS	TDS	BOD	COD	Oil/grease
Tire and tube	8.5	314	2,127.5	184.6	270.4	37.9
Molded extruded fabricated	9.9	140	2,175	60	182	19.5
Latex based	8.8	225	2,590	160	350	18
Reclaimed	8.75	520	2,312.5	824	4,700	1,027.5
Total	**35.95**	**1,199**	**9,205**	**1,228.6**	**5,502.4**	**1,102.9**

Source: CPCB (2007b)

We have also collected the information from the CPCB documents (2007b) about several water pollutants that are generated from the four broad categories of rubber production (Table 4.9).

These are the information we have used to calculate the water pollution parameters in rubber products sector in 2006–2007 which is presented in Table 4.2.

4.2.1.5 Tea, Coffee, and Beverages

This sector is a combined sector. Here we have estimated water pollutants only for coffee and beverages and used it for the group. In instant coffee manufacturing,

Table 4.10 Generation of wastewater estimation from coffee production plant

	Less than 4 ha	4–10 ha	Greater than 10 ha	Total
Number of coffee plant	131,079	6,564	2,650	140,293
Kilo liter per plant	207	277	708	
Wastewater (kL)	27,133,353	1,818,228	1,876,200	30,827,781

Source: Computed by the authors from CPCB (2006a)

Table 4.11 Water pollution from coffee processing and cultivation (mg/L)

	Coffee processing	Cultivation
BOD (5 days)	646	6,500
COD	3,702	25,000
SS	90	5,000
TDS	2,110	25,000
Oil and grease	8.5	
pH	9.43	5

Source: CPCB (2006a)

wastewater is generated from spent coffee waste. This wastewater is acidic in nature and has BOD, 600–1,000 mg/L; COD, 2,500–10,000 mg/L; and SS, 100–1,000 mg/L. The wastewater generation is about 300 KLD which is generally 50–55 % of water use (CPCB 2006a).

We have collected various information to calculate the wastewater generation and water pollutants generated from coffee processing. The generation of wastewater from coffee plant is documented in Table 4.10. In India, the coffee production plants are mostly small in size (less than 4 ha) as seen from Table 4.10, and the generation of wastewater depends on the area of the coffee production plant.

Table 4.11 explains the different effluents generated from coffee processing and coffee cultivation. For calculating the total water pollution from each parameter, all the information is used along with total coffee production in India, that is, 288,000 metric tons in 2006–2007 (Coffee Board 2010).

We obtained from Nagaraj and Kumar (2008) that 3.20 billion liters (2006–2007) of alcohol production release 4.5 billion liters of wastewater. Using the information from CPCB 2002–2003a, we could get the data on the different types of pollutants generated from beverages. Together with the water pollutant parameters generated from coffee and beverages, we calculate the total volume of different types of water pollution generated from tea, coffee, and beverages which is presented in Table 4.2. It should be mentioned that we could estimate water pollutants for SS, DS, BOD, COD, and pH for this group.

4.2.1.6 Livestock

The livestock sector plays an important role in the Indian economy. Estimates show that the GDP from livestock sector is at Rs. 1,239 billion in 2004–2005 which makes up 24.7 % share in agriculture and allied GDP. It also provides nutritive food (rich in animal protein) and generates employment in the rural sector, particularly among the landless, small, marginal farmers and women. Moreover, since the distribution of livestock wealth in India is more egalitarian than that of land, from the equity and livelihood perspectives, livestocks are considered an important component in poverty alleviation programs (Chacko et al. 2010).

With growing annual per capita meat consumption, high meat export potential, and large non-utilization of potential of animal meat, the development of the meat industry in India is necessary. However, this sector is controlled by existing market forces and not by the government. Thus, its unorganized nature is a main feature of the industry, and as a result, it has not been able to use the state of the art of technology available in global meat market (Chacko et al. 2010).

In India, the meat production in 2005 was 2.6 million tons and poultry production was 2.3 million tons (Livestock Census 2011). Total meat and poultry production is equivalent to 4.9 million tons in 2005. The wastes from slaughter houses and packaging houses are similar chemically to domestic sewage but are considerably more concentrated. They are almost wholly organic, chiefly having dissolved and suspended material. The principal deleterious effect of these wastes on streams and water courses is their deoxygenation. The typical characteristics of the effluent coming out from the slaughter house are as follows.

Features of the Parameters

1. Quantity – 2,000 cu.m/day
2. Total solids – 4,000 to 5,000 mg/L
3. BOD – 4,000 mg/L
4. COD – 8,000 mg/L
5. pH – 6 to 7

Source: GOI (2011a)

At present, there are no official norms for classification of slaughter houses. However, depending upon the type of animals slaughtered, the slaughter houses are classified into the following.

Large animal (i.e., cattle, buffalo, etc.) slaughter house
Goat and sheep slaughter house
Pig slaughter house
Poultry slaughter house (2011b)

In order to assess the variations in pollution load with respect to the number of animals slaughtered, bovines and goat and sheep slaughter houses are further classified into three categories.[1] Large-scale slaughter houses are located mainly in big cities, medium-scale slaughter houses in district/towns, while the small-scale slaughter houses are scattered all over the country.

[1] Large scale – more than 200 large animals, i.e., bovines per day or more than 1,000 goat and sheep per day.

Medium scale – more than 50 and up to 200 large animals or more than 300 up to 1,000 goat and sheep per day.

Small scale – less than 50 bovines and 300 goat and sheep per day.

Liquid Waste/Effluent

During the abovementioned operations, the waste generated is of both liquid and solid nature. The liquid waste should be washed away by safe potable and constant supply of freshwater at adequate pressure throughout the premises of slaughtering. The wastewater from slaughter house is heavy in pollution, and, therefore, it should not be allowed to mix with the municipal drain system without pretreatment meeting sewage standards as per the Bureau of Indian Standards (BIS). The detailed discussion on treatment is given in the cost section.

Using production information for the year 2006–2007 along with wastewater generation available from different sources helps us estimate the total volume of water pollutants from this sector which is shown in Table 4.2.

4.2.1.7 Cotton Textile

Textile is another sector which occupies an important position and plays a vital role in the Indian economy. India is the world's second largest textile producer after China, accounting for about 15 % of the world production of cotton textiles. This is one of the major sources of foreign exchange earnings for India. Currently the industry accounts for 4 % of GDP, 20 % of industrial production, and slightly more than 30 % of export earnings. About 38 million are employed in the Indian textile industry (USITC 2001).

The Indian textile and apparel industry is diversified and has the capacity to provide a wide variety of textiles to meet different market needs. The broad division of textile industry includes natural fibers (cotton, jute, wool, and silk) and man-made fibers and synthetic blends. Out of the total textile production, cotton covers 70 %, while wool, silk, and jute 10 % and man-made synthetic 20 %. There are almost 1,400 spinning mills and 280 compost mills. The production of apparel in India was, until recently, reserved for the small-scale industry (SSI) sector. Apparel units with larger investments were allowed to operate only as export-oriented units (EOUs). As a result, India's apparel sector has been highly fragmented and uses low levels of technology (USITC 2001).

As India steps into an increasingly liberalized global trade regime, the Government of India has implemented several programs to help the textile and apparel industries adjust to the new trade environment. On November 2, 2000, the Government of India unveiled its National Textile Policy (NTP) 2000, aimed at enhancing the competitiveness of the textile and apparel industry and increasing India's share of world textile and apparel exports. The production structure of textile industry is given in Table 4.12.

The main sources of wastewater from a textiles mill are from designing, kiering, scoring, bleaching, rinsing, mercerizing, dying, and printing. Table 4.13 presents wastewater generation for the year 2006–2007. About 230 L of water is required for processing 1 kg of fabrics and 360 L of water is required for 1 kg of cloth. Based on these, an average of 295 L of water is considered to calculate the total water requirement in textile plant for a particular year (CPCB 2000–2001). With this

Table 4.12 Structure of India's textile production in 2000

Cotton (spun yarn) million kg	2,205
Cotton (fabrics)[a] million sq mt	19,089
Cotton (fibers) million kg	3,000

Source: USITC (2001)

[a]Fabric weight is usually listed as a GSM value (grams per square meter). If fabric is on a roll, measure width of the roll and multiply by GSM rating to get weight in grams per linear meter. There are various measurement: (i) GSM rating 155, roll width 3 m = 465 g or 0.65 kg per linear meter; (ii) GSM rating 500, roll width 2.5 m = 1,250 g or 1.25 kg per linear meter

Table 4.13 Wastewater generation from cotton textile production in 2006–2007[a]

	Kilo liter
First estimate	4,351,102,500
Second estimate	2,755,580,250
Third estimate	1,533,640,244

Source: Authors' estimate

[a]According to different GSM rating, the estimate of wastewater generation differ

Table 4.14 Water pollutants from cotton textile plant (mg/L)

	pH	TDS	SS	COD
Total	65.1	19,833	1,409	6,269

Source: CPCB (2000–2001)

information we have calculated the wastewater generation from cotton textile (Table 4.13) using the production of cotton (spun yarn, fabrics, etc.) for the year 2006–2007 (Table 4.12). The rate of effluents released from wastewater mg/L is accounted in Table 4.14.

Using all these information, we have computed water pollutant from textile industry presented in Table 4.2.

4.2.1.8 Jute, Hemp, and Mesta Textile

The rate of different water pollutants has been sourced from Chakraborty et al. (2001). Using the production of raw jute of 8.2 million bales or 1.47 billion kg available from Economic Survey of India 2009–2010 (GOI 2009–2010), the volume of pollutants for the year 2006–2007 has been calculated and shown in Table 4.2.

4.2.1.9 Woolen and Silk Textile

Woolen and silk textile plays an important role in the textile industry of India. For the pollution data preparation, we have used the information from a case study conducted by CPCB (2004–2005) where 15 silk-screen printing units in Serampore,

Table 4.15 Water quality from Serampore silk-screen plant (mg/L)

	Highest	Lowest	Average
BOD	2,274	57	1,658.692
COD	8,385	141	1,768.29
TDS	6,526	17	1,055.516
TSS	266	553	169.122
pH	6.66	7.45	8.87

Sources: CPCB (2004–2005)

West Bengal, were considered. The water requirement per unit of silk and wool production was approximately 10–15 L of water. Total raw silk and wool production in 2007–2008 was 63.57 million kg (Ministry of Textiles 2009–2010). The average data of water quality of Serampore plant has been applied to calculate the total volume of pollution in India from woolen and silk textile for the year 2006–2007 documented in Tables 4.2 and 4.15.

4.2.1.10 Miscellaneous Textile

To calculate the volume of water pollution generated by the miscellaneous textile for the year 2006–2007 (Table 4.2), the average water pollution coefficient of all kinds of textile (cotton; jute, hemp, and mesta; and woolen and silk) has been used together with production data according to the report by Ministry of Textile.

4.2.1.11 Sugar

Sugar industry is one of the most advanced agro-based industries in India, but it is also one of the most water-polluting industries and is facing various challenges including deterioration of environment due to its industrial activities (AARRO 1996).

The industry generates large quantity of wastewater at all stages of sugar production process occurring at the mill house. Cooling pond and distillery (mills that also produce industrial alcohol from molasses) are water intensive and discharged water with very high levels of oil, suspended solids, organic matter, and chemicals. It also generates gaseous emission and solid waste that can cause pollution problem. Recent studies indicate that pollution concentrations for some sugar factories in India have as high as 1,154 mg/L of BOD, 5,915 mg/L of COD, and 5,759 mg/L of SS. The industry has to incur a significant cost to reduce these very high effluent concentrations of pollutants to the Minimum National Standards (MINAS) of 35 mg/L of BOD, 250 mg/L of COD, and 100 mg/L of SS in India (Murty et al. 2006).

Based on the local audits data in the ETPI surveys, the unit wastewater flow for sugar production was estimated to be 2 L/kg, 1.53 L/kg for sugar processing, and 15 L/kg for molasses production (Rao et al. 2011). Thus, 3.53 L of water is needed to produce one kg of sugar. Based on sugarcane production for the year 2006–2007,

Table 4.16 Water pollutant parameters from sugar plant in India

Sugar	Tons/day	Tons/year	Thousand tons
BOD	266	87,780	87.78
COD	532	175,560	175.56
TDS	450	148,500	148.5
Oil and grease	3.07	1,013.1	1.0131
SS	113	37,290	37.29

Source: Authors' estimate from CPCB (2002–2003a)

Table 4.17 Water pollutant parameters from pulp and paper plant in India

	Tons/day	Tons/per year	Thousand tons
BOD	1,510	498,300	498.3
COD	2,067	682,110	682.11
SS	1,980	653,400	653.4

Source: Authors' estimate

the wastewater generated was 48,788,000 kL. From wastewater generation and information from the CPCB (2002–2003a), we have calculated the pollutants released from the sugar plant given in Table 4.16.

4.2.1.12 Paper and Paper products

The paper manufacturing industry in India is quite old as the first handmade paper is made in 1159 AD (CPCB 2002–2003a). The importance of paper in the development of an economy is significant as it is directly related to industrial and economic growth of a country. The pulp and paper industry is broadly classified in three categories: (a) wood based, (b) agro based, and (c) wastepaper based. The problem of water pollution is predominant in these industries particularly in agro-based small-scale units. All types of paper industries release major water pollutants: SS, BOD, and COD. As per information available in CPCB, 99 % of the pulp and paper mills have adequate facilities to comply with the standards. Agro-based and wastepaper-based mills are considered as small-scale industries. For calculation purposes, the number of working days in a year is assumed to be 330 days. Using the source from the CPCB document (2002–2003a), Table 4.17 has been prepared.

4.2.1.13 Mining and Quarrying

Mineral resources play a very significant role in an economy, and India has been generously endowed with minerals. Mining and quarrying sector accounts for 2.5 % of India's GDP, as estimated by the Central Statistical Organization. According to the Indian Ministry of Mines, India produces as many as 87 minerals, which include 4 fuel, 10 metallic, 47 nonmetallic, 3 atomic, and 23 minor minerals including building and other minerals. In India, 80 % of mining is in coal and the remaining

Table 4.18 Rate of water quality from iron ore processing plant in India (mg/L)

	Average
TSS	196.7775
pH	6.6575
Oil and grease	11.32
Total dissolved solids	520

Source: CPCB document (2007–2008)

Table 4.19 Water use and wastewater generation in oil refineries through cooling system and recirculation cooling system

	Water consumption, kilo liter/1,000 ton of crude processed		Wastewater generation, kilo/liter/1,000 ton of crude processed	
	Max	Min	Max	Min
Cooling water system	27,589	18,021	27,573	17,972
Recirculation cooling system	5,652	1,350	1,811	320

Source: CPCB (2002–2003b)

20 % is in the various metals and other raw materials such as gold, copper, iron, lead, bauxite, zinc, and uranium.

In this sector, we only considered iron ore and oil refineries. Total iron ore production in India is 172.296 million tons during 2006–2007. There will not be any wastewater generation process at the mine, but processing the ore to produce the final steel needs 3 cu.m of water per ton (CPCB 2007–2008). It is estimated that 463,290,000,000 litre of water is used for iron ore processing in 2006–2007. Using the above information and the water pollution parameters from the CPCB document (Table 4.18), we have calculated total volume of pollution from iron ore processing for the year 2006–2007.

Oil refining industry is one of the oldest industries in the country. The refineries are classified under two categories: one being those having once-through cooling water system and the other having cooling water recirculation system. The water use and wastewater generation in the oil refineries in the country are noted to be greatly influenced by the type of cooling system used. Table 4.19 provides the rate of water use and wastewater generated with respect to the two classes of refineries. The rate for once-through cooling water system is several times higher than that of the recirculation cooling system. Therefore, MINAS are stipulated both in terms of concentration and quantum of pollutants worked based on wastewater generation of 700 kL per thousand tons of crude oil refined. Table 4.20 shows the characteristics of raw effluent in oil refineries.

The water pollutants released from Indian oil refineries are given in Table 4.21. According to a 330 operation days in a year, we have calculated the total volume of pollutants. The total pollution generated from mining sector including oil refineries and iron ore is given in Table 4.2.

Table 4.20 Characteristics of raw effluent in oil refineries (mg/L)

Parameter	Concentration of pollutants in raw effluent	Average concentration of pollutant in raw effluent
pH	6.5–9.5	
Oil and grease	500–1,000	750
Phenol	20–40	30
SS	800–1,000	900
BOD	200–300	250
Sulfide	40–60	50

Source: CPCB (2002–2003b)

Table 4.21 Rate of water pollutant release from oil refinery (t/day)

	BOD	SS	Oil/grease	Phenol
Tons/day	19	67	56	2.4

Source: CPCB (2002–2003b)

4.2.1.14 Food Products

Traditionally, the food processing industry has been a large water user. In India, large food processing plants regularly use more than 1,000,000 gallons of potable water per day. Although water use will always be a part of the food processing industry, it has become the principal target for pollution prevention and source reduction practices. Among other environmental issues for the food industry, the primary issues of concern with the wastewater it generates are biochemical oxygen demand (BOD); total suspended solids (TSS); excessive nutrient loading, namely, nitrogen and phosphorus compounds; pathogenic organisms, which are a result of animal processing; and residual chlorine and pesticide levels. The content of wastewater released from the food sector, however, is mainly COD, although BOD, suspended solids, oil and grease, and other pollutants are also generated from this sector.

Food processing wastewater can be characterized as nontoxic, because it contains few hazardous and persistent compounds. With the exception of some toxic cleaning products, wastewater from food processing facilities is organic and can be treated by conventional biological technologies. However, these food processes require a large volume of water that generates equally large amounts of effluent. A considerable part of this wastewater is treated for safe disposal to the environment. Table 4.22 shows typical rates of water use for various food processing sectors.

Another contaminant of food processing wastewaters, particularly from meat, poultry, and seafood processing facilities, is pathogenic organisms. Wastewaters with high pathogenic levels must be disinfected prior to discharge. Typically, chlorine (free or combined) is used to disinfect these wastewaters, but ozone,

Table 4.22 Typical rates for water use for various food processing industries

Industry range of flow product	Gal/t
Bread	480–960
Milk products	2,400–4,800
Meat packing	3,600–4,800

Source: UNIDO

Table 4.23 Typical values of BOD5 and COD for different food plant wastewaters

Type of processor	BOD5 (mg/L)	COD (mg/L)	BOD5/COD
Bakery products	3,200	7,000	0.46
Jams and jellies	2,400	4,000	0.60
Meat packing	1,433	2,746	0.52
Meat specialties	530	900	0.59
Poultry processor	1,306	1,581	0.83

Source: UNIDO

ultraviolet (UV) radiation, and other nontraditional disinfection methods are gaining acceptance due to the stricter regulations on the amount of permissible residual chlorine levels in discharged wastewaters. The pH of a wastewater is also of paramount importance to a receiving stream. Biological microorganisms, used in wastewater treatment, are sensitive to extreme fluctuations in pH. Wastewater discharge values that range from 5 to 9 on the pH logarithmic scale are usually acceptable.

At any point in a particular food processing operation, the relationship between BOD5 and COD is fairly consistent. However, the ratio of these two measures varies widely with the type of product (Table 4.23).

Using the above information as well as the data from Chakraborty et al. (2001), we have estimated the water parameter from the food sector which is presented in Table 4.2.

So far we have been able to provide the estimates of water pollution parameters in spite of data problems and limitation for the 14 industries. In addition, the document "Assessment of Industrial pollution" published by the CPCB 2002–2003a has been used to get the data for the following sectors: fertilizer, thermal power plants, leather and leather products, petrochemical, pesticides, inorganic heavy chemicals, other chemicals, organic heavy chemicals, paints and varnishes, plastic products, oil and vanaspati, iron and steel, machinery and metal products, and Other machinery. We were also able to obtain the pollution data for thermal power plant which has been used for electricity gas and water supply while the data on engineering were used to obtain the pollution data for the sectors: (a) machinery and metal products and (b) Other machinery.

The dataset given in the CPCB document provides per day water pollutants release. We have multiplied these datasets by 330 days (operation for most of the plants) to calculate the total volume of the different types of pollutants for the year 2006–2007. However, for the electricity sector, we consider 365 days of operation.

For sectors like fishing, coal and lignite, and nonmetallic mineral products, the pollution data have been taken from Chakraborty et al. (2001) with the necessary adjustments.

In summary, we have estimated the pollution data for 31 out of 38 sectors, and these are presented in Table 4.2.

4.3 Cost Analysis

In this section, we discuss in detail the cost analysis of the treatment of water pollutants in the different industries of India. The pollution abatement cost will involve cost related to the different methods used in the treatment.

Physical, chemical, and biological methods are used to remove contaminants from wastewater. To achieve different levels of contaminant removal, individual wastewater treatment procedures are combined into a variety of systems. These are classified as primary, secondary, and tertiary wastewater treatment. The removal of specific contaminants as well as the removal and control of nutrients include a more rigorous treatment. Natural systems are used for the treatment of wastewater in land-based applications, and the sludge resulting from wastewater treatment operations is treated by various methods in order to reduce its water and organic content and make it suitable for final disposal and reuse (Rout 2012).

The side effects of economic activities on the natural environment have resulted in environmental pollution. Growing industrialization and urbanization have placed increasingly competitive demand on water, the nation's common property resource. Moreover, water resources are the principal recipients of external diseconomies such as industrial, household, and municipal wastes. These external diseconomies can be minimized by the preservation of environmental resources or control of pollution if polluters or some other agent of the economy incur some additional costs.

However, the particular agent will have no incentive to incur pollution abatement cost since the environment is a public good. Environmental resource may be regarded as public good in the sense that benefits (economic burden) from preserved (degraded) environment accrue to a large number of economic agents in the economy or to all users of water resources or society as a whole. It is difficult to define or enforce property rights to the services of these resources, thus it cannot be priced. This justifies the various environmental regulations on control of pollution (Chakraborty et al. 2001).

In light of this, India has enacted several laws in this regard pertaining to industrial pollution abatement. The Water (Prevention and Control of Pollution) Act, 1974, amended in 1986; the Water (Prevention and Control of Pollution) Cess Act, 1977, amended in 1988; and the Environment Protection Act, 1986 are the most important laws. These laws set the national goals for eliminating the practice of discharging pollutants into water bodies without providing the required treatment, and these are specific guidelines for effluent discharges (termed MINAS) (details in Chap. 2).

The CPCB provides source-specific pollution standards for industries with respect to pollution concentration of major water pollutants: BOD, COD, SS, and pH. The CPCB urban centers have launched a water pollution control program for industries. It identified 1,532 large and medium industries and gave a time schedule to these industries for compliance with the prescribed standards. It was found that many of these industries have effluent treatment plants (ETPs), but despite these they still did not comply with the prescribed pollution standards (MoEF 2009). On the other hand, small-scale industries contribute almost 40 % of the industrial water pollution in India with those located in the many industrial estates in India utilizing the common effluent treatment plants (CETPs).

Recently, the Ministry of Environment and Forest (MoEF) has launched the Charter on "Corporate Responsibility for Environmental Protection (CREP)"in March 2003. The object of this charter is to go beyond the compliance of regulatory norms for prevention and control of pollution through the various measures including waste minimization, in-plant process control, and the adoption of clean technologies (MoEF 2003). The charter has set targets concerning water and energy conservation, recovery of chemicals, reduction in pollution, elimination of toxic pollutants, and the processing and management of residues. The charter suggests action points for controlling pollution for the various categories of highly polluting industries. The Task Force was constituted for monitoring the progress of the implementation of CREP recommendations/action points (MoEF 2003).

A minimal national standard for a particular industry is the effluent standard that is achievable by the industry by installing pollution control measures which are within the techno-economic capability of the industry. Generally, two main aspects are taken into consideration for the development of standards for wastewater discharges: (a) the adverse effects on health and environment and (b) the achievability of limits of pollutants by incorporation of appropriate pollution control measures.

The use of the best available and economically feasible technology is the objective of the latter approach. Economically feasible technology assures that the cost of pollution control measures will remain within the affordability of the industrial units. Standards developed on these principles are techno-economic standards and they are uniform throughout the country.

In order to develop the most economic pollution control solution in terms of investment and operational costs, it has been recommended that pollution abatement measures at the sources should be introduced prior to the installation of treatment systems (MoEF 2003).

It is also suggested that the following aspects should be considered before designing a treatment system:

1. Segregation of wastewater based on type and strength
2. Reduction of quantity and strength of wastewater by adopting in-process and in-plant control measures

3. Decision on the best combination of treatment system

In addition, technical and economic feasibility of the treatment system should also be looked at. The following considerations guide the technology to be used in a particular case:

(a) Degree of treatment needed based on the characteristics of the waste and the statutory regulation in respect of the quality of the effluent to be discharged on the receiving body
(b) Capital cost and recurring
(c) Availability of land to accommodate the treatment plant
(d) Availability of the operation and maintenance skills and facilities at the site (MoEF 2003)

The above discussion indicates that different steps have been taken by the Central Pollution Control Board to minimize water pollution. The different industries have taken actions in this direction. However, these actions involve abatement cost and the next section will discuss the preparation of pollution abatement cost data for the different industries.

4.3.1 Abatement Cost Data

It is challenging to obtain data on abatement cost incurred by the different industries for a variety of reasons. Since some of the industries have no systematic approach towards effluent treatment, any figure obtained from them will not provide any practical idea about the cost involved. Moreover, applicability of the types of treatment schemes/alternatives varies for the different categories of a particular industry in terms of its efficiency. Therefore, industries that have effluent treatment systems and also possess information about financial requirements are selected as listed in Table 4.24. Even for these industries, the information is not available in the required form. Thus, further data collection from different sources is done to process and refine the cost data. Despite the various data limitations, we have been able to provide estimates for the different water pollutants for 31 industries; however, cost data could only be estimated for the 16 industries as mentioned in Table 4.24.

For the purpose of this study, we would be dealing only with the operational (or running/recurring) cost aspects of the pollution abatement measures. The running cost of the treatment plant will include cost of power, salaries of the staff, chemicals used, maintenance, repairs, and depreciation. It should be mentioned that different industries generate different types of pollution parameters, and therefore, the removal of pollutants depends on the type of industries. The cost involved in pollution abatement activity of each sector is analyzed and evaluated suitably for clean water valuation of each sector. Details of the cost data analyzed for each of the 16 industries mentioned are discussed.

Table 4.24 Abatement cost data for the selected industries

Serial number	Input–output sector number	Name of the sectors
1	3	Dairy
2	4	Livestock
3	7	Oil and gas (mining)
4	8	Sugar
5	10	Tea, coffee, and beverages
6	11	Food products
7	12	Cotton textile
8	14	Jute, hemp, and mesta textiles
9	15	Miscellaneous textile
10	17	Paper and paper products
11	18	Leather and leather products
12	19	Rubber and rubber products
13	22	Inorganic heavy chemical
14	23	Organic heavy chemical
15	26	Paints, varnishes, and lacquers
16	27	Other chemicals

4.3.1.1 Textile

In processing of textiles, the industry uses a number of dyes, chemicals, auxiliary chemicals, and sizing materials. As a result, contaminated wastewater is generated which can cause environmental problems unless it is properly treated before its disposal. The wastewater treatment is done mostly by primary and secondary processes. However, these conventional treatment systems are not very effective in the removal of pollutants such as dissolved solids, color, trace metals, etc. (CPCB 2007c).

Removal of dyes from the effluent is a major problem in most of the textile industries. Dissolved solids contained in the industry effluents are also a critical parameter. TDS are difficult to be treated with conventional treatment systems. Dissolved solids in effluent may also be harmful to vegetation and restrict its use for agricultural purpose. Textile effluents are often contaminated with non-biodegradable organics termed as refractory materials. Detergents are a typical example of such materials. The presence of these chemicals results in high chemical oxygen demand (COD) value of the effluent. Organic pollutants, which originate from organic compounds of dye stuffs, acids, sizing materials, enzymes, tallow, etc., are also found in textile effluent, and such impurities are reflected in the analysis of biochemical oxygen demand (BOD) and COD. These pollutants are controlled by the use of biological treatment processes (CPCB 2007c).

The majority of the textile industries have installed the conventional treatment systems like physicochemical treatment or physicochemical treatment followed by biological treatment system. The chemical treatment helps reduce color and suspended solids in addition to a significant reduction in BOD and COD values.

Textile effluents may also require tertiary or advanced treatment methods to remove particular contaminant or to prepare the treated effluent for reuse. Some common tertiary operations are the removal of residual organic color compounds by adsorption and removal of dissolved solids by membrane filtration (CPCB 2007c).

The advanced treatment methods in textile industry can effectively recover water and/or salts from effluent streams for their reuse in production process. The application of advanced methods can help meet stringent environmental or regulatory requirements such as zero effluent discharge. Membrane filtrations can produce treated water with high purity. Treatment system like activated carbon adsorption and ozonation can also be used to make the effluent suitable for use in membrane filtration. To minimize effluent volume or achieve a desired concentration of target pollutant, an evaporation system can be employed. An evaporation system and crystallizer combination can also recover salt. Nanofiltration, on other hand, allows passage of salt with the permeate which when used in dying process requires less addition of salt. More importantly, the nanofiltration is capable of removing hardness elements such as calcium or magnesium together with bacteria, viruses, and color. As nanofiltration is operated on lower pressure than reverse osmosis, it costs less to run (CPCB 2007c).

According to the structure of India's textile sector, we have cotton textile categorized as cotton spun yarn, cotton fabrics, and cotton fibers. Here we provide three different estimates of operation and maintenance cost of textile wastewater. Wastewater generation depends on the different technologies adopted such as activated carbon adsorption, ozonation, membrane filtrations and nanofiltration, water requirement to process fabric and cloth,[2] and textile production[3] (CPCB 2007c).

A typical large textile industry situated in Rajasthan was selected for the CPCB study. We have used the data from this study to estimate the abatement cost of the textile industry. Production activities involve weaving, dyeing, and finishing, and these activities generate about 575 KLD of wastewater, which is treated in treatment and recycling plant consisting of primary treatment, ion exchange, ultra-filtration, and reverse osmosis membrane filtration (CPCB 2007c).

The operation and maintenance cost of a primary treatment is Rs. 5.85 lakh per month, that is, Rs. 34.08 per kL. For a combined primary and ultra-filtration system, the recurring cost comes to 9.04 lakh per month which works out to Rs. 52.40 per

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[2] 230 L of water is required for processing 1 kg of fabric; 360 L of water is required for processing 1 kg of cloth. We have considered 295 L as average of processing fabrics and cloths.

[3] Fabric weight is usually listed as a GSM value (grams per square meter).

This is the weight for 1 square meter (1 m × 1 m).

If fabric is on a roll, measure width of the roll and multiply by GSM rating to get weight in grams per linear/metre.

GSM rating 500, roll width 2.5 m = 1,250 g or 1.25 kg per linear meter.

GSM rating 155, roll width 3 m = 465 g or 0.65 kg per linear meter.

Table 4.25 Total operation and maintenance cost for cotton textile

	Lakh Rs.
First estimate	3,185,877.4
Second estimate	2,017,635.9
Third estimate	1,122,931.4

Source: Authors' estimate

Table 4.26 Components of operation and maintenance cost for two different estimates of textile plant by CPCB

	Case 1	Case 2		
Item	Cost (Rs.)	Cost (Rs.)	Average cost of two cases	One unit of wastewater treatment cost
1. Salary of operator	100,800	316,560	316,560	0.387
2. Cost of chemicals	122,452	364,750	364,750	0.452
3. Maintenance cost	18,400	1,512	1,512	0.018
4. Electricity charge	151,200	3,024	3,024	0.143
5. Cost of water used	0	795,960	795,960	
Total	392,852	1,481,806	539,349[a](937,329)	

[a]Without wastewater
Source CPCB (2007c)

Table 4.27 Three estimates of operation and maintenance cost for cotton textile plant in 2006–2007 (lakh Rs.)

	First estimate (high)	Second estimate (medium)	Third estimate (low)
1. Salary of operator	1,232,651	780,645.3	434,474.4
2. Cost of chemicals	1,438,925	911,280.3	507,180.3
3. Maintenance cost	58,809.03	37,244.13	20,728.52
4. Electricity charge	455,492.4	288,466.2	160,548.2
Total	3,185,877.4	2,017,636.9	1,122,931.4

Source: Authors' estimate

kL. The recurring cost of the entire system has been reported 12.63 lakh per month. When calculated in terms of Rs./kL, it comes to be Rs. 73.22 (CPCB 2007c). On the basis of wastewater discharge as it is explained in Sect. 4.2, we have three estimates for total operation and maintenance cost which are given in Table 4.25. To get a more detailed component of operation and maintenance cost, we have considered two different estimates of the CPCB which are shown in Table 4.26. Using these ratios, three estimates have been computed for different categories of operation and maintenance cost. These are shown in Table 4.27.

In our current exercise, we have considered the second estimate which is more reasonable, as it lies between two extremes.

4.3.1.2 Milk and Milk Products

There are various methods to treat the dairy wastewater. The aerobic methods which were used for the treatment and disposal of dairy wastewater have been found to be inadequate, because of the problems associated with bulking and excessive biomass growth (Banu et al. 2007). Moreover, the installation costs for aerobic treatment systems are also quite high, and such systems require considerable input energy for the maintenance of aeration. Anaerobic methods for dairy wastewater treatment, on the other hand, have drawn the attention of researchers.

To estimate the operating cost of effluent treatment of milk and milk products (dairy) plant, we have followed a number of steps. We have considered a typical mother dairy plant in India whose annual turnover is Rs. 500 million and total cost (capital and operation and maintenance cost) of effluent treatment is Rs. 7.5 million. We have estimated the ratio of annual turnover and effluent treatment cost which is 0.015. The total annual turnover of dairy industry in India in 2006 is Rs. 14,438,627 lakh. Using the ratio of annual turnover and effluent treatment, we calculated the annual burden of 2006 which is Rs. 216,579.4 lakh. Using three different technologies, we have calculated three estimates of total operation and maintenance cost. We then used the ratio of operation cost to total cost to compute the operation and maintenance cost for three technologies as given in Table 4.28

For the current exercise, we considered total operation cost as Rs. 109,124.84 using technology 1 which seems to be reasonable (Table 4.29). The other two estimates seem to be very low. Due to unavailability of the data for different categories of operation cost (energy, chemicals, etc.), we considered the average cost structure of allied industries such as food and sugar industries (Table 4.30).

4.3.1.3 Livestock

The wastewater treatment system in livestock sector essentially comprise (1) self-cleaning type screening or two-stage screening, (2) anaerobic treatment, (3) aerobic treatment, and (4) filter press for dewatering of the sludge (GOI 2011b).

For the treatment of liquid waste/effluent from slaughter houses, the guidelines contained in the Manual on Sewerage & Sewage Treatment published by the Ministry of Urban Development in 1993 may be followed. The standards prescribed in the Environment Protection Act, 1986, must also be adhered by each slaughter house (GOI 2011b). The estimated waste generated in a slaughter house is stated in Table 4.31.

The Supreme Court of India, High Courts in States, and Lower Courts have taken a serious view on environmental pollution and have in several cases ordered the closing down of existing slaughter houses and flaying units and other such highly polluting industries. Therefore, the State Governments and Urban Local Bodies have chalked out plans for the modernization of slaughter houses. The Central Pollution Control Board (CPCB) has brought out "Draft Guidelines for

Table 4.28 Operation and capital cost for three different techniques for milk and milk products

	Technology 1 (Rs. lakh)	Operation cost as a proportion of total cost	Technology 2 (Rs. lakh)	Operation cost as a proportion of total cost	Technology 3 (Rs. lakh)	Operation cost as a proportion of total cost
Capital cost annualized	5.79		18.06		29.69	
Operation and maintenance cost	5.88	0.504	7.04	0.281	12.63	0.299
Total cost	11.67		25.1		42.32	

Source: CPCB (1992–1993)

Table 4.29 Operation and maintenance cost for milk and milk products for three technologies

Operation cost	Rs. lakh
Using technology 1	109,124.84
Using technology 2	64,636.055
Using technology 3	60,745.77

Source: Authors' estimate

Table 4.30 Components of operation and maintenance cost for milk and milk products

	Ratio of the average cost structure of food and sugar	Dairy (Rs. lakh)
Energy	0.704	76,893.47
Chemical	0.123	13,443.13
Manpower	0.133	14,601.70
Repair	0.038	4,186.54
Total		109,124.84

Source: Authors' estimate

Table 4.31 Waste generation in slaughter house

Type of slaughter	Capacity annual	Daily waste generated house
1. Large	Large animals > 40,000 Small animals > 6,00,000	6–7 t/day
2. Medium	Large animals = 10,001–40,000 Small animals = 1,00,001–6,00,000	2–6 t/day
3. Small	Large animals up to 10,000 Small animals up to 1,00,000	0.5–1 t/day

Source: GOI (2011b)

Table 4.32 Waste process treatment cost for slaughter house

	Waste process		Treatment cost (lakh/year)	Treatment cost (lakh/ton)
Biogas Plant	1,250 kg/day	412.5 t/year	1.5	0.00364
Waste processing stage 1	65 t/day	21,450 t/year	132	0.00615
Waste processing stage 2	60 t/day	19,800 t/year	31	0.00157

Source: GOI (2011b)

Sanitation in Slaughter Houses" during August 1998 (GOI 2011b). The slaughter house waste process consists of biogas plant and waste processing (Table 4.32).

Based on this information, the waste processing cost per ton is Rs. 0.01136 lakh in a year. Thus, the total cost to process 4,900,000 tons of meat in 2006 is 55,643.7 lakh rupees. Further cost distribution among energy, chemical, manpower, and O&M cost as taken from Chakraborty et al. (2001) is given in Table 4.33.

Table 4.33 Components of operation and maintenance cost for livestock sector

	Ratio of the component of O and M cost	Total O and M cost (lakh rupees)
Energy	0.684	38,062.59
Chemical	0.081	4,531.199
Manpower	0.143	7,975.118
Other operation and maintenance	0.091	5,074.839
Total	1	55,643.75

Source: Authors' estimate

4.3.1.4 Food Products

The food processing industries in India have followed the major technological innovations in the industry, including those in clean technologies and processes. The clean technologies include the following:

(a) *Advanced Wastewater Treatment Practices*. It is defined as any treatment beyond secondary (or biological) treatment. These treatment practices are employed to target specific discharge constituents that are of concern. Pathogens, suspended solids, dissolved solids, nitrogen, and phosphorus are removed in advanced wastewater treatment. The following are some of the technologies being used in advanced wastewater treatment: (i) membrane applications, (ii) disinfection, (iii) charge separation, and (iv) other separation practices.

There are various benefits that can be acquired from these practices. Studies have shown that membrane applications can be less energy intensive than evaporation and distillation operations and take up less space. The technology also gives better control of the process effluent. Unlike chemical precipitation, membrane technology does not produce a sludge disposal problem. The main benefit of disinfecting wastewater is that it improves and protects water quality. Similar to membrane applications, ion exchange does not produce a chemical sludge and, like disinfection, it protects the water quality and decreases the nutrient-loading problems that cause eutrophication in receiving waters. Electrocoagulation is beginning to receive attention as a treatment option and is expected to increase in use in the food processing industry. The use of any of these advanced processes improves the final wastewater effluent quality and increases the likelihood of recycling renovated process water (UNIDO).

(b) *Improved Packaging*. Use of less excessive and more environmentally friendly packaging products (UNIDO).

(c) *Improved Sensors and Process Control*. Use of advanced techniques to control specific portions of the manufacturing process to reduce wastes and increase productivity (UNIDO).

(d) *Food Irradiation*. Use of radiation to kill pathogenic microorganisms.

(e) *Water and Wastewater Reduction* (Closed Loop/Zero Emission Systems). This is basically based on the reduction or total elimination of effluent from the manufacturing process. An increasingly viable option for companies is the

Table 4.34 Ratio of operating cost of different items in food processing plant

Items	Lakh Rs./thousand tons
Energy	0.709
Chemicals	0.106
Manpower	0.127
Operation and maintenance	0.056

Source: Chakraborty et al. (2001)

Table 4.35 Total operation and maintenance cost in food processing sector (lakh Rs.)

	Lakh Rs.
Energy	2,716.721
Chemicals	407.337
Manpower	488.9185
Repair or maintenance	217.3605
Total	3,830.337

Source: Authors' estimate

> "zero discharge" system. Many food processing facilities are looking to pretreatment options that can help reduce the amount of lost product. The "zero emissions" strategy relies on a network of companies utilizing each other's waste streams. The strategy is a more economically efficient system than a "closed loop" because the waste products do not have to be fully treated. Both zero discharge and zero emission systems achieve better effluent water quality and have fewer negative impacts on the environment (UNIDO).

The total generation of BOD from food processing sector in 2006–2007 is 57.63 thousand tons. To estimate the operating cost of food processing sector, we assumed that up to 99 % of BOD is eliminated through treatment. The total cost accrued by the food processing plant is 3,830.337 lakh rupees. Table 4.34 shows the ratio of cost structure used in Chakraborty et al. (2001). These ratios have been used to allocate the operating cost among the different categories of food processing sector in India for the year 2006–2007.

The operating cost structure along with different categories is shown in Table 4.35.

4.3.1.5 Sugar

To calculate cost in this industry, we use the ratio of operation and maintenance cost to total output available from Chakraborty et al. (2001). The total value of output of sugar industry is collected from input–output table of India. The total operation and maintenance cost of effluent removal from the sugar industries is estimated to be Rs. 201,493.00 lakh. The distribution of operation and maintenance cost across different heads has been taken from Chakraborty et al. (2001). Table 4.36 presents the components of operation and maintenance cost.

Table 4.36 Total operation and maintenance cost for sugar sector

	Ratio of operating cost of different items	Rs. lakh
Energy	0.376	75,720.24
Chemicals	0.382	77,003.74
Manpower	0.132	26,523.39
Repair or maintenance	0.110	22,245.62
Total	1.000	201,493

Source: Authors' estimate

4.3.1.6 Tea, Coffee, and Beverages

In the current exercise, we have aggregated the tea, coffee, and beverages in one sector, and therefore, the effluent treatment cost will be presented both separately and in a combined form.

Beverages

We have estimated the operation and maintenance cost for effluent treatment following a typical alcohol plant cost provided by Nagaraj and Kumar (2008). This plant effluent removal capacity is 1,500 kilo liters per year, and the total annual effluent removal cost is Rs. 113.24 lakh. On the basis of this typical plant capacity, operation and maintenance cost, and alcohol production in India for 2006–2007, as we have calculated, the total annual cost of removing effluent from alcohol plants in India for the year 2006–2007 is Rs. 241,578.66 lakh (Table 4.37). Different subcategories under operation and maintenance cost are calculated according to the data from the sample plant (Nagaraj and Kumar 2008) given in Table 4.37.

From Table 4.37 we have prepared Table 4.38 according to the different categories of operational cost.

Coffee

In this category, we have also estimated the operation and maintenance cost of an effluent treatment plant for coffee industry. The annual production of coffee in 2006–2007 is 270,500 t. In instant coffee manufacturing, wastewater is generated from spent coffee waste.

This wastewater is acidic in nature and has BOD, 600–1,000 mg/L; COD, 2,500–10,000 mg/L; and SS, 100–1,000 mg/L. The wastewater generation is about 300 KLD which is generally 50–55 % of water use (CPCB 2006a).

Activated sludge process is generally used for treatment of wastewater from the coffee production followed by physicochemical treatment for color removal. Such treatment process has resulted in

$$\mathrm{BOD} - 10\ \ \mathrm{mg/L, COD} - 93\ \ \mathrm{mg/L\ and\ SS} - 14\ \ \mathrm{mg/L\ (CPCB\ 2006).}$$

Table 4.37 Different components under operation and maintenance cost for alcohol plant

	Rs. lakh		Rs. lakh
Cost of culture	55.13	0.486	117,610.66
Average cost of funds	17.5	0.1545	37,333.3323
Cost of diesel	11.32	0.099	24,149.33
Cost of press mud	5.16	0.045	11,007.99
Cost of transportation of press mud		0	0
Annual manpower cost	6.88	0.060	14,677.33
Depreciation (@ 10 %)	15	0.132	31,999.99
Maintenance	2.25	0.0198	4,799.99
Annual operational cost of effluent plant	113.24	1	241,578.66

Source: Nagaraj and Kumar (2008)

Table 4.38 Total operational and maintenance cost for beverage sector in India (Rs. lakh)

	Rs. lakh
Energy cost	24,149.33
Chemical cost	165,952
Manpower cost	14,677.33
Depreciation	32,000
Maintenance	4,800
Total operational and maintenance cost	241,578.7

Source: Authors' estimate

Normally 80–85 % of BOD can be removed from the effluent plant. According to our estimate, the BOD release from coffee processing plant was 200.38 thousand tons in 2006–2007. Out of this it is assumed that 80 % is removed, that is, 160,304 t of BOD. The cost of removal depends on the size of the plant, whether it is a medium- or a large-scale plant. For large-scale plant, the cost is Rs. 747 per ton, while for medium plant it is Rs. 1,160 per ton. We have taken an average of these two types of plant and have used Rs. 953 per ton of BOD removed (CPCB 2006a). Thus, the BOD treatment cost is Rs. 1,529.14 lakh, which covers only the operation and maintenance cost of the plant. The different categories under operation and maintenance cost are derived from the sample plant of effluent treatment of HLL. On the basis of that information, we have calculated the operation and maintenance cost of effluent treatment of coffee processing plant in India for the year 2006–2007 (Table 4.39).

From the above table, the cost structure is derived and is given in Table 4.40. The cost of chemical and electricity covers almost 76 % of the operation and maintenance cost.

According to our sectoral classification, tea, coffee, and beverages together are considered as one sector. Due to this sectoral classification, we have added the operation and maintenance cost of effluent treatment of coffee processing and beverages which is given in Table 4.41.

Table 4.39 Operating cost of effluent treatment plant of HLL (Rs.)

Items	Cost per annum (Rs.)
Non ferric alum	461,920
Sodium hypochlorite	152,188
Urea	29,256
DAP	21,500
Sulfuric acid	8,970
Poly-electrolyte	21,757
Caustic lye	187,113
Cost of manpower	3,49,320
Cost of power	9,68,400
Cost of repair	51,000
Depreciation	2,04,619
Total	24,56,043

Source: CPCB (2006a)

Table 4.40 Components of operating cost of effluent treatment plant of HLL

	Sample plant cost (Rs)	Ratio of total item cost and total cost	Rs. lakh
Total chemical	882,704.00	0.359	549.57
Cost of manpower	349,320	0.142	217.48
Electricity	968,400	0.394	602.93
Repair and depreciation	255,619	0.104	159.14
Total	2,456,043	1	1,529.144

Source: CPCB (2006a)

Table 4.41 Components of operating cost of effluent treatment plant of coffee processing and beverages (Rs. lakh)

	Coffee processing	Beverages	Total
Total chemical	549.575	165,952	166,501.6
Cost of manpower	217.488	14,677.33	14,894.82
Electricity	602.930	24,149.33	24,752.26
Repair and depreciation	159.149	36,800.00	36,959.15
Total O and M cost	1,529.144	241,578.7	243,107.8

Source: Authors' estimate

4.3.1.7 Leather and Leather Products

Tanneries in India are classified under the category of most polluting industries (Sankar 2000). There are more than 1,200 tanneries in India in 1998, of which about 90 % are small-scale units. Tanneries form an intermediate segment of the leather industry. They get hides and skins from the animal husbandry sector and sale tanned leather to downstream units for manufacturing footwear and leather products. By 1990, there was growing awareness about environmental damages resulting from the discharge of untreated effluents by tanneries into streams and rivers. Public

Table 4.42 Operation and maintenance cost for leather effluent plant of Jajmau and Unnao (million Rs.)

	Jajmau (USB based)	Unnao (ASP based)
Power	4.08	3.06
Wages and salaries	1.2	0.84
Chemicals	0.66	0.036
Maintenance	1.08	0.36
Oil and lubricants	0.3	0.12
Sludge disposal	0.9	0.06
Miscellaneous	0.6	0.3
Total	8.82	4.776
Capacity	36MLD	2.15MLD
Capital cost	191.5	19.3

Source: Tare et al. (2012)

Table 4.43 Components of operation and maintenance cost of effluent treatment plant of leather and leather products (Rs. lakh)

	(Rs. lakh)
Power	521.787
Wages and salaries	143.235
Chemicals	6.138
Maintenance	61.386
Oil and lubricants	20.46
Sludge disposal	10.233
Miscellaneous	51.155
Total	**814.397**

Source: Authors' estimate

interest litigation stages against tanneries are culminated in court orders which directed relocation or closure of tanneries which have not either erected ETPS or connected to CETPs.

The total operation and maintenance cost of leather industry in India is calculated on the basis of data available from two different tannery plants in Uttar Pradesh having two different effluent treatment systems (Table 4.42).

The two different treatments systems are USB- and ASP-based CETP. The capacity of the plants is different and thus the capital cost. The number of working days in the CETP plant is 260 days. The production of raw hides and skin in 2006 is 238.3 thousand tons or 238,300,000 kg (FAO 2013). Given that the total wastewater generation rate is 40 litre per kg of hides and skin processing, the total wastewater generation from leather plants in India was 9,532,000,000 kg. Based on the plant capacity and total cost of the plants in Unnao and Jajmau, we have calculated the total effluent treatment cost of leather plants (Rs. 814.397 lakh) in India for the year 2006–2007 (Table 4.43).

4.3.1.8 Paints, Varnishes, and Lacquers

The paint industry is another highly polluting industry. It mainly releases SS, phenol, BOD, and COD. The operation and maintenance cost of effluent treatment

Table 4.44 Cost structure of effluent plant of a typical paint industry in India

Item (1999–2000)	Cost (Rs.)	Ratio of each item to total cost
1. Salary of operator	144,000	0.139
2. Cost of chemicals	197,736	0.191
3. Maintenance cost	60,000	0.058
4. Cost of water used	354,912	0.343
5. Electricity charge	276,000	0.267
Total operation and maintenance cost	1,032,648	1

Source: CPCB 2002–2003a

Table 4.45 Total operation and maintenance cost of effluent treatment plant of paints industry (Rs. lakh)

Item	Rs. lakh
1. Salary of operator	1,120.353
2. Cost of chemicals and water	4,299.731
3. Maintenance cost	466.814
5. Electricity charge	2,147.344
Total	8,034.244

Source: Authors' estimate

plant of a typical paint plant provided by the CPCB for the year 1999–2000 is given in Table 4.44 (CPCB 2002–2003a). The annual turnover for the particular plant is Rs. 341,488,514, and thus, the ratio of annual turnover and total operation cost is 0.0030239. The total output of the paints industry in 2006–2007 is Rs. 2,656,861 lakh (CSO 2011). Using this information we have calculated the total operation and maintenance cost of effluent treatment plant in the paints industry for the year 2006 as Rs. 8,034.24 lakh. The ratio of each category of operation and maintenance to total cost of a typical plant has been used to calculate these items for the year 2006–2007 in India (Table 4.44). Table 4.45 presents the different components of operation and maintenance cost of effluent plant in the paint industry of India for the year 2006–2007.

4.3.1.9 Paper and Paper Products

The paper industry primarily generates heavy amount of BOD, COD, and SS. The cost of operation and maintenance of effluent treatment plant of M/S Ashoka is given in Table 4.46. The effluent treatment cost depends on the production of paper. Given a production of 11,880 t per year for the plant, the operation and maintenance cost for wastewater treatment is Rs. 524,475.5. To get an estimate for the effluent treatment cost of paper plant in India, we have used the above information from this typical plant. The total paper production in India was 6,600,000 t in 2006 (Dipp 2008). Therefore, the total operation and maintenance cost to remove effluent of paper plant in India for the year 2006–2007 is Rs. 2,916.37 lakh. The category of each item of operation and maintenance as taken from the M/S Ashoka is given in Table 4.46.

Table 4.46 A typical effluent treatment plant of M/S Ashoka

Items	Ratio of total cost and each item cost	O and M cost (Rs. lakh)
Labor	0.067	195.5126
Energy	0.665	1,938.227
Chemical	0.155	451.6313
Repair and maintenance	0.114	331.002
Total	1.000	2,916.372

Source: UNEP (2002)

Table 4.47 Allocation of operation and maintenance cost for rubber and rubber products (Rs. lakh)

	(Rs. lakh)
Energy	985.7871
Chemical	3,493.125
Manpower	1,521.088
	6,000

Source: Authors' estimate

4.3.1.10 Rubber and Rubber Products

The operation and maintenance cost of removing effluent for the industry is estimated based on rubber production and annual turnover. The rubber production in 2005 was 1,052,960 metric tons (CPCB 2007b) and the annual turnover was 200 billion rupees (India Finance and Investment Guide 2013). In this context, we have taken the annual burden from a typical plant at 0.30 % of annual turnover. Using that information, we arrive at the total cost of operation and maintenance for the effluent treatment of rubber and rubber product in India for the year 2005, which was Rs. 6,000 lakh (Table 4.47). The items under the operation and maintenance cost are distributed according to the information used in Chakraborty et al. (2001).

4.3.1.11 Jute, Hemp, and Mesta Textile

The estimation of effluent treatment cost of jute, hemp, and mesta textile is done using the information from Chakraborty et al. (2001). The ratio of operation and maintenance cost to total output of jute, hemp, and mesta plant that is available from Chakraborty et al. (2001) has been applied to calculate the operation and maintenance cost of effluent treatment of jute, hemp, and mesta plant in India for the year 2006–2007. The total output for this sector is Rs. 605,489 lakh for the year 2006–2007 (CSO 2011), and we derive the operation and maintenance cost as Rs. 538.88 lakh for the year 2006–2007. Different components of operation and maintenance cost are also calculated using Chakraborty et al. (2001). Table 4.48 presents the cost structure of this sector.

Table 4.48 Components of operation and maintenance cost for jute, hemp, and mesta textile (Rs. lakh)

Energy	198.063
Manpower	331.624
Repair and maintenance	9.19247
Total	538.885

Source: Authors' estimate

Table 4.49 Allocation of operation and maintenance cost for miscellaneous textile plant (Rs. lakh)

Energy	1,338.572
Chemical	80,622.01
Manpower	1,338.572
Repair and maintenance	1,179.213
Total O&M Cost	84,480.67

Source: Authors' estimate

4.3.1.12 Miscellaneous Textile

Like jute, hemp, and mesta textile, the procedure to calculate the effluent treatment cost of miscellaneous textile is almost similar. Here we also considered the ratio of operation and maintenance cost to total output of miscellaneous textile effluent treatment from Chakraborty et al. (2001). The total output of the plant is Rs. 11,256,845 lakh based on the input–output table of 2006–2007. Using this information we have estimated the total operation and maintenance cost of this sector which is Rs. 84,480.67 lakh for the year 2006–2007. The different components of operation and maintenance cost are also calculated on the basis of Chakraborty et al. (2001) and are shown in Table 4.49.

4.3.1.13 Oil and Gas

Oil and gas sector is considered under the mining and quarrying sector for this study. The operating cost of effluent treatment of this sector is relatively complicated. There are normally three different phases for this operation: (1) onshore, (2) GGS (gas gathering station), and (3) GCS (gas collecting station). The performance of ETP for two typical plants in India is shown in Tables 4.50 and 4.51. It shows that GGS treatment gives better result than GCS (CPCB 2006b). The operation and maintenance cost for effluent treatment of ONGC plant that covers 77 % of oil production in India is Rs. 23,652.5 lakh (Table 4.52). Based on this information, the estimates for the whole economy is Rs. 30,717.53 lakh for the year 2006–2007. The different categories of operation and maintenance cost are given in Table 4.53.

On the basis of the above information, the operation and maintenance cost and its breakdown are presented in Table 4.53.

Table 4.50 Performance of ETP installed at OCS (oil collecting station), M/s. Oil India Ltd. (mg/L)

Parameters unit effluent characteristics	Before treatment	After treatment
1. pH	8.8	8.8
2. TSS	38	36
3. TDS	6,534	6,572
4. Oil and grease	486	
6. COD	246	118
7. Chloride	1,154	1,154

Source: CPCB (2006b)

Table 4.51 Performance of ETP installed at Lakwa GGS, M/s. ONGC (mg/L)

Parameters effluent characteristics	Before treatment	After treatment
1. pH	7.2	7.1
2. TSS	122	
3. TDS	1,238	
4. Oil and grease	845	5.8
5. BOD5	330	19
6. COD	1,642	37
7. Chloride	500	610
8. Sulfate	40	

Source: CPCB (2006b)

Table 4.52 Total operation and maintenance cost for effluent treatment plant of ONGC

	Operating cost (m^3/day)	Effluent treated in ONGC plant (m^3)	O and M cost for effluent treatment (Rs.)
Onshore	1,500	3,500	5,250,000
GGS	1,400	240,000	1,960,000,000
GCS	2,000	6,000	400,000,000
Total			2,365,250,000 or 23,652.5 lakh

Source: CPCB (2006b)

Table 4.53 Allocation of operation and maintenance cost for oil and gas effluent (Rs. lakh)

	Rs. lakh
Energy	9,039.303
Chemicals	14,048.16
Labor	5,247.281
Repair and maintenance	2,382.785
Total	30,717.53

Source: Authors' estimate

4.3.1.14 Inorganic Chemicals and Organic Chemicals

Chemical industry is one of India's oldest industries, contributing significantly towards the industrial and economic growth of the nation. The Indian chemical

Table 4.54 Water pollution load generated from dye stuffs industries in India (before treatment)

Sl No.	Class of dye stuff	Production in t/day	Wastewater generation in MLD	COD load generated in t/day
1	AZO	7.1	0.8	1.2
2	Organic pigment	31.5	12.5	18.8
3	Vat	9.0	41.4	62.1
4	Reactive	18.5	1.5	2.2
5	Optical brightener	6.0	3.5	5.2
	Total	70	58.8	89.4

Source: CPCB (2002–2003a)

industry forms the backbone of the industrial and agricultural development of India and provides the building blocks for several downstream industries. According to the Department of Chemicals and Petrochemicals, the Indian chemical industry is estimated to be worth approximately US$ 35 bn, which is about 3 % of India's total GDP with total employment generated of about 1 million. In terms of volume, it is the 12th largest in the world and 3rd largest in Asia (D&B 2007).

Exports of chemicals from India have increased significantly and account for about 14 % of total exports and 9 % of total imports of the country. The Indian chemical industry comprises both small- and large-scale units. The major sub-segments of this industry include alkali, organic chemicals, inorganic chemicals, pesticides, dyes and dyestuffs, and specialty chemicals. It also deals in products like fertilizers, bromine compounds, catalyst, sodium and sodium compounds, dye intermediates, inks and resins, phosphorous, paint chemicals, coatings, isobutyl, zinc sulfate, zinc chloride, water treatment chemicals, organic surfactants, pigment dispersions, industrial aerosols, and many more (D&B 2007).

For the estimation of effluent treatment cost of inorganic and organic chemicals, we considered primarily the dye and dye intermediates industry. Apart from many other pollutants, it primarily releases COD. Table 4.54 shows an example of COD load generated from a dye and dye intermediate plant in India provided by the CPCB (2002–2003a). It is estimated that for the production of 70 t/day of dyes, about 59 mld of wastewater is generated containing 89 tons of COD every day. COD load works out to be 77 t/day for all classes of dye stuff after treatment. Thus, the effluent treatment plant on an average removes 86.51 % of COD. However, to remove this amount of COD, the plant has to incur some capital cost and operation and maintenance cost of the ETP (Table 4.55).

It has been found that for a large-scale industry, operation cost is around 20 % of total capital cost (Murty and Kumar 2011). Therefore, 20 % of the capital cost of the effluent treatment plant of chemical industry (Table 4.56) is around Rs. 1,728 lakh. Further, distribution across inorganic and organic chemicals was done on the basis of COD release. The COD release is higher from organic compared to inorganic chemicals. Thus, the COD removal cost is higher for organic chemicals relative to inorganic chemicals (Table 4.56). The different items of operation and maintenance under the effluent treatment of these chemical plants are derived from a typical

Table 4.55 ETP capital cost for different units of dye and dye intermediates in India (Rs. lakh)

	ETP capital cost (Rs. lakh)
A.P. (Jeedimetla)	381.0
Patancheru	728.0
Vatva	4,401.0
Ankleshwar	680.0
Subtotal	6,190.0
Other ETP total	2,451.8
Grand total	8,641.8

Source: CPCB (2002–2003a)

Table 4.56 Total operation and maintenance cost of organic and inorganic chemicals sector in India

	COD	Ratio of COD release from organic and inorganic chemicals	Total cost (Rs. lakh)
Organic chemical	267	0.551	953.65
Inorganic chemical	216.9	0.448	774.71
Total	483.9	1	1,728.36

Source: Authors' estimate

Table 4.57 Operation and maintenance cost for a typical plant of inorganic and organic chemicals and its components

Items	Operation cost (2000–2001) rupees	Operation cost (1999–2000) rupees	Average ratio of total cost and each item cost
Service contract/salary of operator	554,000	204,166	0.112
Cost of chemicals	570,000	2,484,540	0.454
Maintenance cost	100,000	581,652	0.101
Electricity charge	1,270,000	957,760	0.331
O and M cost total	2,494,000	4,228,118	1
Capital cost	20,300,000	7,092,500	

Source: CPCB (2002–2003a)

chemical plant. A sample of expenditure on operation and maintenance for two different years is given in Table 4.57. We took the average of two years expenditure and calculate the different categories of expenditure on operation and maintenance for the effluent treatment plant of inorganic and organic chemicals in India. Table 4.58 presents the item-wise operation and maintenance cost for organic and inorganic chemicals sector in India for the year 2006–2007. The cost of chemicals and electricity charges covers almost 78 % which is relatively high compared to other plants.

Table 4.58 Allocation of operation and maintenance cost of inorganic and organic chemicals sector in India for 2006–2007 (Rs. lakh)

Items	Organic	Inorganic
Service contract/salary of operator	107.559	87.375
Cost of chemicals	433.339	352.024
Maintenance cost	96.704	78.557
Electricity charge	316.046	256.741
O and M cost total	953.65	774.7

Source: Authors' estimate

Table 4.59 Total operation and maintenance cost and its allocation for other chemicals sector

Items	Ratio of each item to total operation and maintenance cost	Rs. lakh
Service contract/salary of operator	0.222	57,725.27
Cost of chemicals	0.228	59,392.43
Maintenance cost	0.040	10,419.72
Electricity charge	0.509	132,330.5
Total operation and maintenance cost	1	259,867.9

Source: Authors' estimate

4.3.1.15 Other Chemicals

To derive the operation and maintenance cost of effluent treatment for other chemical sector, we considered mainly the pharmaceutical industry. We have also used the ratio of total operation and maintenance cost (Rs. 2,494,000) to total revenue (Rs. 158,192,615) of a typical effluent plants provided by Chokhavatia Associates 2012. Together with the total gross output of other chemical plant in India which is Rs. 16,483,235 lakh (I-O table 2006–2007) for the year 2006–2007, we calculated the total operation and maintenance cost for the effluent treatment of other chemicals in India for the year 2006–2007, which is Rs. 259,867.9 lakh. Furthermore, the estimation of different categories under operation and maintenance cost is taken from a typical pharmaceutical plant in India which is shown in Table 4.59. The operation and maintenance category shows high electricity charges similar to the inorganic and organic chemicals sectors, but the cost for chemicals is slightly lower.

4.3.2 Abatement Cost in Summary Form

The pollution abatement costs of different industries as estimated using the different sources are presented in summary form in Table 4.60.

Table 4.61 records the percentage share of different categories of operation and maintenance cost of the different industries. A look at the table reveals the variation of the components of cost within a sector and also among the sectors. We find that cost of energy dominates in sectors like dairy, livestock, food, leather, paper, and

Table 4.60 Pollution abatement cost of different industries in India for the year 2006–2007 (Rs. lakh)

I-O sector number		Energy	Chemicals	Labor	Other operation and maintenance	Total
3	Dairy	7,689.347	1,344.313	1,460.17	418.6539	10,912.48
4	Livestock	38,062.59	4,531.199	7,975.118	5,074.839	55,643.75
7	Oil and gas (mining)	9,039.303	14,048.16	5,247.281	2,382.785	30,717.53
8	Sugar	75,720.24	77,003.74	26,523.39	22,245.62	201,493
10	Tea, coffee, and beverages	24,752.26	166,501.6	14,894.82	36,959.15	243,107.8
11	Food products	1,631.788	244.7439	293.5954	130.5139	2,300.641
12	Cotton textile	23,708.68	74,897	64,160.27	3,061.049	165,827
14	Jute, hemp, and mesta textile	198.0631	–	331.6244	9.192477	538.88
15	Miscellaneous textile	1,338.572	80,622.01	1,338.572	1,179.213	84,478.37
17	Paper and paper products	1,938.227	451.6313	195.5126	328.3796	2,913.75
18	Leather and leather products	521.7875	87.98769	143.2358	61.38676	814.3977
19	Rubber and rubber products	985.7871	3,493.125	1,521.088	–	6,000
22	Inorganic chemicals	256.7414	352.0248	87.37591	78.55795	774.7
23	Organic chemicals	316.0467	433.3399	107.5591	96.70426	953.65
26	Paints, varnishes, and lacquers	2,147.345	4,299.731	1,120.354	466.8141	8,034.244
27	Other chemicals	132,330.5	59,392.43	57,725.27	10,419.72	259,867.9
	Total	320,637.3	487,703	183,125.2	82,912.59	1,074,378

Source: Authors' estimate

other chemicals, while chemicals cost is high in tea, coffee beverages, rubber, and miscellaneous textile. The contribution of labor is not significant in most of the sectors except in jute, hemp, and mesta textile and cotton textile. These variations in the component of cost structure will have some impact on output and prices of the whole economy which will be rather evident in our subsequent analysis.

The cost data that have been estimated are incorporated in the input–output framework through introduction of a new sector, the "clean water" sector, as presented in the row and column 39 of the I-O table presented in Appendix A. Of the running cost items, cost of power and chemicals (inorganic) has been treated endogenously into the system, while other cost of operation and maintenance and the salaries of the staffs are treated exogenously as components of gross value added.

Table 4.61 Share of different categories of operation and maintenance cost of different industries in India

I-O sector number		Energy	Chemicals	Labor	Other operation and maintenance
3	Dairy	0.704638	0.12319	0.133807	0.0383647
4	Livestock	0.684041	0.081432	0.143325	0.0912023
7	Oil and gas (mining)	0.294272	0.457334	0.170824	0.0775708
8	Sugar	0.375796	0.382166	0.131634	0.1104039
10	Tea, coffee, and beverages	0.101816	0.684888	0.061268	0.1520278
11	Food products	0.709278	0.106343	0.127642	0.0567471
12	Cotton textile	0.142972	0.451657	0.386911	0.0184593
14	Jute, hemp, and mesta textile	0.367546	0	0.615396	0.0170585
15	Miscellaneous textile	0.015845	0.954351	0.015845	0.0139588
17	Paper and paper products	0.6652	0.155	0.0671	0.1127
18	Leather and leather prod	0.640704	0.10804	0.175879	0.0753769
19	Rubber and rubber products	0.164298	0.582188	0.253515	0
22	Inorganic chemicals	0.331407	0.454401	0.112787	0.1014043
23	Organic chemicals	0.331407	0.454401	0.112787	0.1014043
26	Paints, varnishes, and lacquers	0.267274	0.535176	0.139447	0.0581031
27	Other chemicals	0.704638	0.12319	0.133807	0.0383647
	Total	0.684041	0.081432	0.143325	0.0912023

Source: Authors' estimate

4.4 Limitation of Data

Though we have made a modest attempt to estimate the generation of different types of pollutants and also treatment cost (abatement cost) of different industries, the problems being faced in data collection, processing, and analysis cannot be ignored. Some of them are as follows:

1. Adequately detailed, appropriate, and recent up-to-date data on different types of water pollutants generated by different industries of the Indian economy were lacking.
2. Detailed pollution abatement activities of different industries were not available in required form. The cost data of pollution abatement activities could be estimated for only 16 industries due to data constraints.

Discussion and analysis of results have to be considered with care because of these data problems.

Appendix 4.A.1: Aggregation Scheme of the Input–Output Table of 2006–2007

Serial number	Aggregated sectors	Sectors in input–output table	Sector number in I-O table
1	Agriculture	Paddy, wheat, jowar, bajra, maize, gram, pulses, fruits, vegetables, other crops	1–7, 18–20
2	Other agriculture	Sugarcane, groundnut, coconut, other oilseeds, jute, cotton, tea, coffee, rubber, tobacco, forestry and logging	8–17, 25
3	Milk and milk products	Milk and milk products	21
4	Livestock	Animal services (agricultural), poultry and eggs, other livestock products and gobar gas	22–24
5	Fishing	Fishing	26
6	Coal and lignite	Coal and lignite	27
7	Mining and quarrying	Natural gas, crude petroleum, iron ore, manganese ore, bauxite, copper ore, other metallic minerals, lime stone, mica, other nonmetallic minerals	28–37
8	Sugar	Sugar, khandsari-boora	38–39
9	Oil and vanaspati	Hydrogenated oil (vanaspati), edible oils other than vanaspati	40–41
10	Tea, coffee, and beverages	Tea and coffee processing, beverages	42, 44
11	Food products	Miscellaneous food products, tobacco products	43–45
12	Cotton textile	Khadi, cotton textiles (handlooms), cotton textiles	46–47
13	Woolen and silk textile	Woolen textiles, silk textiles, art silk, synthetic fiber textiles	48–50
14	Jute, hemp, and mesta textiles	Jute, hemp, and mesta textiles	51
15	Miscellaneous textile products	Carpet weaving, readymade garments, miscellaneous textile products	52–54
16	Wood and wood products	Furniture and fixtures-wooden, wood and wood products	55–56
17	Paper and paper products	Paper, paper products and newsprint, printing and publishing	57–58
18	Leather and leather products	Leather footwear, leather and leather products	59–60
19	Rubber products	Rubber products	61
20	Plastic products	Plastic products	62
21	Petroleum and coal tar products	Petroleum products, coal tar products	63–64
22	Inorganic heavy chemicals	Inorganic heavy chemicals	65
23	Organic heavy chemicals	Organic heavy chemicals	66

(continued)

Serial number	Aggregated sectors	Sectors in input–output table	Sector number in I-O table
24	Fertilizers	Fertilizers	67
25	Pesticides	Pesticides	68
26	Paints, varnishes, and lacquers	Paints, varnishes, and lacquers	69
27	Other chemicals	Drugs and medicines, soaps, cosmetics and glycerin, other chemicals	70–71, 73
28	Synthetic fibers, resin	Synthetic fibers, resin	72
29	Other nonmetallic mineral products	Structural clay products, cement, other nonmetallic mineral prods.	74–76
30	Iron and steel	Iron and steel ferro alloys, iron and steel casting and forging, iron and steel foundries	77–79
31	Machinery and metal products	Nonferrous basic metals, hand tools, hardware, miscellaneous metal products, tractors and agri. implements, industrial machinery (F & T), Industrial machinery (others), machine tools, other nonelectrical machinery	80–87
32	Electrical machinery	Electrical industrial machinery, electrical wires and cables, batteries, electrical appliances, communication equipments, other electrical machinery, electronic equipments (including TV)	88–94
33	Transport equipment	Ships and boats, rail equipments, motor vehicles, motor cycles and scooters, bicycles, cycle, rickshaw, other transport equipments	95–100
34	Other machinery	Watches and clocks, medical, precision and optical instruments, gems and jewelry, aircraft and spacecraft, miscellaneous manufacturing	101–105
35	Construction	Construction	106
36	Electricity gas and water supply	Electricity gas and water supply	107–108
37	Transport services and communication	Railway transport services, land transport including via pipeline, water transport, air transport, supporting and aux. transport activities, storage and warehousing, and communication	109–115
38	Other services	Trade, hotels and restaurants, banking, insurance, ownership of dwellings, education and research, medical and health, business services, computer and related activities, legal services, real estate activities, renting of machinery and equipment, O.com, social and personal services, other services, public administration	116-130

Source: CSO (2011)

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Chapter 5
Experiment with Models: Results and Discussion

This chapter analyzes the results of the application of the models developed in Chap. 3. Results on direct and indirect water pollution requirement and water pollution content of the total final demand of different sectors of India will be presented followed by the discussion on the effects of pollution abatement costs on output and prices of different goods and services.

5.1 Results on Direct and Indirect Water Pollution Requirement

We have estimated the direct and total (direct and indirect) water pollution generation coefficients of different sectors, respectively, for the year 2006–2007. The ten sets of pollution output coefficient that make up matrix W are used in the computation. As it is well known, the inverse $(I-A)^{-1}$, where A represents structural (input coefficients) matrix of a given economy, describes the total, that is, direct and indirect effect of "one lakh rupees" worth increase in the final demand for the products of any given industry on the total output of this and every other industry. The amounts of each one of the ten different kinds of water pollutants generated in connection with the increase in level of all output contributing directly or indirectly to deliver to final users of one "lakh rupees" worth of each particular kind of good are represented accordingly by the matrix product, $W^* (I-A)^{-1}$.

In other words, direct and indirect water pollution coefficients of the Indian industries are given by the matrix product $R' = W * (I-A)^{-1}$.

Here:

R' is the direct and indirect water pollution coefficient matrix of different sectors (10×38).

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W is the direct water pollution coefficient matrix of different sectors (10×38).
$(I - A)^{-1}$ is the Leontief matrix multiplier of different sectors (38×38).

We noticed that for all industries, total coefficient is significantly higher compared to the corresponding data in direct coefficient (Appendices 5.A.1 and 5.A.2). The sector having zero direct coefficients signifies that the sector is non-polluting; however, the corresponding nonzero entry in total coefficient stresses that though the sector is non-polluting, it indirectly participates in the overall pollution-generating machinery. Further, the type of pollutants released is also differing across sectors. For example, the other machinery sector generates only BOD, COD, and phenol out of ten pollutants. Electricity sector generates only suspended solids and marginal COD.

Due to lack of data, some sectors such as transport and communication, other services, and electrical machinery are assumed to be non-polluting in these exercises. However, the total pollution coefficient emphasizes that though the above sectors are assumed non-polluting, they indirectly participate in the overall pollution generation (through the inputs they use). Direct total pollution generation in transport equipment, electrical machinery, construction, and transport and communication services is absent, but (through the inputs they use) they generate pollution indirectly at a certain rate of SS, DS, oil and grease, BOD, and COD, respectively, per lakh rupees of the products of these sectors.

Figures 5.1, 5.2, 5.3, and 5.4 present the direct coefficient of four important water pollutants: COD, BOD, SS, DS respectively. These figures capture the sectors having the highest direct coefficients. The highest contribution of DS per lakh rupees is generated by cotton textile sector, while for suspended solids, it is by electricity. Leather and leather products, milk and milk products, and paper products are also in the top lists of these two pollutants. An interesting feature is noticed for the direct coefficients of BOD and COD. Most of the sectors are common in these pollutants: agriculture; milk and milk products; livestock; jute, hemp, and mesta textiles; tea, coffee, and beverages; and rubber products. Apart from that, cotton textile, leather and leather products, and paper and paper products are also prominent in case of COD release.

The contribution of total coefficients is observed for almost all the sectors even though direct coefficients for some of the sectors reveal zero.

Tables 5.1 and 5.2 show total coefficients for 12 sectors across four important pollutants: BOD, COD, SS, and DS. We noticed that most of the sectors are common in direct and total coefficient across pollutants. For example, sectors like electricity; jute, hemp, and mesta textiles; cotton textile; agriculture; and paper and paper products are common in both direct and total coefficient list of suspended solids. The new entries of metallic sector, chemicals, pesticides, and transport equipment are due to the indirect influence of the sectors. This is quite evident

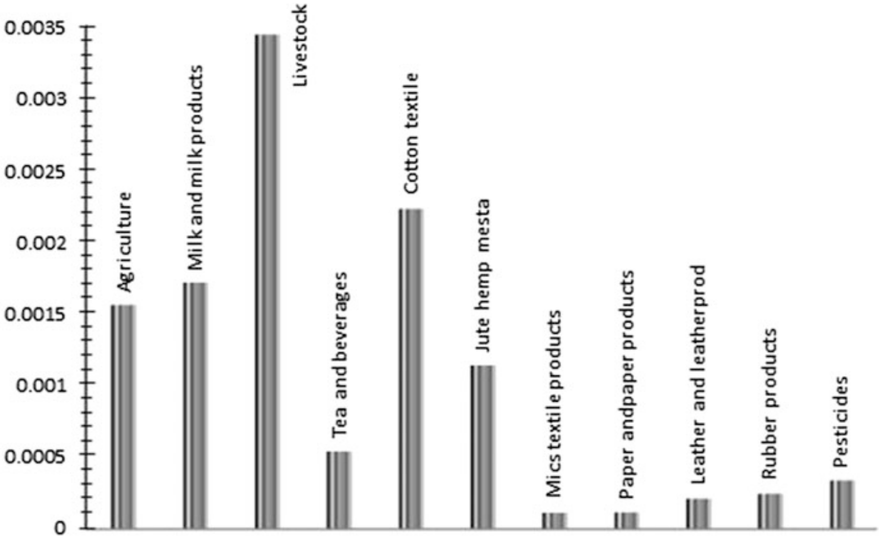

Fig. 5.1 Direct coefficients of COD for important sectors (thousands tons of COD per lakh rupees of output for the year 2006–2007) (Source: Results from the study)

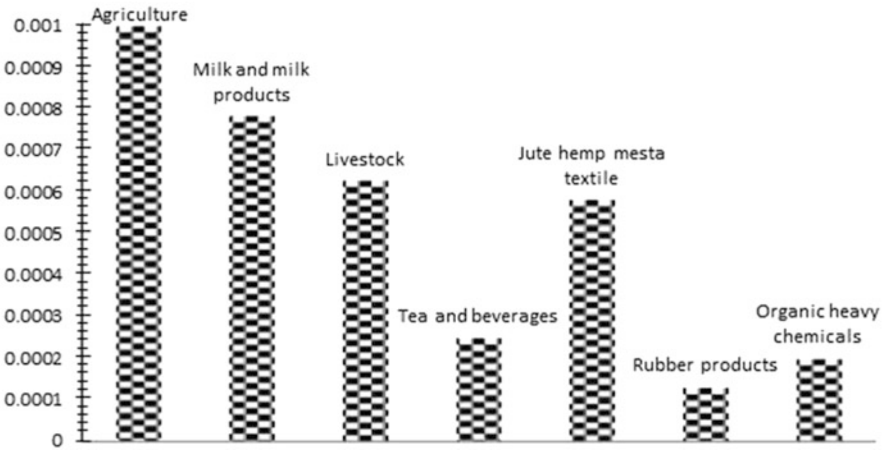

Fig. 5.2 Direct coefficients of BOD for important sectors (thousands tons of BOD per lakh rupees of output for the year 2006–2007) (Source: Results from the study)

through input–output analysis and also helpful for the policy makers. In most cases, the policy makers identify the sectors looking at the direct water pollution coefficient and suggest policies on how to minimize that without considering the values of the total coefficient. Unless the total coefficient is considered, the policies

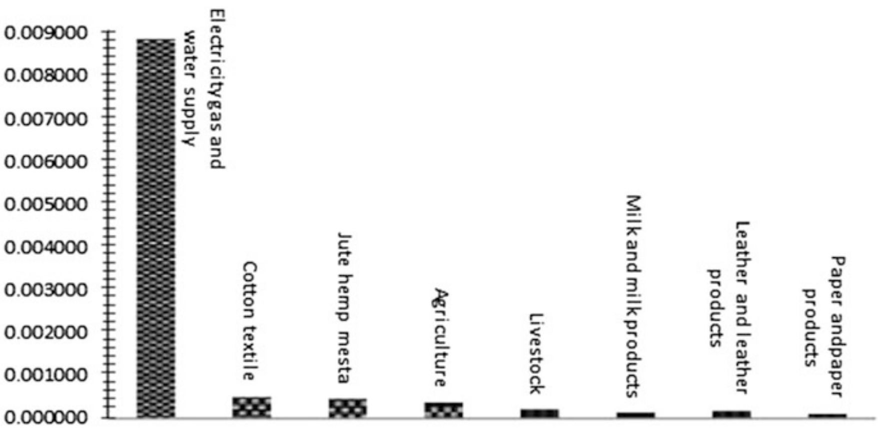

Fig. 5.3 Direct coefficients of SS for important sectors (thousands tons of SS per lakh rupees of output for the year 2006–2007) (Source: Results from the study)

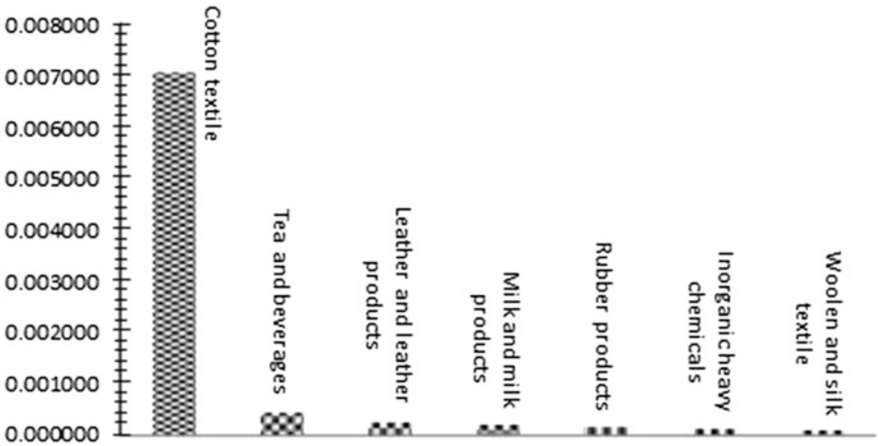

Fig. 5.4 Direct coefficients of DS for important sectors (thousands tons of DS per lakh rupees of output for the year 2006–2007) (Source: Results from the study)

suggested may not yield the desired results. The total coefficients of sectors identified as top for the dissolved solids are almost common in direct coefficients.

The sectors identified as top 12 under BOD and COD also release DS. Sectors at the top of the direct coefficient list are also present in the total coefficient list. Between BOD and COD (Table 5.1), we observed that most sectors are common in the list of total coefficients. Apart from these common sectors, organic chemical, paper products, and oil and vanaspati are important sectors in terms of BOD, while textile group plays a large role in COD release. As we mentioned, the type of pollutant released mostly depends on the type of sectors; however, the top sectors in

Table 5.1 Total coefficients of BOD and COD for selected sectors (thousand tons of pollutants directly and indirectly discharged per lakh rupees of output for the year 2006–2007)

Sectors	BOD	Sectors	COD
Agriculture	0.001227	Livestock	0.003893
Livestock	0.000895	Cotton textile	0.002604
Milk and milk products	0.000872	Agriculture	0.002018
Jute, hemp, mesta	0.000617	Milk and milk products	0.001870
Food products	0.000451	Jute, hemp, mesta	0.001241
Tea, coffee, and beverages	0.000361	Leather and leather products	0.000923
Organic heavy chemicals	0.000277	Food products	0.000832
Leather and leather products	0.000229	Tea, coffee, and beverages	0.000764
Rubber products	0.000192	Miscellaneous textile products	0.000629
Pesticides	0.000159	Pesticides	0.000494
Paper and paper products	0.000150	Rubber products	0.000403
Oil and vanaspati	0.000115	Woolen and silk textile	0.000359

Source: Results from the study

Table 5.2 Total coefficients of SS and DS for selected sectors (thousand tons of pollutants directly and indirectly discharged per lakh rupees of output for the year 2006–2007)

Sectors	SS	Sectors	DS
Electricity gas and water	0.012485	Cotton textile	0.007981
Cotton textile	0.001440	Miscellaneous textile products	0.001358
Jute, hemp, mesta	0.001327	Tea, coffee, and beverages	0.000497
Other nonmetallic mineral	0.001101	Woolen and silk textile	0.000470
Iron and steel	0.001092	Leather and leather products	0.000362
Organic heavy chemicals	0.000885	Rubber products	0.000250
Inorganic heavy chemicals	0.000857	Milk and milk products	0.000213
Paper and paper products	0.000810	Inorganic heavy chemicals	0.000178
Woolen and silk textile	0.000800	Other chemicals	0.000071
Agriculture	0.000796	Livestock	0.000068
Transport equipment	0.000721	Plastic products	0.000062
Pesticides	0.000718	Petroleum and coal tar products	0.000056

Source: Results from the study

the BOD and COD list are almost the same as that for suspended solids and dissolved solids. Overall observation from both the direct and total coefficient reveals that the water pollution intensive sectors are textile group, light manufacturing, agriculture, and agri-food sectors. The detail list of sectors contributing to direct and total coefficients is given in Appendices 5.A.1 and 5.A.2, respectively.

5.2 Total Amount of Pollution in Total Final Demand and Its Component

In this section, we determine the total amount of the different types of pollution generated from total final demand and different components of final demand of the different industries. In matrix notations, the complete set of such multiplication can be described as follows:

$$R = R * Y$$

R is the amount of each one of the ten different kinds of pollutants (SS, DS, chloride, sulfide, oil and grease, phenol, zinc and others, BOD, and COD) generated directly and indirectly to meet the total final demand of the different sectors (10×38) of the years 2006–2007.

R^* is the direct and indirect water pollution coefficient matrix of the different sectors (10×38).

Y is the diagonal matrix of total final demand (38×38).

Tables 5.3 and 5.4 show the results of such computations. In this section, matrices are transposed for the sake of conveniences. Rows of the table offer the total amount of different types of pollutant generated in the years 2006–2007 by total final demand of different sectors. Some figures in table show negative entries as the total final demand of those particular industries is negative.

The total amount of different types of water pollution with respect to total final demand of all the sectors taken together and its components are shown in Table 5.3. It appears from Table 5.3 that in that particular year, 203, 228.84, 66, 201.23, 3, 144.41, 81, 668.44, and 174,803.13 thousand tons of suspended solids, dissolved solids, chloride, BOD, and COD, respectively, are generated by total final demand of all the sectors.

Examining the entries in final demand (Appendix 5.A.3), it is observed that the additional output of SS generated to the delivery to final users of one additional lakh rupees worth of sugar product was responsible for the generation of 425.28 thousand tons of SS. Similar calculation has been done for each of the ten pollutants and other components of final demand (private final consumption expenditure, government final consumption expenditure, gross fixed capital formation, change in stock, and export and import). Results of such computations are shown in the table, respectively.

Table 5.3 Total amount of different water pollutant contents in final demand and its component of India for the year 2006–2007 (figures in '000 tons per lakh rupees of final demand)

	Final demand	Private final consumption expenditure	Export	Import	Govt. final consumption expenditure	Change in stock	Gross final capital formulation
SS	203,229	113,148.71	39,071.1	50,908.9	21,171.24	6,025.84	74,720.838
DS	66,201.2	46,567.68	19,960.5	5,497.36	966.3	1,926.64	2,277.446
Chloride	3,144.41	1,850.72	1,138.56	474.86	78.56	137.16	414.277
Sulfide	1,227.53	691.54	457.67	187.06	40.56	56.18	168.645
Oil/grease	3,737.28	3,138.88	669.46	775.28	154.95	−5.15	554.417
Phenol	426.92	190.4	554.21	849.43	27.86	46.63	457.252
Zinc	39.07	6.3	5.69	11.76	1.08	−0.53	38.293
Others	14,292.2	11,495.63	1,865.63	1,288.75	574.63	474.29	1,170.811
BOD	81,668.4	69,972.96	9,041.72	7,814.35	2,522.12	1,912.34	6,033.65
COD	174,803	144,862.52	20,227.4	10,932.6	5,109.72	4,400.72	11,135.41

Source: Results from the study

Table 5.4 Effects of pollution control cost on output of different goods and services (lakh rupees)

		New gross output with clean water	Old gross output	Percentage change
1	Agriculture	57,661,454.32	57,629,197	0.06
2	Other agriculture	15,790,278.60	15,759,855	0.19
3	Milk and milk products	14,441,099.20	14,438,630	0.02
4	Livestock	8,598,718.26	8,588,824	0.12
5	Fishing	4,015,763.06	4,015,304	0.01
6	Coal and lignite	4,772,565.13	4,636,815	2.93
7	Mining and quarrying	9,477,488.46	9,186,905	3.16
8	Sugar	4,109,031.14	4,102,013	0.17
9	Oil and vanaspati	5,052,639.51	5,047,260	0.11
10	Tea, coffee, and beverages	8,506,362.14	8,496,684	0.11
11	Food products	16,860,115.04	16,848,685	0.07
12	Cotton textile	7,753,163.20	7,750,841	0.03
13	Woolen and silk textile	5,130,943.06	5,125,327	0.11
14	Jute, hemp, and mesta textiles	608,795.74	605,491	0.55
15	Miscellaneous textile products	11,261,700.17	11,256,847	0.04
16	Wood and wood products	2,222,129.05	2,206,365	0.71
17	Paper and paper products	5,970,355.37	5,928,380	0.71
18	Leather and leather products	2,217,642.02	2,212,585	0.23
19	Rubber products	3,995,537.58	3,982,413	0.33
20	Plastic products	5,588,451.66	5,550,096	0.69
21	Petroleum and coal tar products	29,586,879.67	29,303,980	0.97
22	Inorganic heavy chemicals	4,962,070.24	4,404,579	12.65
23	Organic heavy chemicals	3,933,195.32	3,712,881	5.93
24	Fertilizers	4,811,474.08	4,780,094	0.66
25	Pesticides	1,196,137.06	1,174,691	1.83
26	Paints, varnishes, and lacquers	2,669,184.77	2,656,868	0.46
27	Other chemicals	16,641,887.60	16,483,235	0.96
28	Synthetic fibers, resin	4,085,359.73	4,019,046	1.65
29	Other nonmetallic mineral products	9,762,911.43	9,742,535	0.21
30	Iron and steel	25,989,543.16	25,940,192	0.19
31	Machinery and metal products	34,707,600.05	34,583,931	0.36
32	Electrical machinery	37,502,298.47	37,431,227	0.19
33	Transport equipment	15,198,756.07	15,185,879	0.08
34	Other machinery	12,159,213.04	12,103,599	0.46
35	Construction	90,703,863.15	90,623,003	0.09
36	Electricity gas and water supply	20,323,054.42	19,268,534	5.47
37	Transport services and communication	72,726,331.66	72,472,275	0.35
38	Other services	214,012,011.26	213,520,795	0.23
39	Clean water	3,029,765.14	3,025,939	0.13
	Total	*799,004,079.02*	*793,801,798*	0.66

Source: Results from the study

Table 5.5 Impact on output by different categories

Category	Sectors
Above 10 %	Inorganic chemicals
Above 5 %	Electricity gas and water supply; organic heavy chemicals
Above 1 %	Coal and lignite; mining and quarrying; pesticides; synthetic fiber, resin
Below 1 %	The rest of sectors

Source: Results from the study

5.3 Effects of Pollution Abatement Cost on Output

This section will present the effects of pollution abatement cost on output. We have conducted an experiment with pollution abatement cost data (based on the extended input–output model as described earlier in Chap. 3) that resulted in a new set of outputs and prices as formally illustrated through Tables 5.4 and 5.5. We have augmented the original input–output system with incorporation of a clean water sector (Chap. 3).

Table 5.5 shows that output has increased for all the sectors in the economy with the consideration of pollution abatement costs. To have a closer look at the effects on output, the sectors could be grouped (as presented in Table 5.5) under three broad categories, depending on percentage effect on its output (namely, above 10 %, above 5 %, above 1 %, and below 1 %).

Due to the introduction of clean water sector in the original input–output model, a revised gross output which is 0.65 % more than the actual total output is generated. It is seen that inorganic chemicals sector experiences a large output increase of 12.65 %, from lakh rupees 4,404,579 to lakh rupees 4,962,070. An increase of more than 5 % is observed for electricity gas and water supply and organic heavy chemicals sectors as electricity and chemicals are essential inputs for all pollution control activities such as ETP, CETP, and any small-scale pollution control strategy. Four sectors experienced more than 1 % increase (but below 5 %) in output due to pollution control. Among them, pesticides and synthetic fiber and resin are most important. There are some sectors that despite seeing less than 1 % increase in output are significant such as fertilizer; petro coal products; plastic products; rubber products; other chemicals; paper and paper products; wood and wood products; paints, varnishes, and lacquers; machinery; and metal and metal products. These sectors may be indirectly involved in the process of reducing pollution leading to the small increase in output.

Here we noticed backward and forward linkages across sectors. As the clean water sector makes use of power and chemical inputs, the demand for these sectors increases, thus resulting in their increased production. This, in turn, increases the demand for products – like coal and lignite, mining minerals, and other chemicals – used as inputs in the production of power and chemicals, which further increases the demand for goods used in their production (involving again power, chemicals, and others). Changes in the demand for or production of goods tend to give rise to changes in the demand for or production of goods used in producing them, causing output increases for all the sectors of the economy. This is because the sectors are all interlinked with or interdependent on each other directly or indirectly as modeled by input–output method. The higher percentage increase (as depicted from column 3 Table 5.4) for inorganic chemicals; electricity, gas and water supply; coal and lignite; and mining sectors indicates that these are sectors having extensive linkage with the demand for clean water.

5.4 Effects of Pollution Abatement Cost on Prices

Considering the treatment activity undertaken, there is a value-added vector with a nonzero element (v2) and nonzero matrix element A_{12}, A_{21}, A_{22} (Eq. 3.7 in Chap. 3). Whereas when the treatment is not undertaken, all of these terms disappear. Therefore, prices for all products will be different and higher in the former case than in the latter case.

The added cost will of course be included in the price of the marketed products. Any shift in cost will tend to have an effect on prices. The direct cost of clean water production is not the whole effect. Since many industries are affected, the cost of purchased intermediate goods and services will also rise unevenly across the economy. Almost all sectors are impacted by the implementation of pollution abatement activities (clean water) as evident from Table 5.6.

Table 5.6 shows that prices have also increased for all the sectors of the economy. The explanation behind it is similar to that of output increase. The increase in price is the outcome of a new gross value added derived from the addition of salaries to the staff and cost of operation and maintenance because of the incorporation of an additional sector, the clean water. As a result, the price increase is not high for the sectors in which demand or production percentage increase is high but is high for sectors for which pollution abatement costs have been available. The reason is that additional cost in the form of salaries of the staff and cost of operation and maintenance by convention influence the economic decision (of price fixing) of the sectors.

Moreover, direct as well as indirect effects of the increased demand for and production of goods used as inputs by the clean water sector (as reflected through the extended $[I - A]^{-1}$ matrix) also influence the price increase to some extent. The percentage increase in price is marginal for sector which does not incur additional cost related to pollution control measures, with the exception of agriculture, and other agriculture.

Herein, the whole economy could also be categorized under three groups depending on the percentage effect on its prices (namely, above 5 %, above 1 % and below 5 %, and below 1 %) as depicted in Table 5.7.

The sectors mentioned in Table 5.7 (cotton textile, agriculture, construction, and electricity, gas, and water) are expected to see a large increase in price due to the clean water cost. These may be due to the increased demand for production of these products corresponding to the clean water sector's input requirements.

Table 5.6 Effects of pollution control cost on prices of different goods and services (lakh rupees)

	Sectors	Old price	New price	Percentage change
1	Agriculture	1.00	1.0596	5.96
2	Other agriculture	1.00	1.0276	2.76
3	Milk and milk products	1.00	1.0299	2.99
4	Livestock	1.00	1.0240	2.40
5	Fishing	1.00	1.0004	0.04
6	Coal and lignite	1.00	1.0007	0.07
7	Mining and quarrying	1.00	1.0134	1.34
8	Sugar	1.00	1.0212	2.12
9	Oil and vanaspati	1.00	1.0191	1.91
10	Tea, coffee, and beverages	1.00	1.0264	2.64
11	Food products	1.00	1.0496	4.96
12	Cotton textile	1.00	1.1293	12.93
13	Woolen and silk textile	1.00	1.0089	0.89
14	Jute, hemp, and mesta textiles	1.00	1.0077	0.77
15	Miscellaneous textile products	1.00	1.0150	1.50
16	Wood and wood products	1.00	1.0005	0.05
17	Paper and paper products	1.00	1.0220	2.20
18	Leather and leather products	1.00	1.0200	2.00
19	Rubber products	1.00	1.0174	1.74
20	Plastic products	1.00	1.0157	1.57
21	Petroleum and coal tar products	1.00	1.0150	1.50
22	Inorganic heavy chemicals	1.00	1.0284	2.84
23	Organic heavy chemicals	1.00	1.0123	1.23
24	Fertilizers	1.00	1.0289	2.89
25	Pesticides	1.00	1.0156	1.56
26	Paints, varnishes, and lacquers	1.00	1.0299	2.99
27	Other chemicals	1.00	1.0333	3.33
28	Synthetic fibers, resin	1.00	1.0080	0.80
29	Other nonmetallic mineral products	1.00	1.0093	0.93
30	Iron and steel	1.00	1.0094	0.94
31	Machinery and metal products	1.00	1.0091	0.91
32	Electrical machinery	1.00	1.0086	0.86
33	Transport equipment	1.00	1.0101	1.01
34	Other machinery	1.00	1.0365	3.66
35	Construction	1.00	1.0654	6.54
36	Electricity gas and water supply	1.00	1.0903	9.03
37	Transport services and communication	1.00	1.0091	0.91
38	Other services	1.00	1.0014	0.14

Source: Results from the study

Apart from these sectors, other machinery, fertilizer, oil and vanaspati, sugar, petro coal tar products, organic heavy chemicals, pesticides, inorganic heavy chemicals, other chemicals, and livestock also experience more than 1 % but below 5 % increase in price. Other sectors are having less than 1 % increase in price. As mentioned before, indirect effect plays a very important role in the case of

Table 5.7 Impact on prices by different categories

Scenario 2	Sectors
Above 5 %	Cotton textile; construction; electricity gas and water supply; agriculture
Above 1 % and below 5 %	Other machinery, fertilizer, oil and vanaspati, sugar, petro coal tar products, organic heavy chemicals, pesticides, inorganic heavy chemicals, other chemicals, livestock
Below 1 %	Other nonmetallic mineral; electrical machinery; iron and steel; synthetic fiber, resin; machinery and metal products, etc.

Source: Results from the study

price increase. Even though the clean water cost is implemented on milk and milk products, livestock, food products, and sugar, the indirect impact affects a number of other sectors such as agriculture, other agriculture, fertilizer, pesticides, and oil and vanaspati. On the other hand, a direct impact is seen for sugar and food products. For the industrial sector, there is also a similar direct and indirect impact observed. For example, construction sector is affected indirectly.

Appendices

Appendix 5.A.1: Direct Water Pollution Output Coefficients (Thousand Tons Discharged per Lakh Rupees of Output at 2006–2007 Price)

Sectors	SS	DS	Chloride	Sulfide	Oil/grease
Agriculture	0.0003723	0.0000000	0.0000000	0.0000000	0.0000269
Other agriculture	0.0000004	0.0000001	0.0000000	0.0000000	0.0000001
Milk and milk products	0.0001366	0.0002112	0.0000192	0.0000000	0.0000529
Livestock	0.0002094	0.0000624	0.0000000	0.0000000	0.0000170
Fishing	0.0000021	0.0000000	0.0000000	0.0000000	0.0000009
Coal and lignite	0.0000000	0.0000001	0.0000000	0.0000000	0.0000000
Mining and quarrying	0.0000123	0.0000262	0.0000000	0.0000000	0.0000026
Sugar	0.0000091	0.0000362	0.0000000	0.0000000	0.0000032
Oil and vanaspati	0.0000064	0.0000000	0.0000000	0.0000000	0.0000065
Tea, coffee, and beverages	0.0000181	0.0004395	0.0000000	0.0000000	0.0000000
Food products	0.0000041	0.0000000	0.0000000	0.0000000	0.0000054
Cotton textile	0.0005009	0.0070510	0.0000000	0.0000000	0.0000000
Woolen and silk textile	0.0000412	0.0001012	0.0000976	0.0000449	0.0000030
Jute, hemp, and mesta textiles	0.0004542	0.0000002	0.0010619	0.0006210	0.0000083
Miscellaneous textile products	0.0000320	0.0000069	0.0000800	0.0000435	0.0000006
Wood and wood products	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Paper and paper products	0.0001102	0.0000000	0.0000000	0.0000000	0.0000000
Leather and leather products	0.0001749	0.0002525	0.0002542	0.0000020	0.0000000

(continued)

Sectors	SS	DS	Chloride	Sulfide	Oil/grease
Rubber products	0.0000205	0.0001630	0.0000000	0.0000026	0.0000032
Plastic products	0.0000000	0.0000146	0.0000000	0.0000000	0.0000000
Petroleum and coal tar products	0.0000103	0.0000295	0.0000000	0.0000038	0.0000300
Inorganic heavy chemicals	0.0000036	0.0001319	0.0000000	0.0000000	0.0000000
Organic heavy chemicals	0.0000433	0.0000000	0.0000000	0.0000000	0.0000460
Fertilizers	0.0000691	0.0000000	0.0000000	0.0000000	0.0000000
Pesticides	0.0000766	0.0000000	0.0000776	0.0000000	0.0000000
Paints, varnishes, and lacquers	0.0000078	0.0000000	0.0000000	0.0000000	0.0000088
Other chemicals	0.0000000	0.0000309	0.0000000	0.0000000	0.0000000
Synthetic fibers, resin	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Other nonmetallic mineral products	0.0000051	0.0000000	0.0000000	0.0000000	0.0000000
Iron and steel	0.0000377	0.0000000	0.0000066	0.0000002	0.0000000
Machinery and metal products	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Electrical machinery	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Transport equipment	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Other machinery	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Construction	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Electricity gas and water supply	0.0088113	0.0000000	0.0000000	0.0000000	0.0000000
Transport services and communication	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Other services	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000

	Phenol	Zinc	Others	BOD	COD
Agriculture	0.0000000	0.0000000	0.0001217	0.0009952	0.0015586
Other agriculture	0.0000000	0.0000000	0.0000000	0.0000004	0.0000010
Milk and milk products	0.0000000	0.0000000	0.0001270	0.0007796	0.0017162
Livestock	0.0000000	0.0000000	0.0003169	0.0006246	0.0034404
Fishing	0.0000000	0.0000000	0.0000006	0.0000041	0.0000087
Coal and lignite	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Mining and quarrying	0.0000001	0.0000000	0.0000000	0.0000007	0.0000000
Sugar	0.0000000	0.0000000	0.0000037	0.0000214	0.0000428
Oil and vanaspati	0.0000000	0.0000000	0.0000000	0.0000369	0.0000546
Tea, coffee, and beverages	0.0000000	0.0000000	0.0000002	0.0002478	0.0005391
Food products	0.0000000	0.0000000	0.0000000	0.0000034	0.0000059
Cotton textile	0.0000000	0.0000000	0.0000231	0.0000390	0.0022288
Woolen and silk textile	0.0000004	0.0000000	0.0000023	0.0000352	0.0001300
Jute, hemp, and mesta textiles	0.0000023	0.0000000	0.0000083	0.0005780	0.0011396
Miscellaneous textile products	0.0000000	0.0000002	0.0000666	0.0000515	0.0001135
Wood and wood products	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Paper and paper products	0.0000000	0.0000000	0.0001632	0.0000841	0.0001151
Leather and leather products	0.0000000	0.0000000	0.0001133	0.0000526	0.0002102
Rubber products	0.0000000	0.0000000	0.0000063	0.0001288	0.0002467
Plastic products	0.0000000	0.0000000	0.0000000	0.0000049	0.0000122
Petroleum and coal tar products	0.0000004	0.0000000	0.0000000	0.0000034	0.0000086
Inorganic heavy chemicals	0.0000000	0.0000000	0.0000212	0.0000204	0.0000606
Organic heavy chemicals	0.0000136	0.0000000	0.0000055	0.0001980	0.0000584

(continued)

	Phenol	Zinc	Others	BOD	COD
Fertilizers	0.0000000	0.0000000	0.0000479	0.0000000	0.0000000
Pesticides	0.0000000	0.0000000	0.0000262	0.0000741	0.0003371
Paints, varnishes, and lacquers	0.0000041	0.0000000	0.0000000	0.0000265	0.0000033
Other chemicals	0.0000000	0.0000000	0.0000000	0.0000106	0.0000602
Synthetic fibers, resin	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Other nonmetallic mineral products	0.0000000	0.0000038	0.0000021	0.0000000	0.0000031
Iron and steel	0.0000012	0.0000000	0.0000047	0.0000126	0.0000315
Machinery and metal products	0.0000031	0.0000000	0.0000000	0.0000104	0.0000032
Electrical machinery	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Transport equipment	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Other machinery	0.0000175	0.0000000	0.0000000	0.0000595	0.0000185
Construction	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Electricity gas and water supply	0.0000000	0.0000000	0.0000000	0.0000000	0.0000026
Transport services and communication	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Other services	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000

Source: Results from the study

Appendix 5.A.2: Total (Direct and Indirect) Water Pollution Output Coefficients (Thousand Tons of Pollutants Directly and Indirectly Discharged per Lakh Rupees Worth of Sales of Each Industries to Final Demand)

Total pollution coefficients	SS	DS	Chloride	Sulfide	Oil/Grease
Agriculture	0.0007956	0.0000100	0.0000027	0.0000011	0.0000354
Other agriculture	0.0001386	0.0000095	0.0000016	0.0000003	0.0000030
Milk and milk products	0.0002080	0.0002134	0.0000195	0.0000001	0.0000558
Livestock	0.0004255	0.0000682	0.0000009	0.0000004	0.0000255
Fishing	0.0000881	0.0000375	0.0000164	0.0000096	0.0000031
Coal and lignite	0.0004645	0.0000088	0.0000007	0.0000004	0.0000018
Mining and quarrying	0.0002962	0.0000324	0.0000009	0.0000006	0.0000043
Sugar	0.0001908	0.0000478	0.0000019	0.0000008	0.0000063
Oil and vanaspati	0.0002336	0.0000134	0.0000018	0.0000007	0.0000113
Tea, coffee and beverages	0.0003892	0.0004970	0.0000048	0.0000026	0.0000063
Food products	0.0004990	0.0000365	0.0000049	0.0000018	0.0000234
Cotton textile	0.0014403	0.0079805	0.0000061	0.0000031	0.0000043
Woolen and silk textile	0.0008005	0.0004699	0.0001170	0.0000544	0.0000125
Jute, hemp, and mesta textiles	0.0013271	0.0000268	0.0010789	0.0006305	0.0000115
Miscellaneous textile products	0.0006810	0.0013581	0.0000986	0.0000520	0.0000055
Wood and wood products	0.0003519	0.0000278	0.0000042	0.0000019	0.0000039
Paper and paper products	0.0008102	0.0000284	0.0000024	0.0000014	0.0000047

(continued)

Total pollution coefficients	SS	DS	Chloride	Sulfide	Oil/Grease
Leather and leather products	0.0005778	0.0003623	0.0003184	0.0000039	0.0000066
Rubber products	0.0006009	0.0002499	0.0000099	0.0000060	0.0000111
Plastic products	0.0006998	0.0000620	0.0000043	0.0000017	0.0000104
Petroleum and coal tar products	0.0004038	0.0000557	0.0000009	0.0000044	0.0000347
Inorganic heavy chemicals	0.0008567	0.0001781	0.0000053	0.0000022	0.0000126
Organic heavy chemicals	0.0008852	0.0000460	0.0000060	0.0000022	0.0000593
Fertilizers	0.0006466	0.0000487	0.0000024	0.0000019	0.0000127
Pesticides	0.0007179	0.0000396	0.0000955	0.0000022	0.0000114
Paints, varnishes, and lacquers	0.0006685	0.0000479	0.0000048	0.0000022	0.0000189
Other chemicals	0.0005479	0.0000715	0.0000050	0.0000025	0.0000104
Synthetic fibers, resin	0.0005426	0.0000512	0.0000039	0.0000021	0.0000164
Other nonmetallic mineral products	0.0011010	0.0000260	0.0000023	0.0000015	0.0000054
Iron and steel	0.0010917	0.0000136	0.0000090	0.0000010	0.0000038
Machinery and metal products	0.0006976	0.0000169	0.0000030	0.0000010	0.0000035
Electrical machinery	0.0006468	0.0000208	0.0000039	0.0000014	0.0000043
Transport equipment	0.0007208	0.0000227	0.0000041	0.0000011	0.0000034
Other machinery	0.0003563	0.0000225	0.0000026	0.0000010	0.0000033
Construction	0.0005639	0.0000134	0.0000030	0.0000014	0.0000045
Electricity gas and water supply	0.0124848	0.0000158	0.0000010	0.0000010	0.0000062
Transport services and communication	0.0004112	0.0000233	0.0000011	0.0000013	0.0000083
Other services	0.0001170	0.0000075	0.0000007	0.0000004	0.0000019

Total pollution coefficients	Phenol	Zinc	Others	BOD	COD
Agriculture	0.0000003	0.0000000	0.0001642	0.0012266	0.0020176
Other agriculture	0.0000002	0.0000000	0.0000214	0.0000510	0.0002048
Milk and milk products	0.0000001	0.0000000	0.0001395	0.0008718	0.0018697
Livestock	0.0000002	0.0000000	0.0003540	0.0008954	0.0038925
Fishing	0.0000002	0.0000000	0.0000038	0.0000194	0.0000494
Coal and lignite	0.0000007	0.0000000	0.0000025	0.0000134	0.0000249
Mining and quarrying	0.0000006	0.0000001	0.0000018	0.0000102	0.0000177
Sugar	0.0000005	0.0000000	0.0000184	0.0000656	0.0001778
Oil and vanaspati	0.0000004	0.0000000	0.0000181	0.0001154	0.0002450
Tea, coffee, and beverages	0.0000007	0.0000000	0.0000207	0.0003615	0.0007636
Food products	0.0000005	0.0000000	0.0000713	0.0004507	0.0008320
Cotton textile	0.0000007	0.0000000	0.0000356	0.0000780	0.0026036
Woolen and silk textile	0.0000026	0.0000000	0.0000185	0.0001016	0.0003593
Jute, hemp, and mesta textiles	0.0000030	0.0000000	0.0000177	0.0006173	0.0012411
Miscellaneous textile products	0.0000013	0.0000002	0.0000837	0.0001024	0.0006294
Wood and wood products	0.0000011	0.0000000	0.0000121	0.0000378	0.0000948
Paper and paper products	0.0000010	0.0000000	0.0002280	0.0001498	0.0002277
Leather and leather products	0.0000008	0.0000000	0.0002013	0.0002287	0.0009229
Rubber products	0.0000018	0.0000000	0.0000230	0.0001923	0.0004028
Plastic products	0.0000028	0.0000000	0.0000136	0.0000707	0.0001176
Petroleum and coal tar products	0.0000009	0.0000000	0.0000024	0.0000154	0.0000301
Inorganic heavy chemicals	0.0000028	0.0000000	0.0000359	0.0000909	0.0001624

(continued)

Total pollution coefficients	Phenol	Zinc	Others	BOD	COD
Organic heavy chemicals	0.0000169	0.0000000	0.0000205	0.0002771	0.0001705
Fertilizers	0.0000017	0.0000000	0.0000612	0.0000420	0.0000612
Pesticides	0.0000029	0.0000000	0.0000434	0.0001589	0.0004936
Paints, varnishes, and lacquers	0.0000067	0.0000000	0.0000131	0.0000943	0.0001096
Other chemicals	0.0000027	0.0000000	0.0000140	0.0000916	0.0001933
Synthetic fibers, resin	0.0000040	0.0000000	0.0000131	0.0000885	0.0001140
Other nonmetallic mineral products	0.0000008	0.0000042	0.0000087	0.0000220	0.0000457
Iron and steel	0.0000029	0.0000000	0.0000097	0.0000361	0.0000726
Machinery and metal products	0.0000053	0.0000000	0.0000063	0.0000387	0.0000517
Electrical machinery	0.0000025	0.0000001	0.0000082	0.0000350	0.0000593
Transport equipment	0.0000020	0.0000000	0.0000070	0.0000322	0.0000598
Other machinery	0.0000253	0.0000000	0.0000070	0.0001096	0.0000824
Construction	0.0000011	0.0000005	0.0000091	0.0000411	0.0000884
Electricity gas and water supply	0.0000013	0.0000000	0.0000049	0.0000218	0.0000418
Transport services and communication	0.0000010	0.0000000	0.0000072	0.0000377	0.0000659
Other services	0.0000004	0.0000000	0.0000072	0.0000375	0.0000741

Source: Results from the study

Appendix 5.A.3: Total Water Pollution Content of the Total Final Demand of Different Sectors of India for the Years 2006–2007 (Figures in Thousand Tons per Lakh Rupees of Final Demand)

	SS	DS	Chloride	Sulfide	Oil/ grease
Agriculture	28,047.180	352.964	93.906	40.325	1,247.683
Other agriculture	730.585	50.161	8.575	1.523	15.606
Milk and milk products	2,589.849	2,657.075	242.246	1.585	694.557
Livestock	1,667.918	267.215	3.383	1.559	100.021
Fishing	287.997	122.608	53.452	31.208	10.179
Coal and lignite	−505.211	−9.540	−0.777	−0.445	−2.002
Mining and quarrying	−5,495.064	−601.067	−17.086	−10.393	−79.455
Sugar	425.280	106.590	4.168	1.722	14.055
Oil and vanaspati	792.464	45.621	6.045	2.497	38.292
Tea, coffee, and beverages	2,784.895	3,556.406	34.246	18.637	45.177
Food products	6,968.977	510.193	68.348	24.504	326.791
Cotton textile	6,926.438	38,378.429	29.568	14.776	20.881
Woolen and silk textile	2,646.234	1,553.558	386.748	179.704	41.312
Jute, hemp, and mesta textiles	187.270	3.786	152.242	88.964	1.630
Miscellaneous textile products	6,956.574	13,873.530	1,006.801	531.674	56.336
Wood and wood products	−15.890	−1.256	−0.190	−0.085	−0.174

(continued)

	SS	DS	Chloride	Sulfide	Oil/ grease
Paper and paper products	991.176	34.784	2.993	1.696	5.713
Leather and leather products	872.565	547.175	480.806	5.904	10.014
Rubber products	952.330	396.046	15.686	9.494	17.517
Plastic products	938.712	83.112	5.719	2.308	13.981
Petroleum and coal tar products	1,088.405	150.095	2.407	11.989	93.426
Inorganic heavy chemicals	−131.860	−27.413	−0.818	−0.345	−1.936
Organic heavy chemicals	−962.014	−50.032	−6.540	−2.434	−64.417
Fertilizers	−300.668	−22.635	−1.120	−0.862	−5.922
Pesticides	70.788	3.902	9.415	0.212	1.127
Paints, varnishes, and lacquers	261.464	18.719	1.875	0.864	7.408
Other chemicals	3,690.583	481.357	33.463	16.980	70.238
Synthetic fibers, resin	−490.702	−46.265	−3.557	−1.886	−14.797
Other nonmetallic mineral products	−1,536.285	−36.239	−3.145	−2.124	−7.481
Iron and steel	1,318.846	16.488	10.822	1.244	4.560
Machinery and metal products	5,216.749	126.389	22.567	7.328	25.830
Electrical machinery	13,277.001	427.006	79.503	28.461	88.627
Transport equipment	7,666.044	241.886	43.223	11.365	36.406
Other machinery	1,080.839	68.202	7.747	3.030	9.864
Construction	43,064.693	1,020.483	228.822	106.772	345.014
Electricity gas and water supply	40,741.259	51.444	3.255	3.199	20.100
Transport services and communication	14,019.336	794.576	38.971	44.292	284.578
Other services	16,404.083	1,055.877	100.642	52.290	266.543
Total	203,228.843	66,201.234	3,144.410	1,227.531	3,737.282

	Phenol	Zinc	Others	BOD	COD
Agriculture	11.464	0.501	5,787.176	43,239.777	71,124.675
Other agriculture	1.207	0.045	112.743	268.655	1,080.059
Milk and milk products	0.805	0.029	1,737.619	10,856.176	23,282.331
Livestock	0.810	0.029	1,387.706	3,509.713	15,258.271
Fishing	0.695	0.029	12.264	63.494	161.412
Coal and lignite	−0.774	−0.012	−2.760	−14.524	−27.108
Mining and quarrying	−10.483	−1.068	−33.164	−188.816	−329.263
Sugar	1.114	0.050	41.057	146.193	396.408
Oil and vanaspati	1.429	0.036	61.492	391.567	831.342
Tea, coffee, and beverages	5.019	0.138	147.832	2,586.631	5,464.297
Food products	7.248	0.288	996.028	6,294.280	11,620.614
Cotton textile	3.556	0.108	171.040	374.918	12,520.509
Woolen and silk textile	8.509	0.084	61.172	335.898	1,187.909
Jute, hemp, and mesta textiles	0.424	0.002	2.502	87.106	175.134
Miscellaneous textile products	13.698	1.886	855.089	1,046.361	6,429.566
Wood and wood products	−0.047	−0.001	−0.545	−1.705	−4.282
Paper and paper products	1.269	0.035	278.865	183.279	278.524
Leather and leather products	1.186	0.027	303.949	345.302	1,393.721
Rubber products	2.928	0.040	36.376	304.797	638.377

(continued)

	Phenol	Zinc	Others	BOD	COD
Plastic products	3.692	0.033	18.202	94.896	157.741
Petroleum and coal tar products	2.422	0.122	6.408	41.625	81.110
Inorganic heavy chemicals	−0.433	−0.006	−5.524	−13.986	−24.994
Organic heavy chemicals	−18.362	−0.030	−22.276	−301.124	−185.287
Fertilizers	−0.805	−0.016	−28.443	−19.527	−28.454
Pesticides	0.285	0.002	4.282	15.666	48.666
Paints, varnishes, and lacquers	2.613	0.014	5.107	36.866	42.860
Other chemicals	17.941	0.166	94.523	617.054	1,302.306
Synthetic fibers, resin	−3.642	−0.020	−11.835	−80.074	−103.100
Other nonmetallic mineral products	−1.151	−5.886	−12.089	−30.677	−63.702
Iron and steel	3.514	0.043	11.736	43.597	87.700
Machinery and metal products	39.418	0.341	47.052	289.563	386.364
Electrical machinery	50.439	1.672	168.027	717.995	1,216.453
Transport equipment	21.464	0.397	74.494	342.985	635.968
Other machinery	76.610	0.114	21.277	332.446	249.941
Construction	86.624	36.793	695.455	3,139.146	6,747.374
Electricity gas and water supply	4.170	0.120	15.847	71.134	136.267
Transport services and communication	35.058	1.140	244.314	1,285.976	2,247.668
Other services	57.004	1.826	1,009.239	5,255.777	10,385.753
Total	426.920	39.072	14,292.237	81,668.440	174,803.129

Source: Results from the study

Chapter 6
Estimation of Water Pollution Content in India's Foreign Trade

6.1 Trade and Environment

The dialogue on growth and the environment is closely related to the discussion of trade liberalization and the environment particularly due to the large body of evidence associating trade liberalization with increased growth. The WTO in a report has analyzed the much debated relationship between trade and environment (Nordstrom and Vaughan 1999).

The ongoing Doha "Development" Round of the GATT is seen by many as a potential vehicle for real gains for all economies, particularly for the developing economies, in the areas of agricultural reform, improved market access for goods and services, and improvement of trade relations (World Bank 2007). Over the past two decades, trade has been expanding at almost twice the rate of total global economic activity. Integration into the world economy has been a tool for countries to promote economic growth. Trade liberalization consists of policies aimed at opening up the economy to foreign investment and lowering trade barriers in the form of tariff reduction. International trade is becoming an increasingly important driver of economic development.

At the same time, however, most of the world's environmental indicators have been steadily deteriorating, and the global achievement of such important objectives as the Millennium Development Goals remains very much a distant dream. It is well known that trade liberalization leads to environmental degradation either as a result of the relocation of polluting industries from countries with strict environmental laws or due to increased production in existing polluting industries. Increasing economic openness has, thus, led to concerns about the detrimental effects on the environment (Mukhopadhyay 2007). The WTO recognizes that trade and growth do not lead naturally to a more efficient use of natural resources (including energy) and to a better quality of the environment. On the contrary, it recognizes

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that foreign trade might accelerate natural resources depletion and environmental degradation in some cases.

The trade–environment links, however, are complex and depend on many factors. Trade can be a powerful and positive instrument of growth and development when adequate environmental and macroeconomic policies are taken into consideration. The relationship between trade expansion and environmental protection has been characterized by two extreme viewpoints – promoting trade worsens environmental conditions and higher environmental standards impose an economic cost (Jaffe et al. 1995).

The interrelationship between trade and the environment has become a pressing concern across the globe. Its nature varies from country to country, sector to sector, and firm to firm. There are both threats and opportunities in this relationship for countries, local communities, and firms pursuing economic development and environmental protection. How changing trade regimes affect the environment and how stricter environmental regulations impact trade are a serious concern to economists, environmentalists, policy makers, and world bodies like the World Trade Organization (WCED 1987).

Two conflicting hypotheses have emerged from the debate. The first one is the pollution haven hypothesis (PHH). This hypothesis suggests that developed countries impose tougher environmental policies than developing countries, which results in the distortion of existing patterns of comparative advantage. So the polluting industries shift operations from the developed to the developing countries which are seen as "pollution havens." The second hypothesis, the factor endowment hypothesis (FEH), states that trade liberalization will result in trade patterns consistent with the Heckscher–Ohlin–Vanek (HOV) theory of comparative advantage based on factor endowment differentials. Rich countries are typically well endowed with capital. Since capital-intensive goods are often also pollution intensive, factor endowment theories of international trade predict that rich countries specialize in polluting goods. Thus, the manifestation of the PHH is in direct conflict with the FEH (Mukhopadhyay 2006a, 2007).

Theoretical and empirical assessment on the PHH and FEH was attempted by many (Low and Yeats 1992; Mani and Wheeler 1999; Cole and Elliot 2001; Liddle 2001; Xing and Kolstad 2002; Copeland and Taylor 2003; Eskeland and Harrison 2003; Kuik and Gerlagh 2003; Busse 2004; Mulatu et al. 2004; Smarzynska and Wei 2004; Waldkirch and Gopinath 2004; Dagoumas et al. 2006).

Among numerous research on the issue of trade and the environment Lucas et al. (1992), Birdsall and Wheeler (1993) have performed statistical tests on the relationship between the degree of trade openness, growth, and environmental quality. Lucas et al. show that fast-growing closed economies became significantly more pollution intensive in the 1970s and 1980s, whereas the opposite was true for more open economies. Fast-growing open economies experienced mainly pollution neutral structural change in the 1970s and a significant shift towards a less pollution-intensive structure in the 1980s. Birdsall and Wheeler present similar evidence on the above but with reference solely to Latin America. They also find similar trends to the global developing country data, where pollution-intensive industries have tended to locate in the less open economies. Wheeler and Martin (1992) show that in the pulp and paper industry, the more open the economy, the faster the cleaner technologies are adopted and diffused. They also show that a country's level of development has no independent effect on the adoption of clean technologies in industries. Copeland and Taylor (2003) in their exhaustive study set out the two leading theories (pollution haven hypothesis and factor endowment hypothesis) linking international trade to environmental outcomes. They developed the empirical implications and examined their validity using data on measured sulfur dioxide concentrations from over 100 cities worldwide during the period of 1971–1986. The empirical results are provocative. For an average country in the sample, free trade is good for the environment. There is little evidence that developing countries will specialize in pollution-intensive products with further trade. In fact, the results suggest just the opposite: free trade will shift pollution-intensive goods production from poor countries with lax regulation to rich countries with tight regulation, thereby lowering world pollution. The results also suggest that pollution declines amid economic growth fueled by economy-wide technological progress but rises when growth is driven by capital accumulation alone.

Several attempts have been made on trade environment issues by considering the input–output model (Wyckoff and Roop 1994; Gale and Lewis 1995; Antweiler 1996; Proops et al. 1999; Machado et al. 2001; Munksgaard and Pedersen 2001; Hayami and Nakamura 2002; Wadeskog 2002). But only a few have addressed the PHH and FEH using the I–O model (Mukhopadhyay and Chakraborty 2005a, 2006; Dietzenbacher and Mukhopadhyay 2007; Mukhopadhyay 2006a, b, 2007).

The abovementioned literatures cover both theoretical works, identifying a series of hypotheses linking openness to trade and environmental quality, and empirical work, trying to disentangle some of the suggested linkages using cross-country or within-country data. The review of the literature suggests that the empirical evidence is still far from clear (Copeland and Taylor 2004). The methodologies employed to test the hypotheses vary widely and so do the results.

There are large number of literatures on the PHH, and FEH focusing on air pollution but very few researches dealt with water pollution indicators to test these hypotheses. Here we mention a couple of them. Ferraz and Young (1999) estimate the effect of trade liberalization on the industrial structure and pattern of pollution emissions in Brazil. An input–output approach is used to estimate the value of production and potential pollution intensity. They found that the aggregate intensity of pollutant emission has decreased for the whole industrial sector, but for the export sector, the pollution intensity has been increasing after trade liberalization for air parameters as well as water – BOD, TSS, and metal. Kuhn and Bernanuer

(2006) develop three hypotheses and test them for transboundary water pollution for international water management: (1) the intensity of bilateral trade ties has a positive effect on international environmental problem solving, (2) asymmetry of trade ties in favor of the downstream country is conducive to problem solving in upstream–downstream settings, and (3) neither trade intensity nor asymmetry has an effect on reduction in water pollution. The dependent variable is transboundary water quality, specifically concentrations of water pollutants from point- (BOD5) and non-point sources (NO_3). They found that the third hypothesis receives robust empirical support: trade ties do not seem to help in reducing transboundary water pollution, nor do they seem to hinder such efforts. Levinson (2009) analyzes this topic in a different dimension. It shows that most of the decline in pollution from US manufacturing has been the result of changing technology instead of changes in the mix of goods produced, although the pace of that technology change has slowed over time. Second, the evidence shows that increases in net imports of pollution-intensive goods are too small to explain more than about half of the pollution reductions from the changing mix of goods produced in the United States. Together, these two findings demonstrate that shifting polluting industries overseas has played a minor role in the cleanup of the US manufacturing sector. In a recent paper, Dean and Lovely (2010) calculate the pollution content of China's export and import bundles from 1995 to 2005. The calculations rely on official Chinese measurements of direct emissions of four pollutants for about 30 Chinese industries. They found that as China's trade has grown, the pollution intensity of almost all sectors has fallen in terms of water pollution (measured by COD) and air pollution (measured by SO2, smoke, or dust) in 2004. This finding suggests that China has benefited from a positive "technique effect," as emissions per real yuan of output have fallen across a wide range of industries. The study also reveals that China's major exporting industries are not highly polluting, and that the export bundle is shifting towards relatively cleaner sectors over time. In 1995, textiles and apparel accounted for the largest shares of Chinese exports to the world, but these shares fell by about a third over the following decade. Office and computing machinery and communications equipment, in contrast, were the fastest-growing exports and accounted for the largest export share in 2005. Cole and Elliott (2003) confirm that there is a significant positive correlation between capital intensity of production and pollution intensity for many pollutants including water. Hence, they expected that increases in capital abundance would lead to increasing pollution intensity in manufacturing and in exports. Bruneau (2008) constructs Antweiler's (1996) pollution terms of trade (PTT). If the PTT is greater than one, then a country's exports are, on average, dirtier than its imports. The study used a panel regression for 57 countries looking at the pattern of pollution intensities in exports, imports, and their PTT for both air and water pollution parameters. Results support the FEH but offer little support for the PHH.

Though several studies have been conducted on the issue of trade and environment in India primarily focusing on air pollution (Mukhopadhyay and Chakraborty 2005a, b), to the best of the authors' knowledge there is hardly any research linking trade and water pollution in India. Our study has made an effort in that direction.

In this chapter we are trying to investigate the PHH and FEH hypothesis using several water pollutants.

In the next section, we are presenting the trend and pattern of foreign trade in India.

6.2 Trend and Pattern of Foreign Trade in India

The hidden trade liberalization in India has started in the 1980s, and its full effect emerged during the 1990s. The Government of India had introduced liberalized trade policy in the year 1991. Faced with rising inflation (13.6 %) and a Balance of Payments crisis in mid-1991, the Government of India introduced a fairly comprehensive package comprising trade and exchange liberalization, reduction of tax rates, industrial de-licensing, deregulation, currency devaluation, and privatization of the public sector (Mukhopadhyay 2002).

India, being a South Asian developing country, normally exports agricultural commodities and imports industrial manufactures. But the composition of exported and imported commodities has changed after liberalized EXIM (export–import) policy. The growth rate has been much higher for both exports and imports after liberalization.

During the 9th and 10th Five-Year Plans, the Government of India has revised its export and import policy (GOI 2002). As a result, the shares of a few exported commodities are escalating especially those which are energy intensive, and on the other hand imported commodities are also rising. India's exports are also moving away from resource- to technology-based products in the post-liberalization period. Based on this strategic policy shift, India aims to have at least 1 % share in total global exports. Foreign trade in India is also steadily assuming a more significant role in the country's gross domestic product (GDP).

With the adoption of more liberal trade policies by India, commodity trade has grown tremendously. In 1998, India's total commodity trade was only US$99.85 billion with US$46.42 billion of exports and US$53.43 billion of imports, resulting in a slight trade deficit of US$7.0 billion. By 2011, export has grown to US$447.32 billion, imports to US$568.10 billion with trade deficit at its highest at US$120.78 billion. This trade deficit amounted to 6.45 % of GDP approximately. An alarming trend observed in Fig. 6.1 showed that in the last few years, imports have grown at a much faster rate than exports.

In 2011, the top trading partner of India was the United Arab Emirates with US $72.8 billion of trade, followed closely by China with US$72.2 billion. The United States completes the top three trading partner of India. China has risen steadily in the past few years to become an important trading partner for India. This is driven by the significant increase of imports from China to India that increased from just US$1.8 billion (3.6 % of total imports) in 2001 to US$55.5 billion (12.0 % of total imports) in 2011 (Table 6.1).

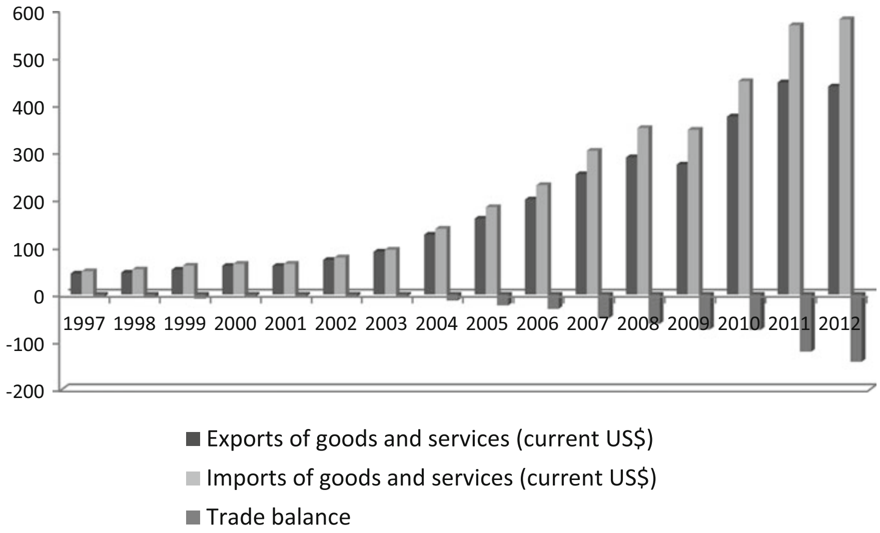

Fig. 6.1 India's commodity trade pattern (Source: WDI 2012)

Table 6.1 India's top five trading partners 2011 (billion US$)

	Country	Export	% of total export	Import	% of total import	Trade balance	Total trade
1	United Arab Emirates	37.4	12.4	35.5	7.7	1.9	72.8
2	China	16.7	5.5	55.5	12.0	−38.8	72.2
3	United States	32.9	10.9	22.6	4.9	10.3	55.5
4	Saudi Arabia	5.1	1.7	28.4	6.1	−23.3	33.6
5	Switzerland	1.0	0.3	31.4	6.8	−30.3	32.4
	Total Trade	301.5	100.0	462.4	100.0	−160.9	763.9

Source: UN Comtrade

The composition of India's commodity import did not change much over the past decade. In 2011, the top commodity import was mineral fuels, oils, and distillation product valued at US$ 157.4 billion followed by pearls, precious stones, metals, and coins at US$93.6 billion. These two sectors represented 54.2 % of total commodity imports into the country in 2011. The composition of India's commodity export however has undergone some transformation over the years. India's main exports are engineering goods (19 percent of total exports), gems and jewelry (15 percent), chemicals (13 percent), agricultural products (9 percent) and textile products (9 percent). India is also one of Asia's largest refined product exporters with petroleum accounting for around 18 percent of total exports (UN Comtrade).

Not to be left behind, India's commercial service trade has also seen a rapid growth in recent years. Commercial service exports increased from US$11.1 billion in 1998 to US$ 123.3 billion in 2010, while import grew from US$14.2 billion to US$116.1 billion over the same period. The majority of India's service export was in the form of computer and communication services that made up 71.5 % of services exports in 2010. This share has increased significantly since 1998. These changes reflected the rapid development and the growing importance of the information technology industry in India and its focus on the outsourcing services (WDI 2012).

With economic reform and ambitious export policies, the Indian economy is now expanding and diversifying its exports. These changes in trade pattern have important implications for the environment and the use of water resources in the economy. This may have some implications on generation of water pollution. This work aims at contributing to this consequential issue. This is the focus of this chapter which measures the water pollution content in trade.

6.3 Methodology

In this section, the methods for investigating pollution haven hypothesis and factor endowment hypothesis are discussed.

6.3.1 Pollution Haven Hypothesis

To examine the relevance of the pollution haven effect, we have to estimate the total water pollution contents in exported and imported commodities. To compute that, we simply multiply the water pollution intensities with export and import vector. But for deriving sectoral contribution we, constructed $n \times n$ matrices of export and import.

Reiterating Eq. (3.4) from Chap. 3

$$R' = W(I - A)^{-1} \tag{3.4}$$

$$\mathrm{C}_{\mathrm{exp}} = R' \; P \tag{6.1}$$

Equation (6.1) measures the pollution content in exported commodities. P is a $n \times n$ matrix of export.

$$\mathrm{C}_{\mathrm{imp}} = R' \; M \tag{6.2}$$

Equation (6.2) derives the pollution content in imported commodities. M is a $n \times n$ matrix of import.

Here we assume identical technology (based on Heckscher–Ohlin theory) to find out the water pollution content of imports of India from the rest of the world.

Thus, a measure of relative pollution content of trade, that is, pollution terms of trade (PTOT), is given in Eq. (6.3):

$$\text{PTOT} = \frac{C_{\text{exp}}}{C_{\text{imp}}} \tag{6.3}$$

This measure is the ratio of the water pollution content of 1 lakh rupees of exports relative to the pollution content of 1 lakh rupees of imports. A country gains environmentally from trade in relative terms whenever its imported goods have higher pollution content than its exported goods.

When the pollution terms of trade are greater (smaller) than 1, then a particular country's exports contain more (less) pollution than it is receiving through imports (Mukhopadhyay and Chakraborty 2005a, b; Mukhopadhyay 2007).

6.3.2 Factor Endowment Hypothesis

We now develop a framework to deal with the factor endowment hypothesis. Here two models based on Leontief (1953) and Leamer (1980) are used.

6.3.2.1 Leontief Framework

Heckscher (1919) and Ohlin (1933) made a major contribution to the theory of international trade by focusing on the relationships between the composition of a country's factor endowments and its commodity trade patterns. The Heckscher–Ohlin theorem states that countries export those commodities which require, for their production, relatively intensive use of those productive factors which are found locally in relative abundance. The pioneering and elaborate effort of testing empirically the validity of this theorem was first attempted by Leontief (1953). In his attempt to see if trade pattern of a country really corroborates the Heckscher–Ohlin conclusion, Leontief applied the tools of the input–output technique and tested the factor intensities of the average export and competitive import of the United States.

We now define

$$G = L(I - A)^{-1} \tag{6.4}$$

This is a $(1 \times N)$ vector. An element of G gives the direct and indirect requirement of labor per unit of output. L indicates sectoral labor coefficients.

Multiplying G with E and M, we obtain the total labor embodied in one million dollar worth of export (lE) and labor embodied in one million dollar of import replacements (lM), respectively:

$$lE = L(I - A)^{-1} \ E = GE \tag{6.5}$$

and

$$lM = L(I - A)^{-1} \ M = GM \tag{6.6}$$

Likewise we define

$$H = K(I - A)^{-1} \tag{6.7}$$

This is a $(1 \times N)$ vector. H refers the direct and indirect requirement of capital per unit of output.

K indicates sectoral capital coefficients.

And then multiplying K by E and M, respectively, the capital embodied in one million dollar worth of export (kE) and one million dollar worth of import replacement (kM) is obtained.

Finally, to verify the Heckscher–Ohlin predictions regarding the pattern of trade for the country in question, a comparison between the capital–labor ratio for exports (kE/lE) and the capital–labor ratio for import replacements (kM/lM) is required to be done. One million dollar worth of export will be more or less capital intensive than one million dollar worth of import replacements:

$$\frac{(kE/lE)}{(kM/lM)} > 1 \tag{6.8}$$

or

$$\frac{(kE/lE)}{(kM/lM)} < 1 \tag{6.9}$$

By conventional wisdom, the United States has more capital per worker than any of the countries with which it trades. Hence, if Heckscher–Ohlin theorem holds, then the United States should export commodities requiring more capital and import commodities which use, when domestically produced, relatively more labor. But this empirical research by Leontief led to the revolutionary finding that the United States apparently exported labor-intensive goods and imported capital-intensive commodities. This finding has been referred to in the literature as Leontief Paradox. In this pioneering research, Leontief (1953) used an input–output table for the United States based on 1947 data and considered two factors of production – labor and capital.

6.3.2.2 Leamer Framework

Leamer (1980) used an alternative theoretical framework and showed that Leontief applied a conceptually inappropriate test of the Heckscher–Ohlin hypothesis when he applied it on the US data for 1947. He proposed a new set of indices for factor abundance and reexamined the same data, and the so-called paradox arrived at by Leontief was found to disappear.

Thus, a country whose trade figures reveal that it is more abundantly endowed with capital rather than labor has to satisfy any of following three conditions as developed by Leamer (1980):

1. $KT > 0$ and $LT < 0$
2. $KT > 0$ and $LT > 0$, then $KT/Ki > LT/Li$
3. $KT < 0$ and $LT < 0$, then $KT/Ki < LT/Li$

KT and LT indicate capital and labor content of trade, respectively. Ki and Li refer to the capital and labor endowment of country, respectively.

Leamer implies that capital is abundant relative to labor in the United States. His argument was that the lower capital per worker as was found to be embodied in exports relative to imports in the case of the United States implied that a country was abundant in labor and scarce in capital (as proposed by Leontief), if and only if the country was found to be net exporter of labor services and net importer of capital services. Leamer used the same set of data for 1947 for the US economy as done by Leontief and found that the United States was a net exporter of both capital and labor services in that year. Based on this, he contended that Leontief's result was based on a false proposition. He further showed that under these circumstances, if a country is capital abundant, its net exports must be more capital intensive than its consumption. The 1947 data on net export for the United States was found to be more capital intensive than the US consumption, and on the basis of this Leamer confirmed that the United States was relatively well endowed with capital than labor in that year. Thus, the so-called Leontief Paradox ceased to exist.

6.4 Analysis of the Results

This section will discuss the results on pollution haven and factor endowment hypotheses derived from the methodology explained above on India for the year 2006–2007.

6.4.1 Pollution Haven Hypothesis

Here we estimated the water pollution content-suspended solids, dissolved solids, chloride, sulfide, oil and grease, phenol, zinc, BOD, COD, etc., in export and import commodities.

The pollution content of sectoral export and imports for different pollution parameters for the year 2006–2007 is given in Appendices 6.A.1 and 6.A.2. However, to focus on the pollution haven hypothesis, we need to compute the pollution terms of trade (PTOT) for all 10 water pollution parameters. This is shown in Table 6.2. It shows that the values of PTOT of 6 parameters out of 10 are greater than 1. These are dissolved solids, chloride, sulfide, BOD, COD, etc. The values reflect that export activities generate more pollution than imports in 2006–2007 for India's trade with the rest of the world. There are a number of reasons behind this high water pollution content in export than import.

The PTOT depends on two factors which are the composition of exports and imports and the pollution coefficient across 10 water pollutant parameters. In some cases, a particular sector may give a high coefficient while the volume of exports and imports matters when the coefficient value is low. For example in the case of SS, the composition of exports and imports indicates that heavy manufacturing like petroleum and coal tar products, iron and steel, and all kinds of machineries have more share in import compared to export thus having SS content in large volume. On the other hand, the agri-food and light manufacturing are dominant in the export basket generating less SS. As a result, the SS content in imports is significantly large than exports leading to the value of PTOT less than 1.

For DS it was found that cotton and miscellaneous textile sectors are major players in the emission of DS. These two sectors made up a large share in the export basket compared to import (Table 6.3). Therefore, the total volume of DS in export is higher than imports, resulting in the value of PTOT greater than 1. Similar type of explanation can be offered in case of BOD and COD. In these two cases, light manufacturing and agriculture and agri-food commodities play an important role.

In addition to high volume of export, high pollution coefficients do matter. Overall, we found that the pollution coefficient for SS is high particularly for heavy manufacturing sector compared to other water pollutants. On the other hand, the pollution coefficients of DS, BOD, and COD are high for light manufacturing and agriculture and agri-food commodities as evident in Table 4.2.

6.4.2 Factor Endowment Hypothesis

The factor endowment hypothesis says that labor-intensive country will export more labor-intensive goods and import capital-intensive goods. Being a labor-rich country, this is highly expected for the Indian economy. According to trade and environment debate, if a country exports pollution-intensive goods, it is expected to

Table 6.2 Pollution terms of trade for ten water pollutants

	Export (thousand tons)	Import (thousand tons)	PTOT
SS	39,071.07	50,908.87	0.76
DS	19,960.53	5,497.358	3.63
Chloride	1,138.563	474.8644	2.39
Sulfide	457.6689	187.0555	2.44
Oil and grease	669.4566	775.2781	0.86
Phenol	554.2103	849.4298	0.65
Zinc	5.689044	11.75948	0.48
Others	1,865.63	1,288.748	1.44
BOD	9,041.72	7,814.352	1.15
COD	20,227.36	10,932.6	1.85

Source: Results from the study

export capital-intensive goods. It is generally thought that labor-intensive good is relatively cleaner than that of capital-intensive good. As a developing country India is endowed with an abundant supply of labor and has a scarcity of capital. Therefore, according to the HO theory, labor should be the most important source of India's comparative advantage. Let us see now what India's trade structure reveals regarding India's sources of comparative advantage using the Leontief and Leamer approaches for the year 2006–2007.

Table 6.4 shows the result based on the Leontief method. Considering the two factors of production labor and capital, it can be observed that labor requirements are relatively greater in India's exports to the rest of the world while capital requirements are relatively greater in import replacements. In other words, the capital intensity of exports relative to labor (k_E/l_E) is lower than that of import replacements (k_M/l_M) and thereby the ratio $[(k_E/l_E)/(k_M/l_M)]$ remains less than unity (0.6462) for 2006–2007. This implies that India's exports are relatively less capital intensive than its import replacements. So, India's trade structure for 2006–2007 reveals India to be a relatively labor-abundant country.

India's export basket for 2006–2007 is still relatively tilted towards labor-intensive goods, whereas capital-intensive goods (including mining) dominate the import basket despite the fact that capital intensity of India's export has been steadily rising in the post-1991 period. In India's export basket, capital-intensive goods that include mining and querying; petroleum and coal tar products; inorganic, organic, and other chemicals; fertilizer; iron and steel; other machineries; machinery and metal products; electrical machinery; and transport equipment have accounted for 46 % (approximately) of total exports, whereas the import share of this group of sectors is 80 % (approximately). Due to this nature of commodity compositions of export and import baskets, the HO theory seems to be valid for India's trade with the ROW.

Table 6.5 shows the result based on Leamer approach.

In 2006–2007, India's export to the ROW is 9,150,642.2 million rupees, whereas its import from this partner is worth of 10,656,950.3 million rupees, resulting in a deficit of 1,506,308.1 million rupees. Labor embodied in these total volume exports

Table 6.3 Sectoral export and import share in India for the year 2006–2007 (%)

		Export share	Import share
1	Agriculture	2.029	0.809
2	Other agriculture	0.383	0.853
3	Milk and milk products	0.001	0.000
4	Livestock	0.306	0.033
5	Fishing	0.712	0.014
6	Coal and lignite	0.018	0.993
7	Mining and quarrying	5.476	22.137
8	Sugar	0.204	0.622
9	Oil and vanaspati	0.621	1.181
10	Tea, coffee, and beverages	0.300	0.056
11	Food products	1.585	0.658
12	Cotton textile	1.308	0.197
13	Woolen and silk textile	0.755	0.529
14	Jute, hemp, and mesta textiles	0.039	0.029
15	Miscellaneous textile products	6.225	0.320
16	Wood and wood products	0.149	0.094
17	Paper and paper products	0.275	1.010
18	Leather and leather products	0.775	0.157
19	Rubber products	0.759	0.235
20	Plastic products	0.554	0.395
21	Petroleum and coal tar products	3.022	3.377
22	Inorganic heavy chemicals	0.345	1.359
23	Organic heavy chemicals	2.312	2.700
24	Fertilizers	0.003	0.350
25	Pesticides	0.257	0.164
26	Paints, varnishes, and lacquers	0.107	0.251
27	Other chemicals	1.604	1.665
28	Synthetic fibers, resin	0.854	1.338
29	Other nonmetallic mineral products	0.519	1.627
30	Iron and steel	2.926	3.124
31	Machinery and metal products	4.765	12.495
32	Electrical machinery	4.807	6.136
33	Transport equipment	2.843	3.051
34	Other machineries	18.349	24.196
35	Construction	0.000	0.000
36	Electricity gas and water supply	0.000	0.000
37	Transport services and communication	5.940	0.721
38	Other services	28.873	7.120

Source: Results from the study

and import replacements are 923.1 and 889.5 million man-years, respectively. Since the labor embodied in net exports (L_E) exceeds that in import replacements (L_M), India was a net exporter of labor services ($L_T = L_E - L_M > 0$) of 33.6 million man-years. The capital embodied in India's total import replacements (18,959,028.0 million rupees) is greater than that embodied in India's total exports

Table 6.4 Factors embodied in one million dollars worth of export and import replacements in India's trade with the ROW 2006–2007 (using Leontief method)

	2006–2007
1. Labor	
[A] Exports (l_E)	100.9
[B] Imports (l_M)	83.5
2. Capital	
[A] Exports (k_E)	1,389,473.8
[B] Imports (k_M)	1,779,029.4
3. Capital/labor	
[A] Exports (k_E/l_E)	13,773.3
[B] Imports (k_M/l_M)	21,313.2
[C] Exports/imports [$(k_E/l_E)/(k_M/l_M)$]	*0.6462*
Trade revealed factor abundance	$L > K$
Labor in man-years, capital in million Rs.	

Source: Results from the study

Table 6.5 Factor content and trade revealed factor abundance in India's trade with the ROW 2006–2007 (using Leamer approach)

1. Labor	
[A] Exports	923.1
[B] Imports	889.5
[C] Net trade (LT)	33.6
2. Capital	
[A] Exports	12,714,577.2
[B] Imports	18,959,028.0
[C] Net trade (KT)	−6,244,450.8
Trade revealed factor abundance	$L > K$
Labor in million man-years, capital in million rupees	

Source: Results from the study

to the ROW (12,714,577.2 million rupees), implying the country is net importer of capital services ($K_T = k_E - k_M < 0$) worth of 6,244,450.8 million rupees. Therefore, according to Leamer criteria, India is a labor-abundant country.

Thus the result based on both Leontief and Leamer approaches do support the Heckscher–Ohlin theorem for India for the year 2006–2007, implying that India exports labor-intensive goods and imports capital-intensive goods.

6.5 Implication of the Findings on Trade and Environment Debate

Results from Table 6.2 reveal that the pollution terms of trade is greater than one for a number of water pollution parameters. Further, analysis of the export and import shares indicates that the share of export is larger for agriculture, agri-food commodities, and light manufacturing compared to that of imports. Among these sectors, the most water pollution intensives are textiles–cotton and miscellaneous, food products, livestock, milk and milk products, tea and beverages, leather and leather products, and rubber and rubber products.

The results above show that India exports more water pollution-intensive goods while importing less (except SS, oil, grease, phenol, and zinc). Therefore, India is a pollution heaven for those water pollution parameters for the year 2006–2007 (BOD, COD, DS, chloride, sulfide, and others). On the contrary, the result of the Leontief and Leamer approaches for factor endowment reveals that India is exporting labor-intensive goods and importing capital-intensive goods.

The current exercise reveals somewhat different results from the trade and environment debate discussed earlier. India, being a labor-rich country, is expected to export more labor-intensive good and import more capital-intensive good. In addition, if a country exports pollution-intensive goods, it is expected to export capital-intensive goods which are dirtier than labor-intensive goods. Yet, being a labor-rich country, India exports both labor-intensive and pollution-intensive goods. In our previous study on air pollution parameters for India, we found that India exports clean goods and imports pollution-intensive goods with respect to air pollution, suggesting that India is not a pollution haven for CO_2, SO_2, and NOx (Mukhopadhyay 2006a; Mukhopadhyay and Chakraborty 2005a). On the other hand, the study on India and the rest of the world (ROW) supports factor endowment hypothesis as India exports labor-intensive goods and imports capital-intensive ones.

Despite these results, there has been another interesting evidence for an emerging economy in Asia. Thailand exports dirty goods and imports clean goods, and this finding seems to support or at least not contradict the pollution haven hypothesis for Thailand in the year 2000 (Mukhopadhyay 2006a, 2007). The study also further investigated the role of factor endowments in determining Thailand's trade with the OECD for the same period. Estimates of capital and labor requirements to produce exports and imports show that Thailand's exports required more capital (more capital per worker) than imports in 2000. More specifically, Thailand's imports are 5 % less capital intensive than its exports. The study on the whole supported the pollution haven hypothesis in 2000 by rejecting the factor endowment hypothesis (Mukhopadhyay 2006a, 2007).

These findings of water pollution content in India's trade with the rest of the world have thrown further insights on the ongoing trade and environment debate.

Appendices

Appendix 6.A.1: Water Pollution Generated from Exported Commodities (Thousand Tons)

Export	SS	DS	Chloride	Sulfide	Oil/ grease	Phenol
Agriculture	1,477.00	18.5876	4.9452	2.1236	65.7047	0.6037
Other agriculture	48.6206	3.3383	0.5707	0.1014	1.0386	0.0803
Milk and milk products	0.1737	0.1782	0.0162	0.0001	0.0466	0.0001
Livestock	119.071	19.0764	0.2415	0.1113	7.1404	0.0578
Fishing	57.4366	24.4523	10.6603	6.2239	2.0301	0.1386
Coal and lignite	7.6338	0.1442	0.0117	0.0067	0.0302	0.0117
Mining and quarrying	1,484.04	162.329	4.6145	2.8069	21.4582	2.8310
Sugar	35.6575	8.9370	0.3495	0.1444	1.1784	0.0934
Oil and vanaspati	132.697	7.6392	1.0122	0.4180	6.4119	0.2393
Tea, coffee, and beverages	106.994	136.635	1.3157	0.7160	1.7357	0.1928
Food products	723.866	52.9937	7.0993	2.5452	33.9437	0.7529
Cotton textile	1,723.37	9,548.99	7.3570	3.6765	5.1955	0.8847
Woolen and silk textile	552.670	324.463	80.7729	37.5314	8.6280	1.7771
Jute, hemp, and mesta textiles	46.8777	0.9478	38.1093	22.2695	0.4079	0.1062
Miscellaneous textile products	3,878.98	7,735.87	561.392	296.461	31.4130	7.6383
Wood and wood products	47.8769	3.7836	0.5712	0.2571	0.5241	0.1430
Paper and paper products	204.078	7.1619	0.6162	0.3492	1.1762	0.2613
Leather and leather products	409.771	256.962	225.794	2.7728	4.7028	0.5570
Rubber products	417.276	173.533	6.8730	4.1601	7.6754	1.2831
Plastic products	354.823	31.4155	2.1618	0.8725	5.2848	1.3955
Petroleum and coal tar products	1,116.66	153.991	2.4695	12.2999	95.8515	2.4852
Inorganic heavy chemicals	270.490	56.2336	1.6788	0.7076	3.9706	0.8890
Organic heavy chemicals	1,873.06	97.4126	12.7336	4.7383	125.4210	35.7504
Fertilizers	1.9657	0.1480	0.0073	0.0056	0.0387	0.0053
Pesticides	168.927	9.3127	22.4679	0.5060	2.6902	0.6809
Paints, varnishes, and lacquers	65.5404	4.6921	0.4699	0.2165	1.8570	0.6551

(continued)

Export	SS	DS	Chloride	Sulfide	Oil/ grease	Phenol
Other chemicals	804.128	104.881	7.2912	3.6997	15.3038	3.9090
Synthetic fibers, resin	423.955	39.9718	3.0734	1.6293	12.7845	3.1466
Other nonmetallic mineral products	523.198	12.3415	1.0710	0.7233	2.5477	0.3920
Iron and steel	2,923.26	36.5467	23.9864	2.7573	10.1066	7.7895
Machinery and metal products	3,041.41	73.6863	13.1568	4.2726	15.0592	22.981
Electrical machinery	2,844.92	91.4965	17.0354	6.0984	18.9905	10.807
Transport equipment	1,875.03	59.1626	10.5718	2.7798	8.9045	5.2500
Other machineries	5,983.18	377.544	42.8865	16.7714	54.6050	424.08
Construction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Electricity gas and water supply	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Transport services and communication	2,235.10	126.679	6.2131	7.0615	45.3704	5.5892
Other services	3,091.27	198.975	18.9655	9.8539	50.2288	10.742
Total	39,071.0	19,960.5	1,138.56	457.668	669.4566	554.21

Export	Zinc	Others	BOD	COD
Agriculture	0.0264	304.7605	2,277.0649	3,745.5211
Other agriculture	0.0030	7.5031	17.8791	71.8782
Milk and milk products	0.0000	0.1165	0.7279	1.5612
Livestock	0.0021	99.0675	250.5564	1,089.2793
Fishing	0.0057	2.4459	12.6630	32.1910
Coal and lignite	0.0002	0.0417	0.2195	0.4096
Mining and quarrying	0.2884	8.9567	50.9931	88.9236
Sugar	0.0042	3.4424	12.2575	33.2367
Oil and vanaspati	0.0061	10.2967	65.5674	139.2072
Tea, coffee, and beverages	0.0053	5.6796	99.3769	209.9353
Food products	0.0299	103.4573	653.7860	1,207.0314
Cotton textile	0.0269	42.5568	93.2840	3,115.2454
Woolen and silk textile	0.0176	12.7759	70.1528	248.0967
Jute, hemp, and mesta textiles	0.0006	0.6262	21.8044	43.8398
Miscellaneous textile products	1.0514	476.7977	583.4509	3,585.1256
Wood and wood products	0.0023	1.6413	5.1376	12.9016
Paper and paper products	0.0072	57.4171	37.7363	57.3468
Leather and leather products	0.0126	142.7399	162.1598	654.5156
Rubber products	0.0177	15.9386	133.5511	279.7135
Plastic products	0.0124	6.8800	35.8697	59.6244
Petroleum and coal tar products	0.1247	6.5742	42.7055	83.2158

(continued)

Export	Zinc	Others	BOD	COD
Inorganic heavy chemicals	0.0129	11.3316	28.6898	51.2714
Organic heavy chemicals	0.0577	43.3720	586.2957	360.7583
Fertilizers	0.0001	0.1860	0.1277	0.1860
Pesticides	0.0057	10.2178	37.3847	116.1363
Paints, varnishes, and lacquers	0.0035	1.2801	9.2412	10.7435
Other chemicals	0.0361	20.5953	134.4477	283.7549
Synthetic fibers, resin	0.0173	10.2253	69.1821	89.0764
Other nonmetallic mineral products	2.0045	4.1169	10.4475	21.6942
Iron and steel	0.0946	26.0127	96.6352	194.3904
Machinery and metal products	0.1987	27.4316	168.8182	225.2544
Electrical machinery	0.3582	36.0039	153.8482	260.6551
Transport equipment	0.0972	18.2204	83.8903	155.5507
Other machineries	0.6321	117.7828	1,840.3177	1,383.5956
Construction	0.0000	0.0000	0.0000	0.0000
Electricity gas and water supply	0.0000	0.0000	0.0000	0.0000
Transport services and communication	0.1818	38.9511	205.0235	358.3462
Other services	0.3442	190.1865	990.4271	1,957.1479
Total	5.6890	1,865.6297	9,041.7203	20,227.3611

Source: Results from the study

Appendix 6.A.2: Water Pollution Generated from Imported Commodities (Thousand Tons)

Import	SS	DS	Chloride	Sulfide	Oil/ grease	Phenol
Agriculture	686.146	8.6349	2.2973	0.9865	30.5233	0.2804
Other agriculture	126.018	8.6523	1.4791	0.2627	2.6918	0.2082
Milk and milk products	0.0042	0.0043	0.0004	0.0000	0.0011	0.0000
Livestock	14.8394	2.3774	0.0301	0.0139	0.8899	0.0072
Fishing	1.3244	0.5638	0.2458	0.1435	0.0468	0.0032
Coal and lignite	491.377	9.2789	0.7557	0.4332	1.9471	0.7527
Mining and quarrying	6,986.76	764.233	21.7247	13.2149	101.0239	13.3283
Sugar	126.517	31.7097	1.2399	0.5123	4.1813	0.3315
Oil and vanaspati	294.062	16.9289	2.2430	0.9264	14.2091	0.5304
Tea, coffee, and beverages	23.0846	29.4798	0.2839	0.1545	0.3745	0.0416
Food products	349.705	25.6017	3.4297	1.2296	16.3985	0.3637
Cotton textile	303.132	1,679.61	1.2941	0.6467	0.9139	0.1556

(continued)

Import	SS	DS	Chloride	Sulfide	Oil/ grease	Phenol
Woolen and silk textile	451.636	265.147	66.0068	30.6703	7.0507	1.4522
Jute, hemp, and mesta textiles	41.1021	0.8310	33.4140	19.5258	0.3577	0.0931
Miscellaneous textile products	231.929	462.537	33.5663	17.7257	1.8782	0.4567
Wood and wood products	35.3969	2.7973	0.4223	0.1901	0.3875	0.1057
Paper and paper products	872.282	30.6116	2.6339	1.4925	5.0274	1.1171
Leather and leather products	96.7711	60.6840	53.3234	0.6548	1.1106	0.1315
Rubber products	150.746	62.6911	2.4830	1.5029	2.7729	0.4635
Plastic products	294.708	26.0930	1.7956	0.7246	4.3894	1.1590
Petroleum and coal tar products	1,453.26	200.409	3.2139	16.0075	124.7442	3.2343
Inorganic heavy chemicals	1,241.14	258.027	7.7032	3.2467	18.2189	4.0790
Organic heavy chemicals	2,547.39	132.482	17.3179	6.4442	170.5745	48.6211
Fertilizers	240.863	18.1329	0.8974	0.6904	4.7444	0.6449
Pesticides	125.685	6.9288	16.7165	0.3765	2.0016	0.5066
Paints, varnishes, and lacquers	178.840	12.8035	1.2822	0.5907	5.0673	1.7875
Other chemicals	971.957	126.770	8.8129	4.4719	18.4979	4.7249
Synthetic fibers, resin	773.943	72.9697	5.6107	2.9743	23.3385	5.7442
Other nonmetallic mineral products	1,909.43	45.0409	3.9088	2.6397	9.2980	1.4306
Iron and steel	3,634.43	45.4377	29.8217	3.4281	12.5654	9.6845
Machinery and metal products	9,289.13	225.053	40.1835	13.0494	45.9941	70.1896
Electrical machinery	4,229.49	136.026	25.3262	9.0664	28.2328	16.0678
Transport equipment	2,343.39	73.9410	13.2126	3.4742	11.1287	6.5614
Other machineries	9,188.70	579.815	65.8632	25.7567	83.8599	651.296
Construction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Electricity gas and water supply	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Transport services and communication	315.822	17.8999	0.8779	0.9978	6.4109	0.7898
Other services	887.802	57.1450	5.4468	2.8300	14.4255	3.0851
Total	50,908.8	5,497.35	474.864	187.055	775.2781	849.429

Import	Zinc	Others	BOD	COD
Agriculture	0.0123	141.5776	1,057.8190	1,739.9958
Other agriculture	0.0078	19.4471	46.3402	186.2991
Milk and milk products	0.0000	0.0028	0.0174	0.0374
Livestock	0.0003	12.3464	31.2258	135.7522
Fishing	0.0001	0.0564	0.2920	0.7423
Coal and lignite	0.0117	2.6841	14.1267	26.3656
Mining and quarrying	1.3580	42.1674	240.0719	418.6460
Sugar	0.0149	12.2142	43.4913	117.9286

(continued)

Import	Zinc	Others	BOD	COD
Oil and vanaspati	0.0134	22.8181	145.3005	308.4895
Tea, coffee, and beverages	0.0011	1.2254	21.4411	45.2947
Food products	0.0145	49.9810	315.8489	583.1259
Cotton textile	0.0047	7.4855	16.4081	547.9547
Woolen and silk textile	0.0144	10.4404	57.3281	202.7420
Jute, hemp, and mesta textiles	0.0005	0.5491	19.1179	38.4385
Miscellaneous textile products	0.0629	28.5083	34.8852	214.3588
Wood and wood products	0.0017	1.2135	3.7984	9.5386
Paper and paper products	0.0308	245.4146	161.2941	245.1141
Leather and leather products	0.0030	33.7092	38.2954	154.5695
Rubber products	0.0064	5.7580	48.2470	101.0501
Plastic products	0.0103	5.7144	29.7926	49.5227
Petroleum and coal tar products	0.1623	8.5559	55.5782	108.2996
Inorganic heavy chemicals	0.0592	51.9951	131.6425	235.2579
Organic heavy chemicals	0.0784	58.9866	797.3712	490.6369
Fertilizers	0.0125	22.7860	15.6431	22.7941
Pesticides	0.0042	7.6023	27.8149	86.4076
Paints, varnishes, and lacquers	0.0097	3.4929	25.2164	29.3158
Other chemicals	0.0436	24.8937	162.5081	342.9770
Synthetic fibers, resin	0.0317	18.6666	126.2940	162.6116
Other nonmetallic mineral products	7.3155	15.0248	38.1288	79.1742
Iron and steel	0.1177	32.3410	120.1444	241.6815
Machinery and metal products	0.6068	83.7818	515.6065	687.9746
Electrical machinery	0.5325	53.5263	228.7230	387.5107
Transport equipment	0.1214	22.7717	104.8455	194.4062
Other machineries	0.9707	180.8855	2,826.2765	2,124.8633
Construction	0.0000	0.0000	0.0000	0.0000
Electricity gas and water supply	0.0000	0.0000	0.0000	0.0000
Transport services and communication	0.0257	5.5038	28.9700	50.6346
Other services	0.0988	54.6209	284.4471	562.0858
Total	11.7595	1,288.7482	7,814.3521	10,932.5972

Source: Results from the study

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Chapter 7
Simulation Exercises on Water Pollution Abatement Policies

7.1 Introduction

To control water pollution is not an isolated activity. It requires a comprehensive action at all levels. Among the various methods employed to abate chemical pollution of waterways, the ideal one is to minimize or avoid the use of chemicals for industrial, agricultural, and domestic purposes. Adapting practices such as organic farming and integrated pest management could help protect waterways (Scheierling 1995), while chemical contamination of waterways from industrial emissions could be reduced by cleaner production processes (UNEP 2002). Other interventions include proper treatment of hazardous waste and the recycling of chemical containers and discarded products containing chemicals to reduce solid waste buildup and the leaching of toxic chemicals into waterways. There are various technical solutions available to filter out chemical waste from industrial processes or to make them harmless. Changing the pH of wastewater or adding chemicals that flocculate the toxic chemicals so that they settle in sedimentation ponds are common methods (Kinniburgh and Smedley 2001).

The costs and benefits associated with interventions to remove chemical contaminants from water need to be assessed on a local or national basis to determine specific needs, available resources, environmental conditions (including climate), and sustainability (Dasgupta et al. 1997; Zhang et al. 1996). The control of water pollution is to reduce the pollution loads from anthropogenic activities to the natural regenerative capacity of the resource. The benefits of the preservation of water quality are numerous as abatement of water pollution generates both marketable and nonmarketable benefits. Marketable benefits include reduced water-borne diseases, savings in the cost of supplying water for household, industrial and agricultural uses, control of land degradation, and development of fisheries, while nonmarketable benefits include improved environmental amenities, aquatic life, and biodiversity (Murty and Kumar 2011).

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In Chap. 5, we have computed the effect of pollution control cost on output and prices for the Indian economy for the year 2006–2007. What has been studied is to estimate the impact of adding clean water sector on output and prices. Our focus in this chapter is to analyze the impact of alternative water pollution abatement policies on the Indian economy especially focusing on sectoral output and prices.

7.2 Interventions to Control Water Pollution in India

Environmental pollution is often viewed as a negative externality. These external diseconomies of development activities can be minimized by controlling pollution, where polluters or some other agents of the economy incur some additional costs. However, since the environment is a public good, the particular agent will have no incentive to incur the pollution abatement cost. The reason being, it is difficult to define or enforce property rights to the services of such resources, making it difficult to be priced. This justifies the governmental regulations and pollution control policies (Chakraborty et al. 2001).

In India, there have been policy responses for the prevention and control of environmental degradation since the 1970s. The Government of India issued a policy statement for the abatement of pollution in February 1992. The policy emphasizes that it is not enough for the government to notify laws which are to be complied with. The policy affirms that the overall objective of the government is to integrate environmental and economic aspects in the development planning at all levels. It focuses on the preventive aspects for the pollution abatement and promotion of technological inputs to reduce industrial pollutants. The following specific steps that have been suggested to meet this objective are to prevent pollution at source; encourage, develop, and apply the best available practical technical solutions; ensure that the polluters pay for the pollution and control arrangements; focus protection on heavily polluted areas and river stretches; involve public in decision making; and increase safety of industrial operations.

The environmental policy in recent times has also recognized the importance of the role of incentive-based policy instruments in controlling and preventing environmental pollution. Formal regulations may be classified into two categories: (a) state intervention in the form of legislations and policies and (b) public investments for environmental cleaning activities, such as the Ganga Action Plan (GAP) and the Yamuna Action Plan (Murty and Kumar 2011).

7.2.1 Laws for Controlling Water Pollution

Earlier, the government had a tendency of relying on direct regulation or the command and control (CAC) type policies for controlling pollution. India is the first country which had made provision for the protection and improvement of environment in its constitution. In the 42nd amendment to the constitution in 1976, provision to its effect was incorporated in the constitution of India with effect from 3 Jan 1977. The Water (Prevention and Control of Pollution) Act 1974 amended in 1986; the Water (Prevention and Control of Pollution) Cess Act 1977 amended in 1988; the Environment Protection Act (EPA) 1986 is the most important law, relating to the industrial pollution abatement in India. Over the years, several amendments have been made in the various existing statutes to meet the need of the environmental issues.

The first two Acts (1974, 1977) are foundational legislations in the context of water pollution in the country. The EPA is designed to fill the gaps still remaining in the legal framework for the control of industrial pollution. The Water Cess Act aims at generating more revenue rather than restricting the consumption of water by industrial units. Central Pollution Control Board and the state boards are empowered to prevent, control, and abate water pollution. These boards will also advise governments regarding pollution matters. The main task of the CPCB is to coordinate the activities of the state boards. These laws have mainly concerned with controlling industrial water pollution. CPCB has also prepared a list of polluting industries in India. According to these acts, the industries have to provide, on demand, all information regarding their effluent and treatment methods. The regulation of water pollution originating from the household and agriculture sectors is not under the purview of these laws.

We observed that the maximum penalty prescribed under The Water (Prevention and Control of Pollution) Cess Act 1977 was only one thousand, while the same under The Water (Prevention and Control of Pollution) Act 1974 was 10,000 rupees. The maximum penalty under the Environment (Protection) Act 1986 was one lakh. However, in the case of water pollution, the fine or penalty prescribed under The Water (Prevention and Control of Pollution) Act 1974 would be applicable as per sub-Section 2 of Section 24 of the Environment Protection Act 1986. Thus, the maximum penalty/fine is limited to 10,000 for case relating to water pollution (CAG 2011).

The Water (Prevention and Control of Pollution) Act maintains a balance of strategies to ensure compliance, education and assistance, monitoring and inspections, communication, and outreach. However, it fails to address the vital aspect of developing fair and differentiated responses to noncompliance. There is not much evidence of the design of enforcement programs to deter illegal conduct by creating negative consequences. Further the law does not address the issue of restoration of the polluted water bodies. It also does not define stricter financial and nonfinancial penalties to environmental offenders. Although the concerns related to water pollution have been adequately addressed in National Water Policy and National Environment policy in India, both at the central and the state level, provisions for generation of resources for prevention of pollution, treatment of polluted water, and ecological restoration of polluted water bodies are not adequate (CAG 2011).

7.2.2 Fiscal Instruments for Pollution Control

Command and control measures are mostly used by the government to prevent pollution. Natural resource management, on the other hand, has been carried out through programs supported by the central and state governments. The use of fiscal instruments (other than the expenditure policy) in the environmental policy has been limited, even though the need to employ economic and fiscal policy instruments for the control of pollution and management of natural resources has gained recognition since the 1990s (Datt et al. 2004).

A task force was constituted by the Ministry of Environment and Forests (MoEF) in 1995 to evaluate the scope for market-based instruments (MBIs) for industrial pollution abatement (GOI 1997). The task force recommended explicit incorporation of MBIs in pollution control laws, greater reliance on economic penalties in the short and medium term, and completely replacing criminal penalties by MBIs in the long run. It also recommended modifying the existing water cess to make it a genuine effluent based that considers pollution load rather than the amount of water consumed. It also recommended abolishing tax concessions for installation of pollution control equipment. The need for systematic data collection to estimate marginal abatement costs and the regulatory burden was highlighted by the task force. Further, it calls for the introduction of additional MBIs.

The actual use of fiscal incentives in the country has been rather limited. These take the form of tax concessions for the adoption of pollution control equipment. Tax incentives are usually specified for identified abatement technologies and activities, not providing dynamic incentives for technological innovation and diffusion. Also, since most of these are end of-the-pipe treatment technologies, these incentives do not promote more efficient use of resources. There are some provisions for the use of levies, cess, fines, penalties, etc., for polluters, but their implementation and effectiveness need to be strengthened (Kumar and Managi 2009).

Although it is widely known that command and control measures do not provide necessary incentives to polluters for the choice of least cost methods of pollution control, the Government of India has so far resorted only to such measures for controlling industrial pollution in India. On the other hand, fiscal instruments, such as pollution taxes or marketable pollution permits, provide incentives to factories for adopting least-cost pollution abatement technologies. There have been no serious attempts in India to use such instruments for the abatement of industrial pollution. The current water cess, whose objective is to raise revenue to pollution control boards, is very nominal. Some of the recent research studies on water pollution abatement in India conclude that the rate of pollution tax on industrial water use should be several times higher than the prevailing rate of water cess if we want to realize the prescribed water quality standards in the country (Murty and Kumar 2011).

A consistent application of polluter–pays principle and a more effective use of economic instruments would be the rationale way of internalizing pollution-related costs. The economic instruments relating to pollution control policies have been classified under the following categories (Mehta et al. 1997): (a) direct economic instruments involving pollution charges/taxes, user charges, tradable permit scheme, deposit refund scheme on used materials and strict liability for potential damages; (b) indirect economic instruments such as taxes/charges on products which generates pollution, taxes/charges on inputs used in production of goods which generates pollution, subsidies on goods which are complements (substitutes) to goods whose production results in pollution, and fiscal incentives for encouraging clean technologies, abatement technologies, and conservation of resources; and (c) financial support for development of environment friendly technologies, common effluent treatment plants, recycling operations, and enhancing the competence of agencies dealing with environment protection policies.

The water-polluting firms in Indian industry are supposed to meet the standards set for pollutants (35 mg/L for BOD, 250 mg/L for COD, and 100 mg/L for SSP) by the Central Pollution Control Board. A survey of a sample of water-polluting industries in India shows that most of the firms have effluent treatment plants and in addition some firms are using process changes in production and input choices to achieve effluent standards (Murty and Kumar 2011).

However, there is a large variation in the degree of compliance among the firms measured in terms of ratio of standard to effluent quality. The laxity of formal environmental regulations by the government and the use of command and control instruments could be regarded as factors responsible for large variations in complying with pollution standards by firms (Murty and Kumar 2011). Murty and Kumar (2004) provide estimates of taxes on one ton of BOD, COD, and SS as Rs. 20,157, Rs. 48,826, and Rs. 21,444, respectively.

In this backdrop, this chapter will carry out several experiments based on alternative set of instruments developed by us. In the next section, we are focusing on the impact of different abatement policies on sectoral output and price of the Indian economy. Two scenarios are developed followed by a discussion on the output and price impact.

7.3 Alternative Water Pollution Abatement Policies and Impact

From the cost estimation process in Chap. 4, we observed that not all the industries have CETPs or ETPs. While preparing the abatement cost of industries, we found that many of the industries are not maintaining the pollution standards. The industries have introduced ETPs/CETPs but not at the required level. In reality, those sectors are quite far from the required effluent standards of different water pollution parameters.

7.3.1 Scenario 1

If these industries could maintain the standards required, then the total abatement cost would increase. This additional cost to achieve the standards can be treated as pollution tax. These pollution tax rates will be different for different industries. For this study, we could estimate abatement cost only for 16 industries as discussed in Chap. 4. The common sectors for clean water treatment and further pollution tax implementation are estimated for 16 industries such as dairy; livestock; mining; sugar; tea, coffee, and beverages; food products; cotton textile; jute, hemp, and mesta textiles; miscellaneous textile; paper and paper products; leather and leather products; rubber and rubber products; inorganic chemicals; organic chemicals; other chemicals; and paints, varnishes, and lacquers. The additional cost borne by these 16 industries will have impact on the whole economy because of the interdependent structure of the industries as captured by the input–output model (Chap. 3).

7.3.1.1 Impacts on Output

Table 7.1 records the impacts of pollution abatement on the different sectors. To have a greater insight, a summary view has been prepared and presented in Table 7.2 which records the list of sectors classified based on degree of impact on output. It is observed that inorganic heavy chemicals witnessed the largest impact followed by organic heavy chemical. On the other hand, the electricity gas and water, mining and quarrying, and coal and lignite sectors grew more than 5 % as the output of these sectors are used as inputs by the pollution abatement sector, that is, clean water sector. Other sectors of the economy will also see some indirect impact. Among them are plastic products, paper products, petroleum and coal tar products, fertilizer, pesticides, synthetic fiber, and resin, as others see only marginal impact (above 1 % and less than 5 %). The clean water sector is expected to experience a significant growth. With the pollution abatement strategy applied on 16 industries, it is expected to have more clean water as evident from Table 7.1.

7.3.1.2 Impact on Prices

Table 7.3 presents the effect of pollution abatement policies on prices only. In Table 7.4, we categorized price impact in several groups: above 4 %, above 1 % but below 4 %, and below 1 %.

Table 7.1 Effect of pollution abatement cost policies on output (scenario 1)

		New gross output	Old gross output	% change
1	Agriculture	57,686,112.30	57,629,197	0.098
2	Other agriculture	15,813,534.82	15,759,855	0.340
3	Milk and milk products	14,442,986.66	14,438,630	0.030
4	Livestock	8,606,281.58	8,588,824	0.203
5	Fishing	4,016,113.97	4,015,304	0.020
6	Coal and lignite	4,876,332.71	4,636,815	5.165
7	Mining and quarrying	9,699,611.62	9,186,905	5.580
8	Sugar	4,114,396.05	4,102,013	0.301
9	Oil and vanaspati	5,056,751.61	5,047,260	0.188
10	Tea, coffee, and beverages	8,513,760.30	8,496,684	0.200
11	Food products	16,868,852.37	16,848,685	0.119
12	Cotton textile	7,754,938.04	7,750,841	0.052
13	Woolen and silk textile	5,135,235.62	5,125,327	0.193
14	Jute hemp mesta textile	611,321.84	605,491	0.962
15	Miscellaneous textile products	11,265,409.75	11,256,847	0.076
16	Wood and wood products	2,234,179.10	2,206,365	1.260
17	Paper and paper products	6,002,441.49	5,928,380	1.249
18	Leather and leather products	2,221,507.78	2,212,585	0.403
19	Rubber products	4,005,570.01	3,982,413	0.581
20	Plastic products	5,617,771.04	5,550,096	1.219
21	Petroleum and coal tar products	29,803,129.19	29,303,980	1.703
22	Inorganic heavy chemicals	7,096,709.28	4,404,579	61.121
23	Organic heavy chemicals	4,101,604.83	3,712,881	10.469
24	Fertilizers	4,835,460.83	4,780,094	1.158
25	Pesticides	1,212,530.45	1,174,691	3.221
26	Paints, varnishes, and lacquers	2,678,599.65	2,656,868	0.817
27	Other chemicals	16,763,162.49	16,483,235	1.698
28	Synthetic fibers, resin	4,136,050.07	4,019,046	2.911
29	Other nonmetallic mineral products	9,778,487.44	9,742,535	0.369
30	Iron and steel	26,027,267.52	25,940,192	0.335
31	Machinery and metal products	34,802,133.19	34,583,931	0.630
32	Electrical machinery	37,556,625.97	37,431,227	0.335
33	Transport equipment	15,208,599.73	15,185,879	0.149
34	Other machineries	12,201,724.80	12,103,599	0.810
35	Construction	90,765,672.80	90,623,003	0.157
36	Electricity gas and water supply	21,129,134.13	19,268,534	9.656
37	Transport services and communication	72,920,533.79	72,472,275	0.6185
38	Other services	214,387,499.25	213,520,795	0.405
39	Clean water	6,132,045.98	3,025,939	102.649
	Total	806,080,080.07	793,801,798	1.546

Source: Results from the study

As noticed from Table 7.4, sugar, cotton textile, tea and beverages, and electricity gas and water sectors show a greater percentage effect on prices (i.e., prices increase around 5 %). Other sectors such as organic heavy chemicals, paints, other

Table 7.2 List of sectors classified based on percentage effects on output

Scenario 1	Sectors
Above 50 %	Inorganic heavy chemicals
Above 10 %	Organic heavy chemicals
Above 5 %	Electricity gas and water, mining and quarrying, and coal and lignite
Above 1 %	Pesticides, petroleum and coal tar products, fertilizer, other chemicals, synthetic fiber and resin, plastic products, wood and wood products, and paper and paper products
Below 1 %	Rest of the sectors

Source: Results from the study

chemicals, iron and steel, and livestock experience more than 1 % but less than 4 % increase in price. The rest of the other sectors are having marginal increase in price.

Sugar and cotton textile sectors belong to the group 4 % and above. It indicates that these industries are far from the required standard and have to bear more pollution tax to comply. On the other hand, price increase for paper, leather, and rubber products is relatively less (less than 4 %) because there are already some levels of measures introduced by these sectors.

It is evident that price increases for all the sectors in the economy even though tax is imposed only on sectors for which we have been able to collect data on water pollution abatement cost. Sectors which have not been taxed show sign of marginal price increase as a consequence of indirect effect. Hence, it is emphasized that the existence of linkages between industries should be accounted for while adopting pollution control policies (in the nature of tax or charges) because the added cost would influence the decision (of price fixing) of the sectors in the economy directly as well as indirectly.

7.3.2 Scenario 2

Due to unavailability of the data for abatement cost of other water-polluting industries, we have adopted another scenario experiment. On the basis of the total pollution tax for the 16 sectors which is 0.76 % of gross value added for India for the year 2006–2007, it is assumed that this pollution tax rate is imposed on all the sectors. The tax rate will be the same but the volume of tax will be different across sectors because the value added differs among the sectors.

As a consequence, the polluting firm takes the initiative of reducing pollution by itself because the tax rate is fixed in a way that the polluting industry finds it more cost effective to take up the effluent treatment plant rather than pay the tax amount. Even if the polluters generate pollution beyond the standards or do not take abatement measures, the revenues thus collected from taxes would be sufficient (for the authorities) to cover the pollution control administrative costs and the

Table 7.3 Effect of pollution abatement cost policies on prices (scenario 1)

		Old price	New price after pollution tax	% change
1	Agriculture	1	1.0047	0.4734
2	Other agriculture	1	1.0033	0.3282
3	Milk and milk products	1	1.0209	2.0925
4	Livestock	1	1.0208	2.0793
5	Fishing	1	1.0048	0.4838
6	Coal and lignite	1	1.0061	0.6128
7	Mining and quarrying	1	1.0070	0.7016
8	Sugar	1	1.0563	5.6322
9	Oil and vanaspati	1	1.0272	2.7183
10	Tea, coffee, and beverages	1	1.0486	4.8554
11	Food products	1	1.0113	1.1300
12	Cotton textile	1	1.2048	20.475
13	Woolen and silk textile	1	1.0373	3.7285
14	Jute hemp mesta textile	1	1.0098	0.9847
15	Miscellaneous textile products	1	1.1215	12.152
16	Wood and wood products	1	1.0078	0.7780
17	Paper and paper products	1	1.0230	2.3009
18	Leather and leather products	1	1.0227	2.2652
19	Rubber products	1	1.0161	1.6063
20	Plastic products	1	1.0130	1.2984
21	Petroleum and coal tar products	1	1.0098	0.9792
22	Inorganic heavy chemicals	1	1.0229	2.2898
23	Organic heavy chemicals	1	1.0152	1.5223
24	Fertilizers	1	1.0104	1.0399
25	Pesticides	1	1.0276	2.7616
26	Paints, varnishes, and lacquers	1	1.0184	1.8442
27	Other chemicals	1	1.0295	2.9464
28	Synthetic fibers, resin	1	1.0125	1.2508
29	Other nonmetallic mineral products	1	1.0118	1.1797
30	Iron and steel	1	1.0167	1.6674
31	Machinery and metal products	1	1.0102	1.0222
32	Electrical machinery	1	1.0127	1.2741
33	Transport equipment	1	1.0101	1.0135
34	Other machineries	1	1.0099	0.9917
35	Construction	1	1.0093	0.9270
36	Electricity gas and water supply	1	1.0487	4.8742
37	Transport services and communication	1	1.0509	5.0873
38	Other services	1	1.0035	0.3486
39	Clean water	1	1.0145787	1.4578

Source: Results from the study

financial assistance/compensation given to the victims of pollution and provide subsidy to set up treatment plants.

Table 7.4 List of sectors classified based on percentage effects on prices

Scenario 1	Sectors
Above 4 %	Sugar, cotton textile, electricity gas and water
Above 1 %	Tea, coffee, and beverages; organic heavy chemicals, pesticides; paints, varnishes, and lacquers; other chemicals; iron and steel; and transport services and communication
Below 1 %	Rest of the sectors

Source: Results from the study

7.3.2.1 Impact on Output

Tables 7.5 and 7.6 show the sectoral output impacts due to the alternative abatement policy. It is observed that the rate of growth of output varies across sectors. However, it should be noted that the impact on each sectors in terms of output growth is lower than that of scenario 1 including the clean water sector.

7.3.2.2 Impact on Prices

Imposition of taxes affects the concerned sectors through increase in prices as it incorporates an additional cost for the particular industry. Tables 7.7 and 7.8 show the impact on prices estimated from scenario 2. Comparing the price impact based on the two scenarios, an interesting observation can be made. Sugar and cotton textile do appear in both cases having more than 4 % increases in price. On the other hand, the price impact is distributed more or less uniformly across all industries in scenario 2 having a range of more than 1–4 % level.

7.4 Effects on Consumers

It is clear from earlier discussion that the price system would be different if through voluntary action or the need to obey a special law each industry undertakes to eliminate at its own expense a portion of pollution generated by it, say 90–95 %. They may either engage in pollution abatement operation (alternatively clean water production) on their own account or be compelled to pay an appropriate proposed tax for pollution generation above MINAS. The added cost would of course be included in the price of marketable products. On the other hand, the product will be more costly if government imposes heavy tax because of generation of pollution above some specified limits. In that case, the producer will voluntarily take necessary steps to keep the pollution within the specified limits. In these two processes, the price of the product is bound to increase. However, if the government is not

Table 7.5 Effect of pollution abatement cost policies on output (scenario 2)

		New gross output	Old gross output	% change
1	Agriculture	57,680,926.54	57,629,197	0.0897
2	Other agriculture	15,808,643.86	15,759,855	0.310
3	Milk and milk products	14,442,589.72	14,438,630	0.027
4	Livestock	8,604,690.96	8,588,824	0.185
5	Fishing	4,016,040.17	4,015,304	0.018
6	Coal and lignite	4,854,509.61	4,636,815	4.695
7	Mining and quarrying	9,652,897.45	9,186,905	5.072
8	Sugar	4,113,267.77	4,102,013	0.274
9	Oil and vanaspati	5,055,886.81	5,047,260	0.171
10	Tea, coffee, and beverages	8,512,204.41	8,496,684	0.183
11	Food products	16,867,014.85	16,848,685	0.109
12	Cotton textile	7,754,564.78	7,750,841	0.048
13	Woolen and silk textile	5,134,332.86	5,125,327	0.176
14	Jute hemp mesta textile	610,790.58	605,491	0.875
15	Miscellaneous textile products	11,264,629.59	11,256,847	0.069
16	Wood and wood products	2,231,644.89	2,206,365	1.146
17	Paper and paper products	5,995,693.54	5,928,380	1.135
18	Leather and leather products	2,220,694.78	2,212,585	0.367
19	Rubber products	4,003,460.11	3,982,413	0.528
20	Plastic products	5,611,604.95	5,550,096	1.108
21	Petroleum and coal tar products	29,757,650.29	29,303,980	1.548
22	Inorganic heavy chemicals	6,851,421.49	4,404,579	55.552
23	Organic heavy chemicals	4,066,187.04	3,712,881	9.516
24	Fertilizers	4,830,416.24	4,780,094	1.053
25	Pesticides	1,209,082.80	1,174,691	2.928
26	Paints, varnishes, and lacquers	2,676,619.63	2,656,868	0.743
27	Other chemicals	16,737,657.47	16,483,235	1.544
28	Synthetic fibers, resin	4,125,389.51	4,019,046	2.646
29	Other nonmetallic mineral products	9,775,211.69	9,742,535	0.335
30	Iron and steel	26,019,333.80	25,940,192	0.305
31	Machinery and metal products	34,782,252.16	34,583,931	0.573
32	Electrical machinery	37,545,200.49	37,431,227	0.304
33	Transport equipment	15,206,529.53	15,185,879	0.136
34	Other machineries	12,192,784.26	12,103,599	0.737
35	Construction	90,752,673.77	90,623,003	0.143
36	Electricity gas and water supply	20,959,609.52	19,268,534	8.776
37	Transport services and communication	72,879,691.62	72,472,275	0.562
38	Other services	214,308,531.30	213,520,795	0.369
39	Clean water	5,275,730.06	3,025,939	74.350
	Total	804,388,060.90	793,801,798	1.334

Source: Results from the study

serious enough regarding pollution control, the producer will be much more reluctant to control the pollution generation to maximize his profits. In that case, the public health will deteriorate and health treatment cost will go up.

Table 7.6 List of sectors classified based on percentage effects on output

Scenario 1	Sectors
Above 50 %	Inorganic heavy chemicals
Above 5 %	Organic heavy chemicals, electricity gas and water, mining and quarrying
Above 1 %	Coal and lignite, pesticides, petroleum and coal tar products, fertilizer, other chemicals, synthetic fiber and resin, plastic products, wood and wood products, paper and paper products
Below 1 %	Rest of the sectors

Source: Results from the study

In the end, consumers ultimately bear the burden of pollution generation, either through price increase – due to pollution abatement cost or taxes imposed by the government on producers – or health treatment cost when pollution is not treated. From the point of view of the household, that is, the consumers the relationship between real cost and real benefits remain nevertheless the same, having paid for some abatement activities or tax imposed by government indirectly, he will have to spend less on health treatment cost indirectly.

7.5 Water Pollution and 12th Five-Year Plan

So far we have discussed the impact of alternative water pollution abatement policies. However, a closer look at the future load of water pollution in the context of India's growth strategy is necessary as it will be useful to the policy makers and academics. The next task in this section will be to carry out that exercise. Here we shall consider the 12th Five-Year Plan of India (2011–2012 to 2016–2017) (GOI 2013). We have attempted several scenarios to estimate the gross output including clean water sector in the year 2016–2017. It is expected that the total output of the economy will increase with economic growth, but the sectoral growth rate would likely to vary. We are expecting that the sectoral output changes not only due to the increase in growth rate of the economy but also due to the implementation of clean water activities in the economic system.

The following three scenarios have been developed.

Scenario 1: This scenario deals with the business as usual growth rate (8 % p.a.) of the Indian economy at 2016–2017. Here the growth rate considered is between 2006–2007 and 2011–2012 which is 8.2 %. This growth rate has been applied on 2006–2007 to project the economy up to 2016–2017. Table 7.9 shows the annual sectoral output growth including clean water in 2016–2017 relative to 2006–2007.

Scenario 2: According to the 12th Five-Year Plan of India, the economy is likely to grow at a rate of 9.5 % p.a (GOI 2013). Now if the economy grows at a rate of 9.5 % per annum, then the gross output of the Indian economy including clean

Table 7.7 Effect of pollution abatement cost policies on prices (scenario 2)

		Old price	New price after tax	% change
1	Agriculture	1	1.0109	1.09
2	Other agriculture	1	1.0101	1.01
3	Milk and milk products	1	1.0164	1.64
4	Livestock	1	1.0176	1.76
5	Fishing	1	1.0108	1.08
6	Coal and lignite	1	1.0120	1.20
7	Mining and quarrying	1	1.0135	1.35
8	Sugar	1	1.0613	6.13
9	Oil and vanaspati	1	1.0124	1.24
10	Tea, coffee, and beverages	1	1.0513	5.13
11	Food products	1	1.0169	1.69
12	Cotton textile	1	1.1143	11.43
13	Woolen and silk textile	1	1.0283	2.83
14	Jute hemp mesta textile	1	1.0138	1.38
15	Miscellaneous textile products	1	1.0728	7.28
16	Wood and wood products	1	1.0131	1.31
17	Paper and paper products	1	1.0170	1.70
18	Leather and leather products	1	1.0167	1.67
19	Rubber products	1	1.0185	1.85
20	Plastic products	1	1.0168	1.68
21	Petroleum and coal tar products	1	1.0134	1.34
22	Inorganic heavy chemicals	1	1.0161	1.61
23	Organic heavy chemicals	1	1.0162	1.62
24	Fertilizers	1	1.0154	1.54
25	Pesticides	1	1.0143	1.43
26	Paints, varnishes, and lacquers	1	1.0205	2.05
27	Other chemicals	1	1.0341	3.41
28	Synthetic fibers, resin	1	1.0167	1.67
29	Other nonmetallic mineral products	1	1.0151	1.51
30	Iron and steel	1	1.0148	1.48
31	Machinery and metal products	1	1.0141	1.41
32	Electrical machinery	1	1.0168	1.68
33	Transport equipment	1	1.0140	1.40
34	Other machineries	1	1.0154	1.54
35	Construction	1	1.0141	1.41
36	Electricity gas and water supply	1	1.0148	1.48
37	Transport services and communication	1	1.0570	5.70
38	Other services	1	1.0105	1.05
39	Clean water	1	1.0086	0.86

Source: Results from the study

water will be increased accordingly. Table 7.9 calculates the annual sectoral output growth including clean water in 2016–2017 relative to 2006–2007 on the basis of scenario 2.

Scenario 3: According to the RBI's survey of professional forecasters, the Indian economy is expected to grow at 7.5 % per annum during the coming 5 years.

Table 7.8 List of sectors classified based on percentage effects on prices

Scenario 2	Sectors
Above 4 %	Sugar; tea, coffee, and beverages; miscellaneous textile products; cotton textile; transport service; and communication
Above 1 %–below 4 %	Rest of the sectors

Source: Results from the study

This implies expectations of substantial improvement in the growth from previous years (2012) 5 % and the expected 6 % growth in the current year (2013) (CMIE 2013).

The economy had grown at 7.8 % and 7.9 % per annum during the 10th and 11th Five-Year Plan periods, respectively. The 12th plan period could see a substantial slowing down from these growth rates. As the current growth rate decreases, expectations of the medium- and long-term growth prospects also dropped. The RBI's survey of professional forecasters reflects this shift. In the 20th round in April–June 2012, the expectation was that in the next 5 years, India would achieve a growth rate of 7.3 % per annum. This expectation dropped to 7.0 % by the 23rd round in January–March 2013 (CMIE 2013).

If we believe that the professional forecasters' expectation of 7.5 % per annum growth in the next 5 years is evenly spread over the next 3 years, then the 12th plan period's growth works out to 6.8 %. If we accept the prime minister's 8.0 % growth in the coming 3 years, then the growth scales up to 7.0 %. And, if we accept the further one percentage point increase per annum expected by the finance minister, then the growth works out to 7.3 % (CMIE 2013).

Thus, current expectations seem to suggest that the economy would grow in the range of 6.8–7.3 % per annum in the 12th Five-Year Plan. The mean expectation is just a shade above 7.0 % per annum (CMIE 2013). For the current exercise, we have considered 7.0 % p.a. to see the output and price effect for Indian economy till 2016–2017.

7.6 Results and Discussion[1]

The results of three scenarios are shown in Table 7.9, which shows the annual percentage change in growth. We observed that the sectoral impacts do differ according to scenarios.

[1] To project the economy we have considered the followings steps. First the economy has been updated from 2006–2007 to 2011–2012 considering the past growth rate. Second the aggregate final demand has been projected from 2011–2012 to 2016–2017 based on three scenarios (Business-as usual, 9.5 % p.a and 7 % p.a). Sectoral final demand has been estimated using the compositional changes between 1998–1999 and 2006–2007.

Table 7.9 Annual growth of sectoral output based on three scenarios in 2016–2017

		Scenario 1	Scenario 2	Scenario 3
1	Agriculture	5.152	6.900	3.532
2	Other agriculture	6.064	7.918	5.733
3	Milk and milk products	4.954	6.680	4.230
4	Livestock	5.028	6.762	4.674
5	Fishing	7.576	9.604	7.174
6	Coal and lignite	8.914	11.096	7.210
7	Mining and quarrying	11.529	14.013	8.055
8	Sugar	7.766	9.368	6.757
9	Oil and vanaspati	7.651	9.459	7.198
10	Tea, coffee, and beverages	18.172	21.423	10.527
11	Food products	11.161	13.603	6.407
12	Cotton textile	8.809	9.127	7.387
13	Woolen and silk textile	4.651	6.341	4.272
14	Jute hemp mesta textile	7.963	10.035	7.164
15	Miscellaneous textile products	12.232	14.798	7.444
16	Wood and wood products	9.374	10.813	7.900
17	Paper and paper products	8.718	11.045	7.503
18	Leather and leather products	6.312	8.489	5.196
19	Rubber products	7.542	10.009	6.975
20	Plastic products	8.627	10.777	7.179
21	Petroleum and coal tar products	9.101	11.305	7.338
22	Inorganic heavy chemicals	8.287	10.378	7.169
23	Organic heavy chemicals	2.712	4.405	1.915
24	Fertilizers	5.745	7.562	5.130
25	Pesticides	7.256	9.248	6.164
26	Paints, varnishes, and lacquers	11.755	14.265	7.749
27	Other chemicals	9.789	12.073	7.601
28	Synthetic fibers, resin	6.979	9.531	6.755
29	Other nonmetallic mineral products	13.471	15.668	8.024
30	Iron and steel	8.740	10.902	6.615
31	Machinery and metal products	7.750	9.798	7.161
32	Electrical machinery	12.293	14.865	8.600
33	Transport equipment	7.088	9.057	6.474
34	Other machineries	7.338	10.070	6.671
35	Construction	10.871	13.279	8.103
36	Electricity gas and water supply	8.561	10.702	6.754
37	Transport services and communication	8.748	10.911	7.413
38	Other services	8.059	10.143	6.533
39	Clean water	7.536	9.560	7.033
	Total	8.662	10.804	6.773

Source: Results from the study

Table 7.10 List of sectors classified based on percentage growth of output under three scenarios

Scenario 1	Sectors
Above 10 % p.a. growth	Tea, coffee, and beverages; mining and quarrying; miscellaneous textile products; food products; paints and varnishes; electrical machinery; other nonmetallic mineral products; construction; and clean water
Scenario 2	Sectors
Above 10 % p.a. growth	Coal and lignite; tea and beverages; other nonmetallic mineral products; mining and quarrying; jute, hemp, and mesta textiles; miscellaneous textile products; food products; wood and wood products; rubber and rubber products; paints and varnishes; electrical machinery; construction; paper and paper products; plastic products; petroleum and coal tar products; inorganic heavy chemicals; other chemicals; iron and steel; electricity gas and water; and transport service and communication
Scenario 3	Sectors
Above 10 % p.a. growth	Tea, coffee, and beverages

Source: Results from the study

A concise form of Table 7.9 is given in Table 7.10 which provides more insight in that direction.

The sector tea, coffee, and beverages appear for all three scenarios having 10 % above growth. The number of sectors having more than 10 % p.a. have increased in scenario 2 compared to scenario 1. Around 20 sectors are likely to increase at 10 % p.a. out of 39 sectors in scenario 2. Few common sectors are observed across scenario 1 and 2 having more than 10 % p.a. growth. These are other nonmetallic mineral products, tea, coffee, and beverages; mining and querying; miscellaneous textile products; food products; paints and varnishes; electrical machinery; and construction. The other additional sectors present in scenario 2 are jute, hemp, and mesta textiles; wood and wood products; rubber and rubber products; paper and paper products; plastic products; petroleum and coal tar products; inorganic heavy chemicals; other chemicals; iron and steel; and electricity gas and water.

Analysis of the growth rate of different sectors across the scenarios reveals that water pollution-generating sectors will also grow rapidly. Accordingly, as abatement activities continue, the output of clean water sector will also grow accordingly. Therefore, our next task is to estimate the volume of water pollution parameters in the year 2016–2017. Here we assume that the pollution coefficient will remain unchanged over the period. The volume of 10 types of water pollution parameters across three scenarios are presented in Table 7.11. Sector wise pollution generated is given in Appendices 7.A.1, 7.A.2, 7.A.3. It shows that each pollutant volume will differ according to the growth rate in each scenario. For example, scenario 2 shows the highest pollution volume for all water pollution parameters as it considers the highest growth rate at 9.5 %.

Table 7.11 Water pollution under three scenarios in 2016–2017 (thousand tons)

	2006–2007	Scenario 1	Scenario 2	Scenario 3
SS	203,228.8	385,978	429,820	348,515.2
DS	66,201.22	126,778	131,323	115,285.6
Chloride	3,144.41	5,711.27	6,386.88	5,080.033
Sulfide	1,227.531	2,356.6	2,629.1	2,060.861
Oil/grease	3,737.282	6,091.53	6,797.72	5,539.726
Phenol	428.54	739.04	841.09	700.5268
Zinc	39.07	91.682	100.343	70.468
Others	14,290.62	22,764.9	25,381.8	20,792.2
BOD	81,668.44	127,857	142,650	115,123
COD	174,803.1	279,599	308,735	254,668

Appendices

Appendix 7.A.1: Sector Wise Pollution Generated for Ten Pollutants in the Year 2016–2017 (Scenario 1)

Sectors/thousand tons	SS	DS	Chloride	Sulfide	Oil/ grease	Phenol
Agriculture	32,529.149	0.000	0.000	0.000	2,345.917	0.000
Other agriculture	11.170	1.867	0.000	0.000	1.513	0.000
Milk and milk products	2,949.267	4,561.081	413.868	0.000	1,141.649	0.000
Livestock	2,706.413	805.922	0.000	0.000	220.084	0.000
Fishing	14.783	0.000	0.000	0.000	6.451	0.000
Coal and lignite	0.000	0.855	0.070	0.142	0.000	0.000
Mining and quarrying	251.572	535.059	0.000	0.000	52.682	1.759
Sugar	66.362	264.272	0.000	0.000	23.069	0.000
Oil and vanaspati	56.641	0.000	0.000	0.000	58.310	0.000
Tea, coffee, and beverages	434.740	10,531.795	0.000	0.000	0.000	0.000
Food products	144.676	0.000	0.000	0.000	193.324	0.000
Cotton textile	7,304.803	102,821.9	0.000	0.000	0.000	0.000
Woolen and silk textile	310.016	760.586	733.349	337.341	22.426	2.933
Jute hemp mesta textile	496.668	0.222	1,161.30	679.081	9.038	2.528
Miscellaneous textile products	800.704	172.285	2,002.09	1,089.84	15.347	1.112
Wood and wood products	0.000	0.000	0.000	0.000	0.000	0.000
Paper and paper products	1,231.678	0.000	0.000	0.000	0.000	0.000
Leather and leather products	632.704	913.497	919.627	7.275	0.000	0.000
Rubber products	143.827	1,142.447	0.000	17.896	22.704	0.000
Plastic products	0.000	151.923	0.000	0.000	0.000	0.000
Petroleum and coal tar products	583.205	1,665.783	0.000	213.623	1,697.836	19.922
Inorganic heavy chemicals	39.149	1,429.911	0.000	0.000	0.000	0.000
Organic heavy chemicals	216.500	0.000	0.000	0.000	230.034	68.221
Fertilizers	523.316	0.000	0.000	0.000	0.000	0.000

(continued)

Sectors/thousand tons	SS	DS	Chloride	Sulfide	Oil/ grease	Phenol
Pesticides	158.143	0.000	160.252	0.000	0.000	0.000
Paints, varnishes, and lacquers	45.241	0.000	0.000	0.000	51.142	23.604
Other chemicals	0.003	1,018.976	0.008	0.010	0.000	0.000
Synthetic fibers, resin	0.000	0.000	0.000	0.000	0.000	0.000
Other nonmetallic mineral products	117.908	0.000	0.000	0.000	0.000	0.000
Iron and steel	1,836.212	0.000	320.699	11.387	0.000	60.565
Machinery and metal products	0.000	0.000	0.000	0.000	0.000	189.17
Electrical machinery	0.000	0.000	0.000	0.000	0.000	0.000
Transport equipment	0.000	0.000	0.000	0.000	0.000	0.000
Other machineries	0.000	0.000	0.000	0.000	0.000	369.22
Construction	0.000	0.000	0.000	0.000	0.000	0.000
Electricity gas and water supply	332,372.9	0.000	0.000	0.000	0.000	0.000
Transport services and communication	0.000	0.000	0.000	0.000	0.000	0.000
Other services	0.000	0.000	0.000	0.000	0.000	0.000
Total	385,977.8	126,778.4	5,711.26	2,356.60	6,091.525	739.04

Sectors/thousand tons	Zinc	Others	BOD	COD
Agriculture	0.000	10,630.335	86,944.013	136,172.607
Other agriculture	0.000	0.011	10.076	24.304
Milk and milk products	0.000	2,742.484	16,836.468	37,062.412
Livestock	0.000	4,095.240	8,071.381	44,457.637
Fishing	0.000	4.078	28.651	61.240
Coal and lignite	0.000	0.159	0.000	0.000
Mining and quarrying	0.000	0.000	13.926	0.000
Sugar	0.000	26.908	156.214	312.429
Oil and vanaspati	0.000	0.000	328.656	487.109
Tea, coffee, and beverages	0.000	4.569	5,938.357	12,919.158
Food products	0.000	0.000	122.036	209.007
Cotton textile	0.000	337.504	568.187	32,500.930
Woolen and silk textile	0.000	16.943	264.886	977.114
Jute hemp mesta textile	0.000	9.042	632.123	1,246.185
Miscellaneous textile products	3.781	1,666.955	1,290.024	2,842.501
Wood and wood products	0.000	0.000	0.000	0.000
Paper and paper products	0.000	1,824.275	939.310	1,285.797
Leather and leather products	0.000	409.909	190.346	760.225
Rubber products	0.000	44.334	902.436	1,729.246
Plastic products	0.000	0.000	50.641	126.603
Petroleum and coal tar products	0.000	0.000	193.894	485.275
Inorganic heavy chemicals	0.000	229.758	221.596	657.402
Organic heavy chemicals	0.000	27.552	989.784	292.087
Fertilizers	0.000	362.771	0.000	0.000
Pesticides	0.000	54.085	152.872	695.830

(continued)

Sectors/thousand tons	Zinc	Others	BOD	COD
Paints, varnishes, and lacquers	0.000	0.000	154.082	19.277
Other chemicals	0.000	0.000	347.651	1,984.006
Synthetic fibers, resin	0.000	0.000	0.000	0.000
Other nonmetallic mineral products	87.901	47.046	0.000	70.665
Iron and steel	0.000	230.935	613.948	1,532.054
Machinery and metal products	0.000	0.000	641.280	199.545
Electrical machinery	0.000	0.000	0.000	0.000
Transport equipment	0.000	0.000	0.000	0.000
Other machineries	0.000	0.000	1,254.092	390.179
Construction	0.000	0.000	0.000	0.000
Electricity gas and water supply	0.000	0.000	0.000	98.078
Transport services and communication	0.000	0.000	0.000	0.000
Other services	0.000	0.000	0.000	0.000
Total	91.682	22,764.893	127,856.93	279,598.9

Source: Results from the study

Appendix 7.A.2: Sector Wise Pollution Generated for Ten Pollutants in the Year 2016–2017 (Scenario 2)

Sectors/thousand tons	SS	DS	Chloride	Sulfide	Oil/ grease	Phenol
Agriculture	36,282.512	0.000	0.000	0.000	2,616.599	0.000
Other agriculture	12.459	2.082	0.000	0.000	1.688	0.000
Milk and milk products	3,289.567	5,087.360	461.622	0.000	1,273.377	0.000
Livestock	3,018.692	898.913	0.000	0.000	245.479	0.000
Fishing	16.488	0.000	0.000	0.000	7.195	0.000
Coal and lignite	0.000	0.954	0.078	0.158	0.000	0.000
Mining and quarrying	280.599	596.797	0.000	0.000	58.761	1.962
Sugar	72.345	288.099	0.000	0.000	25.149	0.000
Oil and vanaspati	62.443	0.000	0.000	0.000	64.284	0.000
Tea, coffee, and beverages	484.902	11,747.002	0.000	0.000	0.000	0.000
Food products	161.369	0.000	0.000	0.000	215.631	0.000
Cotton textile	7,428.641	104,565.104	0.000	0.000	0.000	0.000
Woolen and silk textile	345.787	848.346	817.966	376.265	25.013	3.272
Jute hemp mesta textile	553.976	0.248	1,295.296	757.436	10.081	2.820
Miscellaneous textile products	893.093	192.164	2,233.106	1,215.599	17.118	1.240
Wood and wood products	0.000	0.000	0.000	0.000	0.000	0.000
Paper and paper products	1,384.816	0.000	0.000	0.000	0.000	0.000
Leather and leather products	717.144	1,035.412	1,042.361	8.246	0.000	0.000
Rubber products	164.053	1,303.105	0.000	20.412	25.897	0.000

(continued)

Sectors/thousand tons	SS	DS	Chloride	Sulfide	Oil/ grease	Phenol
Plastic products	0.000	169.453	0.000	0.000	0.000	0.000
Petroleum and coal tar products	650.498	1,857.989	0.000	238.272	1,893.740	22.220
Inorganic heavy chemicals	43.624	1,593.380	0.000	0.000	0.000	0.000
Organic heavy chemicals	245.333	0.000	0.000	0.000	260.669	77.306
Fertilizers	583.699	0.000	0.000	0.000	0.000	0.000
Pesticides	176.391	0.000	178.742	0.000	0.000	0.000
Paints, varnishes, and lacquers	50.461	0.000	0.000	0.000	57.043	26.328
Other chemicals	0.003	1,136.550	0.009	0.011	0.000	0.000
Synthetic fibers, resin	0.000	0.000	0.000	0.000	0.000	0.000
Other nonmetallic mineral products	128.940	0.000	0.000	0.000	0.000	0.000
Iron and steel	2,048.083	0.000	357.702	12.701	0.000	67.553
Machinery and metal products	0.000	0.000	0.000	0.000	0.000	211.00
Electrical machinery	0.000	0.000	0.000	0.000	0.000	0.000
Transport equipment	0.000	0.000	0.000	0.000	0.000	0.000
Other machineries	0.000	0.000	0.000	0.000	0.000	427.38
Construction	0.000	0.000	0.000	0.000	0.000	0.000
Electricity gas and water supply	370,723.7	0.000	0.000	0.000	0.000	0.000
Transport services and communication	0.000	0.000	0.000	0.000	0.000	0.000
Other services	0.000	0.000	0.000	0.000	0.000	0.000
Total	429,819.6	131,322.95	6,386.884	2,629.101	6,797.723	841.09

	Zinc	Others	BOD	COD
Agriculture	0.000	11,856.912	96,976.014	151,884.831
Other agriculture	0.000	0.013	11.238	27.108
Milk and milk products	0.000	3,058.925	18,779.138	41,338.844
Livestock	0.000	4,567.767	9,002.694	49,587.365
Fishing	0.000	4.549	31.957	68.306
Coal and lignite	0.000	0.177	0.000	0.000
Mining and quarrying	0.000	0.000	15.532	0.000
Sugar	0.000	29.334	170.299	340.597
Oil and vanaspati	0.000	0.000	362.326	537.011
Tea, coffee, and beverages	0.000	5.096	6,623.552	14,409.830
Food products	0.000	0.000	136.117	233.123
Cotton textile	0.000	343.225	577.820	33,051.915
Woolen and silk textile	0.000	18.898	295.449	1,089.858
Jute hemp mesta textile	0.000	10.085	705.060	1,389.976
Miscellaneous textile products	4.217	1,859.296	1,438.873	3,170.482
Wood and wood products	0.000	0.000	0.000	0.000

(continued)

	Zinc	Others	BOD	COD
Paper and paper products	0.000	2,051.092	1,056.097	1,445.664
Leather and leather products	0.000	464.615	215.750	861.685
Rubber products	0.000	50.569	1,029.343	1,972.424
Plastic products	0.000	0.000	56.484	141.211
Petroleum and coal tar products	0.000	0.000	216.266	541.268
Inorganic heavy chemicals	0.000	256.025	246.929	732.557
Organic heavy chemicals	0.000	31.222	1,121.600	330.986
Fertilizers	0.000	404.629	0.000	0.000
Pesticides	0.000	60.326	170.511	776.118
Paints, varnishes, and lacquers	0.000	0.000	171.861	21.501
Other chemicals	0.000	0.000	387.764	2,212.929
Synthetic fibers, resin	0.000	0.000	0.000	0.000
Other nonmetallic mineral products	96.125	51.448	0.000	77.277
Iron and steel	0.000	257.581	684.788	1,708.830
Machinery and metal products	0.000	0.000	715.274	222.569
Electrical machinery	0.000	0.000	0.000	0.000
Transport equipment	0.000	0.000	0.000	0.000
Other machineries	0.000	0.000	1,451.647	451.644
Construction	0.000	0.000	0.000	0.000
Electricity gas and water supply	0.000	0.000	0.000	109.395
Transport services and communication	0.000	0.000	0.000	0.000
Other services	0.000	0.000	0.000	0.000
Total	100.343	25,381.784	142,650.383	308,735.306

Source: Results from the study

Appendix 7.A.3: Sector Wise Pollution Generated for Ten Pollutants in the Year 2016–2017 (Scenario 3)

Sectors/thousand tons	SS	DS	Chloride	Sulfide	Oil/ grease	Phenol
Agriculture	29,050.65	0	0	0	2,095.056	0
Other agriculture	10.94005	1.8285	0	0	1.481794	0
Milk and milk products	2,806.467	4,340.2	393.829	0	1,086.371	0
Livestock	2,642.656	786.93	0	0	214.8996	0
Fishing	14.44524	0	0	0	6.303693	0
Coal and lignite	0	0.7779	0.06390	0.12920	0	0
Mining and quarrying	210.9791	448.72	0	0	44.18139	1.47519
Sugar	62.59239	249.26	0	0	21.75878	0
Oil and vanaspati	55.18701	0	0	0	56.81361	0
Tea, coffee, and beverages	316.7578	7,673.6	0	0	0	0
Food products	112.1726	0	0	0	149.8917	0
Cotton textile	6,752.696	95,050.5	0	0	0	0

(continued)

Sectors/thousand tons	SS	DS	Chloride	Sulfide	Oil/ grease	Phenol
Woolen and silk textile	301.9862	740.88	714.354	328.603	21.84496	2.857418
Jute hemp mesta textile	474.5933	0.2122	1,109.68	648.898	8.636562	2.41611
Miscellaneous textile products	628.2541	135.17	1,570.89	855.123	12.04153	0.872575
Wood and wood products	0	0	0	0	0	0
Paper and paper products	1,151.709	0	0	0	0	0
Leather and leather products	589.4403	851.033	856.744	6.77780	0	0
Rubber products	139.1766	1,105.51	0	17.3170	21.96988	0
Plastic products	0	140.11	0	0	0	0
Petroleum and coal tar products	529.3798	1,512.0	0	193.906	1,541.137	18.08304
Inorganic heavy chemicals	36.75452	1,342.4	0	0	0	0
Organic heavy chemicals	202.9253	0	0	0	215.6105	63.9435
Fertilizers	502.8546	0	0	0	0	0
Pesticides	148.1316	0	150.106	0	0	0
Paints, varnishes, and lacquers	36.91135	0	0	0	41.72588	19.2581
Other chemicals	0.002487	906.28	0.00710	0.00888	0	0
Synthetic fibers, resin	0	0	0	0	0	0
Other nonmetallic mineral products	90.54471	0	0	0	0	0
Iron and steel	1,628.061	0	284.344	10.0963	0	53.6993
Machinery and metal products	0	0	0	0	0	182.9052
Electrical machinery	0	0	0	0	0	0
Transport equipment	0	0	0	0	0	0
Other machineries	0	0	0	0	0	355.0163
Construction	0	0	0	0	0	0
Electricity gas and water supply	300,018.9	0	0	0	0	0
Transport services and communication	0	0	0	0	0	0
Other services	0	0	0	0	0	0
Total	348,515.2	115,285	5,080.03	2,060.86	5,539.725	700.526

	Zinc	Others	BOD	COD
Agriculture	0	9,493.5837	77,646.683	121,611.03
Other agriculture	0	0.0110346	9.8681205	23.803294
Milk and milk products	0	2,609.6967	16,021.268	35,267.898
Livestock	0	3,998.7663	7,881.2399	43,410.329
Fishing	0	3.9848962	27.997331	59.842148
Coal and lignite	0	0.1444844	0	0
Mining and quarrying	0	0	11.678639	0
Sugar	0	25.379379	147.3414	294.68279
Oil and vanaspati	0	0	320.22218	474.60834
Tea, coffee, and beverages	0	3.3291249	4,326.7744	9,413.0893
Food products	0	0	94.618876	162.05088
Cotton textile	0	311.99473	525.24285	30,044.469
Woolen and silk textile	0	16.50445	258.02491	951.80616

(continued)

	Zinc	Others	BOD	COD
Jute hemp mesta textile	0	8.6400142	604.02784	1,190.7977
Miscellaneous textile products	2.9668	1,307.9378	1,012.1872	2,230.3021
Wood and wood products	0	0	0	0
Paper and paper products	0	1,705.8308	878.32388	1,202.3149
Leather and leather products	0	381.87965	177.33063	708.24224
Rubber products	0	42.900875	873.26017	1,673.3385
Plastic products	0	0	46.703686	116.75921
Petroleum and coal tar products	0	0	175.9989	440.4875
Inorganic heavy chemicals	0	215.7074	208.0444	617.1985
Organic heavy chemicals	0	25.8248	927.7237	273.7731
Fertilizers	0	348.5870	0	0
Pesticides	0	50.66103	143.1939	651.7794
Paints, varnishes, and lacquers	0	0	125.7126	15.727448
Other chemicals	0	0	309.2032	1,764.591
Synthetic fibers, resin	0	0	0	0
Other nonmetallic mineral products	67.501	36.12793	0	54.26542
Iron and steel	0	204.7561	544.3516	1,358.382
Machinery and metal products	0	0	620.0177	192.9288
Electrical machinery	0	0	0	0
Transport equipment	0	0	0	0
Other machineries	0	0	1,205.829	375.1637
Construction	0	0	0	0
Electricity gas and water supply	0	0	0	88.53110
Transport services and communication	0	0	0	0
Other services	0	0	0	0
Total	70.468	20,792.24	115,122.8	254,668.2

Source: Results from the study

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Chapter 8
Estimates of Green GDP

8.1 Introduction

So far we have studied different aspects of water resources, direct and indirect water pollution generation, abatement cost, and its effect on output, prices as well as on consumers in India.

Environmental deterioration due to water pollution generation has adverse effect on human welfare of a country. The need to account for the environment and the economy in an integrated way arises because of the crucial functions of the environment in economic performance and in the generation of human welfare.

Conventional national accounts focus on the measurement of economic performance and growth as reflected in market activity. GDP is usually defined as the total market value of all final goods and services produced within a territory in a given period of time (usually a year), including net exports. It has been used as a standard measure of the size of an economy in national accounting and is often regarded as an indicator of economic performance. GDP omits many of the important goods and services that we derive from nature because its scope is delimited completely by the market. Conventional national accounts have only partly accounted for these functions, focusing on market transactions and indicators that reflect important factors in welfare generation, but they do not measure welfare itself. These accounts as indicators of economic performance have failed to consider the actual scarcity of natural resources and corresponding welfare losses.

However, new scarcities of natural resources now threaten the sustained productivity of the economy while economic production and consumption activities may impair environmental quality by overloading natural sinks with wastes and pollutants. By not accounting for the private and social costs of the use of natural resources and the degradation of the environment, conventional accounts may send wrong signals of progress to decision makers who may then set society on a non-sustainable development path (UN 2000). Growing pressures on the environment and an increasing environmental awareness have generated the need to

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account for the manifold interactions between all sectors of the economy and the environment.

For a more comprehensive assessment of the sustainability of growth and development, the scope and coverage of economic accounting needs to include the use of nonmarketed natural assets and losses in income generation resulting from the depletion and degradation of natural capital (Bartelmus 1999).

Green GDP is simply a conventional gross domestic product figure adjusted for the environmental costs of economic activities. It is a measure of how a country is prepared for sustainable economic development. The concept of "green GDP" arose in the early 1990s in response to the deficiencies of the traditional gross domestic product (GDP) to account for the economic costs of depleted natural resources and incurred pollution, which in turn affect human welfare. Green GDP is an index of economic growth with the environmental consequences of that growth factored in. Some environmental experts prefer physical indicators (such as "waste per capita" or "carbon dioxide emissions per year"), which may be aggregated to indices such as the "sustainable development index" (World Bank 2012).

Natural resource accounting (NRA) is a necessary step to measure sustainability of development. It provides indicators of loss of natural resources, changes in environmental quality, and their consequence for long-term economic development. There is considerable debate and controversy going on environmental accounting (Perman et al. 1996). The debate on environmental accounting is largely centered on the incorporation of environmental costs and benefits in national accounts.

In order to cope with these shortcomings, the United Nations and the World Bank have developed alternative macro-indicators for environmentally adjusted and sustainable national income and products. The UN Statistical Division published a System of National Accounts Handbook in 1993 to provide a conceptual basis for the implementation of a System for Integrated Environmental and Economic Accounting (SEEA) and environmentally adjusted domestic product (Green GDP) that illustrate the interrelationships between the natural environment and the economy.

Based on this, the United Nations has published a set of accounting guidelines in the *Handbook of National Accounting: Integrated Environmental and Economic Accounting* known as SEEA (UN 1993, 2003), which provide a common framework for valuating environmental contributions to economies and economic impacts on the environment (Wu and Wu 2010).

8.2 A Brief Review on Resource Accounting

Some attempts have already made towards green GDP in developed countries. The treatment of environmental issues in the accounting framework was initiated by Nordhares and Tobin (IGIDR 1992) in the United states and the work on developing a natural resource accounting framework began in Norway in 1974 (Alfsen 1994).

Physical accounting of resources was later followed by French (beginning 1978) and Canadian government also. "World Resource Institute" (WRI) developed a methodology for natural resource accounting (Repetto et al. 1989) and initiated a few country studies using their methodology. The SEEA was tested in Canada, Colombia, Ghana, Indonesia, Japan, Mexico, Papua, New Guinea, the Philippines, the Republic of Korea, Thailand, and the United States. Costanza et al. (1997) have estimated the economic value of the world's ecosystem services to be US$33 trillion per year on average, mostly outside the market and almost twice as much as the global GDP total.

In the case of developing countries, we find very few attempts to measure green GDP. China has included the costs of environmental degradation into economic growth and published its green GDP data for the years 2004 and 2006 (Wu and Wu 2010). In India, efforts have also been made since the 1990s.

A framework for NRA of India has been prepared by IGIDR in 1992(IGIDR 1992). This framework considers the guidelines given by the United Nations through their documents for "Integrated Economic and Environmental Accounting" (UN 1993).

Another major attempt in that direction was constituted by GAISP (the "Green Accounting for Indian States and Union Territories Project") in 2004. GAISP proposes to build a framework of adjusted national accounts that represents genuine net additions to national wealth. These are referred to as "green accounts." Green accounts for India and its states will provide a much better measure of development than GDP (national income) growth percentages and GSDP (gross state domestic product) growth measures and will encourage the emergence of sustainable development as a focus of economic policy at the operative state level. GAISP evaluates a series of related set of areas of adjustments to GSDP accounts. These are as follows.

(1) The value of timber, carbon, fuelwood, and non-timber forest produce in India's forests; (2) estimating the value of agricultural cropland and pasture land in India; (3) the value of India's subsoil assets; (4) eco-tourism and biodiversity values in India; (5) estimating the value of educational capital formation in India; (6) investments in health and pollution control and their value to India; (7) accounting for the ecological services of Indian forests: soil conservation, water augmentation, and flood prevention; and (8) estimating the value of freshwater resources in India. Some of these are briefly reviewed. GAISP Monograph 4 (Gundimeda et al. 2006) attempts to value the biodiversity functions of India's natural ecosystems and suggest a method to adjust national (GDP) and state income (GSDP) accounts. The study indicates that the biodiversity benefits of forests are very material in the aggregate and significant with respect to national and state GDP. GAISP Monograph 7 attempts to account for three functions of forests – (1) soil conservation (prevention of soil erosion), (2) water augmentation, and (3) avoidance of flood damage – on broad ecological criteria and indicators. It is logical to assume that if the forest area is not disturbed, the national total value of ecological benefits – 103.76 billion rupees in 2001 – would recur every year to the society forever (Gundimeda et al. 2007). GAISP Monograph 8 attempts to estimate the economic

cost of deterioration in water quality, over the period of study (1993–2003). In states like Bihar, Orissa, Uttar Pradesh, and Sikkim, the incidence of pollution is quite high and, therefore, the stock of fresh water capital is depleted in these states. In industrialized states like Gujarat, Goa, and Tamil Nadu, the water availability may not be very high, but these states face pollution at a larger scale. Groundwater pollution contributes significantly to the overall pollution and hence to the total cost of pollution abatement. This monograph shows that the cost of treating only the water for drinking purposes is high. If the treatment of water for irrigation and industry was also required or if water quality continued to decline, the result would be unsustainable. The cost of treatment would far exceed the state net GDP (Kumar et al. 2007).

Gundimeda et al. (2007) applied an SEEA-based methodology to reflect the true value of forest resources in India's national and state accounts. They have addressed four components of value creation in forests: timber production, carbon storage, fuelwood usage, and the harvesting of non-timber forest products. The results of their analysis suggest that prevailing measures of national income in India underestimate the contribution of forests to income. They were also able to identify some states which performed poorly in the context of sustainability framework, reflecting natural capital losses due to degradation and deforestation. The integrated national and forest accounts for the year 2002–2003 show that the ratio of ESDP (environmentally adjusted state domestic product) to NSDP (net state domestic product) is less than 1, reflecting that the growth has come at the expense of environmental degradation for India. For an economy to be on a sustainable path, the ratio of ESDP to NSDP should be greater than one. In the states Arunachal Pradesh, Manipur, Meghalaya, Nagaland, Sikkim, Tripura, Kerala, and Tamil Nadu, the ratio of ESDP to adjusted NSDP (i.e., adjusted for unaccounted forest income) is greater than 1, whereas for other states it is at or below 1. They found that some of these states are experiencing great stress on their forests (especially states which are highly dependent on tourism) and others are experiencing stress due to very state-specific factors. For the state of Goa, well known for tourism, they found that there is significant depletion of 5 % of adjusted NSDP. In Himachal Pradesh, depletion as percent of adjusted NSDP works out to almost 26 %.

Very recently, a comprehensive work has been done by the World Bank (2012). It estimates the social and financial costs of environmental damage in India due to urban air pollution; inadequate water supply, poor sanitation, and hygiene; and indoor air pollution. It also estimates the monetary valuation of three natural resource damages: (1) agricultural damage from soil salinity, water logging, and soil erosion; (2) rangeland degradation; and (3) deforestation. The study estimates the total cost of environmental degradation in India at about 3.75 trillion rupees (US $80 billion) annually, equivalent to 5.7 % of gross domestic product in 2009. Of this total, outdoor air pollution accounts for 1.1 trillion rupees, followed by the cost of indoor air pollution at 0.9 trillion rupees, cropland degradation cost at 0.7 trillion rupees, inadequate water supply and sanitation cost at around at 0.5 trillion rupees, pasture degradation cost at 0.4 trillion rupees, and forest degradation cost at 0.1 trillion rupees.

Recently, the Government of India (MOEF chief) announced that India's GDP numbers would be adjusted with economic costs of environmental degradation by 2015 (Green GDP 2009). The green GDP estimate would be a huge step in environmental governance for India. The Ministry of Statistics and Programme Implementation is preparing a national database to calculate the cost of depletion of natural resources. India would be one of the few countries to release a green GDP estimate.

Towards that end, an attempt has been made in this chapter to measure the environmentally adjusted domestic product (EDP) as well as welfare loss for India due to water pollution. The current exercise compiled part of the SEEA framework. The reasons behind these are the lack of data and the controversies relating to certain valuations of nature services and their welfare effects.

8.3 Different Categories of Adjustments to the National Accounts

There is now a wide measure of agreement that the conventional system of National Accounts, in most countries that are based upon the System of National Account (SNA), designed by the United Nations Statistical Office, is not adequate as a means of measuring the impact of environmental changes on income and welfare (Perman et al. 1996). The conceptual basis of the National Account is governed by definition of income and wealth which did not make any allowance for depletion of natural capital or the cost of environmental damage such as pollution. However, the production and consumption activities have environmental side effects which imposed considerable cost.

So there are three categories of adjustments to the national accounts, which have been proposed to reflect the cost and benefits of human activity on the environment. These are the (a) depletion of natural capital, (b) environmental degradation, and (c) defensive expenditure.

8.4 Environmental Degradation

Environmental degradation describes the erosion of the natural environment through the depletion of resources, the destruction of ecosystems, and the extinction of plant and animal species. It is caused by direct or indirect human activity. The extraction of natural resources and the production of waste and other pollutants have severely degraded many of the planet's ecosystems. Mining, deforestation, fossil fuel burning, and pollution are just some of the human activities that have led to the environmental degradation.

A significant number of industries (livestock, oil refineries, coal, chemical industries, distilleries, man-made fiber, dye, leather, textiles, etc.) in India are producing pollution above the environmental standard by several times. These industries are discharging wastewater onto land and water in an alarming proportion, thus degrading land and water resources. This degradation of resources is hazardous to health, fertility of land, aquatic life, etc.

The cost of environmental degradation in India is roughly comparable with other countries with similar income level. Studies of the cost of environmental degradation were conducted using a similar methodology in Pakistan, a low-income country, and several low- and lower-middle-income countries in Asia, Africa, and Latin America. They show that monetary value of increased morbidity, mortality, and natural resources degradation typically amounts to 4–10 % of GDP, compared to 5.7 % of GDP in India[1] (World Bank 2012).

In the following subsection, we elaborate how we have estimated the different components of green GDP for India. We have considered health hazards, damages to crops, and defensive expenditure to arrive at green GDP estimate in India for the year 2006–2007.

8.4.1 Health Hazards

The main health impacts of unclean water and poor hygiene are diarrheal diseases, typhoid, and paratyphoid. In addition, there are costs in the form of averting expenditures to reduce health risk. Diarrheal and related illness contributes to the major share of the health cost. In India, about 67 % of all diseases are waterborne which includes typhoid, jaundice, cholera, and dysentery. Research by Jodhpur University Chemistry Department (CSE 1985) has identified several carcinogenic compounds in the effluents. The Gandhi Peace Foundations (GPF) identified various forms of cancer, among other diseases in the area. In India, one study (IGIDR 1992) has estimated that in terms of health hazards, waterborne communicable diseases affect a large number of people and about 73 million workdays are loss annually due to water-related diseases. Waterborne infections, which account for about 80 % of sickness in India, make every fourth person dying of such diseases in the world an Indian. Annually, 1.5 million deaths are attributed to waterborne diseases.

Parikh (2004) provided an estimate of damage costs due ill effects of water pollution and poor sanitation facilities in 1995 which amounts to Rs. 366 billion (3.95 % of the GDP). It may, however, be emphasized that these damage costs do

[1] The environmental media included in the analysis include indoor–outdoor air pollution, inadequate water supply, sanitation and hygiene, and natural resource degradation (soils salinity/ erosion, pastures degradation, deforestation and forest degradation, fishery loss). Losses from natural disasters were included in CED study in Peru and in Iran.

not fully reflect the loss in social welfare. These estimates only suggest that the abatement of pollution is socially desirable and economically justified. This estimate has been used in this study making necessary adjustment in prices[2] which becomes 622 billion rupees.

The World Bank (2012) noted that a significant part of the health burden, especially from water supply, sanitation, and hygiene, is borne by children under 5. It suggests that about 23 % of all under-5 mortality can be associated with indoor air pollution and inadequate water supply, sanitation, and hygiene. The Office of the Registrar General indicates that 14 % of child mortality was due to intestinal diseases. Based on this, a baseline diarrheal mortality rate of 14 % of under-5 child mortality is used for diarrheal mortality estimation. Moreover, the study shows that 88 % of diarrheal illness is attributable to water, sanitation, and hygiene. It also provides estimates of DALYs lost to waterborne diseases. About 60 % of the DALYs are from diarrheal child mortality. Typhoid/paratyphoid deaths add another 20 % of DALY (World Bank 2012). The total cost including cost of mortality and morbidity due to waterborne diseases is estimated at 489 billion rupees. This estimate is also used as health cost in the current exercise.

8.4.2 Damages to Crops

We have considered the estimates of damages to crop for arriving at green GDP for India using two different sources: (1) World Bank study in 2012 and (2) GAISP Monograph 2 (Gundimeda et al. 2005).

Major categories of land degradation in India are similar to those in other Asian countries. They include (1) water and wind soil erosion and, in particular, irrigation-related land degradation, including secondary salinity, water logging, and irrigation-related soil erosion; (2) pasture and range land degradation; and (3) degradation of forests and bushes and related loss of biodiversity. Land degradation not only affects agricultural productivity, biodiversity, and wildlife but also increases the likelihood for natural hazards (World Bank 2007). Crops irrigated with polluted waters of rivers, reservoirs, and lakes have high probability of damages of various forms. Moreover, excessive acidity or alkalinity (Ph below 4 and above 9) is not suitable for crop growth. Losses to croplands and rangelands include damages from soil salinity and water logging due to improper irrigation practices and human-induced soil erosion[3] (World Bank 2012). Soil salinity and water logging reduce the productivity of agricultural lands, and if a threshold

[2] Using GDP deflator.

[3] Due to the absence of data, the World Bank (2012) study considers the annual increase in salinity and eroded croplands and rangelands, the annual loss of agricultural production (crop and rangeland fodder) which is estimated based on accumulated degradation. This estimate may be more or less than the net present value (NPV) of annual production losses depending on the rate of annual increase in degradation.

salinity level is exceeded, the land becomes unfit for cultivation. According to the conventional welfare economics, if agricultural markets are competitive, the economic costs of salinity would be measured as the losses in consumer surplus and producer surplus associated with the loss in productivity[4] (World Bank 2012 The World Bank study estimated the land degradation in India as 187.8 ha in 2002. It covers water erosion (loss of topsoil and terrain deterioration), wind erosion, chemical deterioration (loss of nutrient and salinization), and physical deterioration. Apart from that, another category of agricultural land that cannot be cultivated at all due to high salinity (13 million hectares) has also been included in their estimation. In addition to soil salinity, land degradation caused by wind and water erosion is substantial in India. The major impacts of this erosion are sedimentation of dams and loss of nutrients in the soil. The soil erosion and the loss of soil nutrients are valued in terms of the costs to replace the losses.

The estimated cost of soil nutrients (in terms of nitrogen, phosphorus, and potassium) substitution is about 320–600 billion rupees. The middle range of this amount Rs. 460 billion has been considered for this study (0.7 % of GDP in 2010). The annual losses due to salinity amount to between Rs. 63 and 148 billion. The middle of the above range is Rs. 110 billion which is equivalent to 0.17 % of GDP has been considered (World Bank 2012). Adding up the two categories of losses arising from land degradation in India, we get a total of Rs. 570 billion which has been used for this study.

On the other hand, the cost of externalities considered by Gundimeda et al. (2007) included the replacement cost of soil nutrients and cost of treatment of sediments from the waterways.[5] They considered the state wise as well as national contribution. It is seen that in most of the states agriculture does impose significant external costs on the environment in the form of soil erosion and sedimentation of waterways. Their estimate shows that the costs range from 0.3 to 4.5 % of the NSDP (net state domestic product) (adjusted for subsidies) in different states.[6]

There are various ways to measure the "changes in the quality of soil and land" either through the tons of soil lost or through the lost output approach. The GAISP

[4] These losses include direct losses through reduced yields as the land becomes saline or degraded. In practice, the calculations can be more complex as account needs to be taken of crop substitution to more saline-tolerant but less profitable crops and other indirect losses (World Bank 2012).

[5] The total adjustments for depletion and degradation were computed by summing up the depletion and externality costs imposed by agriculture on the environment.

[6] To estimate the cost of the loss of nutrients through soil erosion, GAISP Monograph 2 used the replacement cost approach. As soil erosion represents a major cause of on-site nutrient loss, the volume of soil loss can be used to estimate the nutrient loss of the study area. This will help in estimating the value of loss in nonmarketed environmental attribute (soil) occurring as a result of farming activities (marketed good). In order to estimate the value of loss in environmental attribute, they used the data on macronutrient loss. This loss is specific to the site similar to the soil erosion data.

Monograph 2 (Gundimeda et al. 2007) attempted to value both to get an idea about how these estimates would differ.[7]

In the current exercise, we considered the loss of agricultural output due to soil erosion and land degradation as replacement of soil nutrient cost Rs. 240,854.7 million and sedimentation cost Rs. 90,489 million (total Rs. 331,343.7 million) for 2001–2002 as estimated in GAISP Monograph 2 (Gundimeda et al. 2007).

8.4.3 Defensive Expenditure

"Defensive expenditures" can be defined as expenditures incurred by households and governments to reduce the effects of pollution. More specifically, expenditures which are incurred to protect environment and to prevent degradation are called defensive expenditure. Some environmentalists argue that such defensive expenditure should be excluded from or at least deducted from GDP (Daly 2005). Examples of defensive expenditures for the household include buying water purification equipment to improve drinking water quality or buying a malaria prophylactic. For the government, this could include expenditures on litter removal or repairing degraded recreational sites. There is no agreement on to how to handle these expenditures.

Maler (1991) argues that such expenditures should not be deducted from the NDP if the changes in the values of "environmental services" (e.g., air and water quality) are included, since this would amount to double counting. Dasgupta (1995), on the other hand, states that defensive expenditures should be included in final demand. Bartelmus and van Tongeren (1994) argue that the cost of restoring polluted or damaged natural environments to their original state at the beginning of the accounting period should be deducted from NDP.

If defensive expenditure is not undertaken, there is degradation and hence depletion of natural capital. The defensive expenditure in this study is nothing but the cost of wastewater treatment.

The cost of wastewater treatment includes

(a) Capital cost: The capital cost of the treatment includes cost of the civil engineering required for construction of treatment units, installing charges for mechanical equipment, and electrical works including general lighting and supplying power to the various units (IGIDR 1992).
(b) Running cost: The running cost of the treatment plant includes cost of power, salaries of the staff, chemical cost, maintenance, repairs, and depreciation.

[7] For the loss in production method, GAISP Monograph 2 used the net present value of agricultural land. In the case of salinity, the NBSSLUP (1990) has estimated the loss of production at 25 % across soil qualities and crops. However, some individual estimates put the losses at about 50 % on an average for different crops and intensities of degradation (Reddy 2003). GAISP Monograph 2 has used the former value as it gives an aggregate estimate for the whole of India.

In this study, we have only considered the operation and maintenance cost of treatment because valuation of any product (clean water) depends upon the running expenditure including depreciation. In this study, the total cost involved for the treatment of wastewater has been calculated to be about Rs. 3,025,929.129 lakhs, based on water pollution abatement cost estimation in Chap. 4.

8.5 Environmentally Adjusted National Accounting

"[The] difference in the treatment of natural resources and other tangible assets [in the existing national accounts] reinforce the false dichotomy between the economy and 'the environment' that leads policy makers to ignore or destroy the latter in the name of economic development" (Repetto et al. 1989). Like other accounting systems, environmental account should link opening stocks, flows to and from that stocks, and closing stocks. Opening and closing stocks represent the state of the environment at the beginning and at the end of the accounting period and flows records the impact of the actions of the economic agents on environment.

However, as in our case we are dealing with water resource, that is, renewable which implies that its stock is infinite in the present period of time but its future holds a finite state being depleted gradually over time. So for this study, opening stock will be accounted only. Environmental accounting seeks to track environmental resource use, including both resource depletion and environmental degradation over a given period of time, the reporting period which is usually a year.

Gross income or products as conventionally measured do not indicate an economically sustainable level until they have been pruned for capital consumption. Considering the costs of depletion and pollution as consumption of natural capital suggests that they may be subtracted along with the consumption of produced capital from GDP and GNI (gross national income) to arrive at environmentally adjusted net domestic product (EDP) and national income.

Such adjustment will give a more realistic indication of wealth creation and consumption of goods and services and, of course, where environmental costs are growing faster than GDP, EDP growth rates will be below those of GDP.

Table 8.1 shows the framework of SEEA with flow and stock account and environmental assets.

The expansion of the asset boundary of conventional accounts for the inclusion and valuation of natural assets and asset changes permits the calculation of a range of aggregates. In this analysis the whole economy has been broken up into two sectors, one is water resource sector (natural resource) and other sectors are aggregated into one sector.

The aggregates can be presented as the sum total and elements of conventional accounting identities. These accounting identities are maintained in the SEEA in the following way:

Table 8.1 SEEA flow and stock accounts with environmental assets

	Domestic production	Final consumption (households, government)	Capital formation	Rest of the world
1 Supply of products	(i) Other sectors output (ii) Environmental sectors output			Imports (M)
2 Use of products (intermediate consumption [IC])	(i) Other sectors output (ii) Environmental sectors output	(i) Other sectors final consumption (ii) Environmental sectors final consumption	(i) Gross capital formation of other sectors (GCF1) (ii) Gross capital formation of environmental sectors (GCF2)	Exports (X)
3 Use of fixed capital	Fixed capital consumption of other sectors (CC)		Capital consumption (CC)	
4 Value added (VA/NDP)	NVA = O − IC − CC NDP = ΣNVA			
5 Use of natural assets (depletion and degradation and defensive expenditure)	Environmental cost of industries defensive expenditure (EC1) + loss of production (EC2)	Environmental cost of household (ECh)	Natural capital consumption EC = EC1 + EC2	
Environmental-adjusted indicators	EVA = NVA − EC EDP = ΣEVA − ECh		ECF = (CF − CC) − EC	

Source: UN (1993, 2000)

(a) Supply use identity:

$$O + M = IC + C + CF + X \tag{8.1}$$

where

O is the supply of goods and services produced by different sectors.
M is the supply of goods and services imported by sectors.
IC is the goods and services used in intermediate and C is the final consumption.
CF and X are the capital formation and export.

(b) Value added (environmentally adjusted) identity for different sectors:

$$EVA = O - IC - CC - EC = NVA - EC \tag{8.2}$$

where

EVA is the environmentally adjusted value added of industries.
CC is the fixed capital consumption.
EC is the environmental depletion and degradation costs.
NVA is the net value added of industries.

(c) Domestic-product identity (environmentally adjusted) for the whole economy:

$$EDP = \Sigma EVA - ECh = NDP - EC = C + CF - CC - EC + X - M \quad (8.3)$$

where

EDP is the environmentally adjusted net domestic product.
ECh is the environmental costs generated by household.

Using the estimates of health hazards, damages to crops, and defensive expenditure as provided in Sect. 8.4.1, 8.4.2 and 8.4.3, we have attempted to estimate environmentally adjusted national income accounting for the year 2006–2007 based on the framework of SEEA (Table 8.1). Estimates are shown in Tables 8.2 and 8.3.

Tables 8.2 and Table 8.3 show the environmentally adjusted national income accounting for the year 2006–2007 which has been constructed based on the framework presented in Table 8.1. We have applied two different estimates of environmentally adjusted national income accounting. These two estimates differ in terms of (1) loss due to soil erosion, (2) sedimentation as well as soil salinity, and (3) health cost. Case 1 is based on the estimates accounted in GAISP Monograph 2 and Parikh (2004) and Case 2 by World Bank study (2012). EDP calculation in detail has been presented in Tables 8.2 and 8.3.

Accounting for the costs of consumption of natural capital obtains not only an EDP but also an aggregate of environmentally adjusted (net) capital formation (ECF), Table 8.2.

Here, as evident from Table 8.2 (Case 1), the total domestic production of goods and services (O), given by the sum of intermediate consumption's (IC), final consumption (C), capital formation (CF), and net export (export–import) of all the sectors (Rs. 790,775,859.3 lakhs) including water resource (Rs. 3,701,692 lakhs), is Rs. 794,477,551.3 (lakhs). EVA derived from NVA by subtracting EC (Environmental Depletion and Degradation Cost, i.e., Rs. 6,339,366.12 lakhs) account to Rs. 346,000,481.3 lakhs while EDP which is environmentally adjusted value added (EVA) – household environmental cost (ECh) as depicted in Equation 3 – is calculated to be Rs. 339,780,481.3 lakhs. Consequently percentage of loss in terms of NDP is 3.56 %. Furthermore, ECF (environmentally adjusted capital formation) is estimated at Rs. 91,936,357.51 lakhs.

Another estimate from World Bank is presented in Table 8.3 (Case 2). The total domestic production of goods and services remains the same as it is quoted in case 1 at Rs. 794,477,551.3 lakhs. However, EVA differs from case 1 due to the natural capital consumption (EC) which is estimated to be Rs. 8,725,929.12 lakhs (including soil erosion, soil salinity, and defensive expenditure). In this case, EVA is

Table 8.2 Case 1: Environmentally adjusted national accounting of India for the year 2006–2007 (in lakh Rs.)

	Domestic production	Final consumption (households, government)	Capital formation	Rest of the world
1 Supply of products				
897,345,362.3	(i) 790,775,859.27			106,569,503
	(ii) 3,701,692			
2 Use of products				
897,345,362.3	(i) 396,696,119.27	(i) 269,127,205	(i) 140,015,616	(i) 91,506,422
	(ii) 3,131,529	(ii) 570,163	(ii)	(ii)
3 Use of fixed capital	(i) 41,739,892.36		(i) 41,739,892.36	
4 Value added (VA/NDP)	NVA or NDP			
GDP at factor cost 394,079,740.79	352,339,847.4			
5 Defensive expenditure	3,025,929.129	Health cost 6,220,000		
Loss due to soil erosion	2,408,547		Natural capital consumption EC = 6,339,366.12	
Sedimentation	904,890			
Total EC = 6,339,366.12	EVA = NVA − EC = 346,000,481		ECF = 91,936,357.51	
Total EVA = 346,000,481.3	EDP = ΣEVA − ECh = 339,780,481.3			
Total EDP = 339,780,481.3				
% loss in terms of NDP	*3.56*			

Source: Results from the study
(i) Stands for "other sectors"
(ii) Stands for "water resource"

Table 8.3 Case 2: Environmentally adjusted national accounting of India for the year 2006–2007 (in lakh Rs.)

		Domestic production	Final consumption (households, government)	Capital formation	Rest of the world
1	Supply of products				
	897,345,362.3	(i) 790,775,859.27			106,569,503
		(ii) 3,701,692			
2	Use of products				
	897,345,362.3	(i) 396,696,119.27	(i) 269,127,205	(i) 140,015,616	(i) 91,506,422
		(ii) 3,131,529	(ii) 570,163	(ii)	(ii)
3	Use of fixed capital	(i) 41,739,892.36		(i) 41,739,892.36	
4	Value added (VA/NDP)	NVA or NDP			
	GDP at factor cost 394,079,740.79	352,339,847.4			
5	Defensive expenditure	3,025,929.129	Health cost 4,890,000		
	Loss due to soil erosion	4,600,000		Natural capital consumption EC = 8,725,929.12	
	Loss due to soil salinity	1,100,000			
	Total EC = 8,725,929.129	EVA = NVA – EC = 343,613,918.3		ECF = 89,549,794.5	
	Total EVA = 343,613,918.3	EDP = ΣEVA – ECh = 338,723,918.3			
	Total EDP = 338,723,918.3				
	% loss in terms of NDP	*3.91*			

Source: Results from the study
(i) Stands for "other sectors"
(ii) Stands for "water resource"

estimated at Rs. 343,613,918.3 lakhs and finally EDP is calculated at Rs. 338,723,918.3 lakhs resulting in a 3.91 % corresponding percentage loss in terms of NDP. The environmentally adjusted capital formation (Rs. 89,549,794.5 lakhs) is reduced compared to case 1 due to natural capital consumption.

8.6 The Contribution of the Environment to Economic Performance and Welfare Generation

The quality of life and welfare of an individual or of a society cannot be precisely defined, but it is common (at least among social scientists) to associate welfare with levels of income. Higher-income levels permit higher levels of consumption, and consumption is a measure – though by no means the only determinant – of welfare. It follows that when we assert that a particular environmental change has reduced welfare it is similar to saying that the income of those affected by the change has fallen and there has been a reduction in the aggregate income of the society. Therefore, the need to account for the environment and the economy in an integrated way arises because of the crucial functions of the environment in economic performance and in the generation of human welfare. The purpose of production is to meet human wants and to ultimately increase human welfare. While GDP is a measure of production and a significant contributor to welfare, it is not a welfare measure itself. One reason is that the goods and services produced may affect human well-being in many ways that are not reflected in their market value.

The environment is an important contribution to both production and human welfare, through three broad sets of environmental function such as

1. Resource functions: the provision of resource, including space for human activity
2. Waste absorption functions: the neutralization, dispersion, or recycling of wastes from human activity
3. Environmental service functions: the protection of environment from different deteriorations

These above three sets of functions can each contribute to human well-being in a variety of ways, including:

(a) Indirectly, via the economic production system
(b) Directly, through the maintenance of human health

Environmental deterioration clearly has an adverse impact on human welfare. In the context of GDP measurement, national accounts are not meant to measure welfare. However, they can give insights into welfare generation. For instance, accounting indicators of the depletion or deterioration of stocks of environmental assets, in physical or money terms, provide signals about possible losses of our long-term capability to maintain environmental functions and hence their welfare contributions. Defensive expenditures that increase GDP in terms of additional investment can be deducted away from GDP to arrive at EDP as this kind of investment is made to compensate for the welfare loss resulting from environmental degradation and depletion. As a result, the very same indicators may drive policy action, resulting in both the betterment of the environment and an increase in welfare.

Another way of estimating loss in GDP is by calculating the ratio of the sum of all types of environmental expenditure (Rs. 12,559,366.12 lakhs for Case 1 and Rs. 13,615,929.13 lakhs for Case 2) to NVA or NDP (Rs. 352,339,847.4 lakhs). Using this method, the corresponding loss in terms of NDP are around 3.56 % in Case 1 and 3.91 % in Case 2, respectively, given the EDP estimates of Rs. 339,780,481.3 lakhs (Case 1) and Rs. 338,723,918.3 lakhs (Case 2). Apart from welfare loss aspect, one must also consider the positive impact (Schäfer and Stahmer 1989) of incurring defensive expenditure. That is, this kind of investment made for pollution abatement provides an upsurge in employment generation through the acceleration principle, thereby raising income and output level.

8.7 Environmentally Adjusted Domestic Product with Respect to Pollution Control Policies

We have already discussed that gross income or products as conventionally measured do not indicate an economically sustainable level of growth until they have been pruned for capital consumption. Therefore, considering the costs of depletion and pollution as consumption of natural capital suggests that they may be subtracted, along with the consumption of produced capital from NDP and NNI to arrive at environmentally adjusted NET domestic product (EDP) and national income. Based on the simulation experiment carried out in the Chap. 7 with different pollution control policies (in terms of tax), a new set of EDP would arise as EDP is derived from GDP or NDP. Calculation of these new set of EDP is illustrated herein.

8.7.1 Simulated EDP

In Chap. 4, we have estimated the water pollution abatement cost including energy, chemical, labor, and other operation and maintenance costs for the year 2006–2007. More specifically, only the industries having a functioning CETP or ETP in 2006–2007 are considered for the estimation. From this estimation process, we observed even if the plants have installed CETP/ETP, most are not sufficient to achieve and are quite far from the required effluent standards of different water pollution parameters; towards that end, a revised estimate has been conducted. The plants are considered to have spent on abatement cost but are not up to the required level, and thus they have to incur extra cost compared to the current expenditure (as discussed in scenario 1 in Chap. 7). We have included this cost as pollution tax in our estimate for the year 2006–2007.

As a result of the targeted abatement cost, the revised GDP at factor cost will be Rs. 397,141,628.7 lakhs, an increased from actual GDP at factor cost Rs. 394,079,740.79 lakhs. Similarly, the revised NDP/NVA will increase from Rs. 352,339,847.4 lakhs to Rs. 355,401,735.3 lakhs (a hike of 0.87 %). Hence, the new EDP according to Case 1 will increase marginally to Rs. 342,842,369.2 lakhs (Table 8.4) from the original EDP of Rs. 339,780,489.3 lakhs while for Case 2 the new EDP will be Rs. 341,785,806.2 lakhs (Table 8.5) from the original EDP of Rs. 338,723,918.3 lakhs. Therefore, for Case 1 the loss in terms of the new NDP is 3.53 % (Table 8.4) and is only marginally less (0.03 %) than that of original NDP loss of 3.56 % (Table 8.2). Similarly for Case 2, the loss in terms of the new NDP is 3.83 % (Table 8.5) which is 0.079 % less compared to the original NDP loss of 3.91 %. It is observed from this simulation (simulation exercise 1) that NDP loss is only marginally reduced, that is, 0.02 %, because additional cost (equivalent to tax) has been imposed on the required plants, and that leads to the increase GDP at factor cost.

In addition to the above, we have also estimated Green GDP according to a different pollution control measure (simulation exercise 2). As described in Chap. 7, due to unavailability of the data on abatement cost, we could not include all industries under the pollution control policy measure. An attempt to overcome this problem is by imposing a uniform 0.76 % tax (as a percentage of GDP) for all industries (detail in Chap. 7). In this section, we have calculated a revised GDP loss due to the imposition of a uniform pollution tax as presented in Case 1 (Table 8.6) and Case 2 (Table 8.7). Again, Case 1 is based on the estimates accounted in GAISP Monograph 2 and Parikh (2004) and Case 2 by World Bank study (2012). The loss in terms of NDP will be 3.50 % according to Case 1, while it is 3.79 % for Case 2 which is marginally low compared to actual GDP loss as quoted in Table 8.2 (3.56 %) and Table 8.3 (3.91 %), respectively.

The current exercise only covers the water-resource-related expenditure which should be included under the national income accounting framework. There are several other environmental expenditures such as biodiversity, flood damage, forest, etc., that are not accounted in this study. From this analysis, it can be concluded that along with the defensive expenditure, pollution control policies also affect the whole process of EDP calculation as percentage loss in terms of NDP declines with the adoption of pollution abatement measures.

Table 8.4 Simulation exercise 1 (Case 1): Environmentally adjusted national accounting of India for the year 2006–2007 (in lakh Rs.)

		Domestic production	Final consumption (households, government)	Capital formation	Rest of the world
1	Supply of products				
	897,345,362.3	(i) 790,775,859.27			106,569,503
		(ii) 3,701,692			
2	Use of products				
	897,345,362.3	(i) 396,696,119.27	(i) 269,127,205	(i) 140,015,616	(i) 91,506,422
		(ii) 3,131,529	(ii) 570,163	(ii)	(ii)
3	Use of fixed capital	(i) 41,739,892.36		(i) 41,739,892.36	
4	Value added (VA/NDP)	NVA or NDP			
	GDP at factor cost 397,141,628.7	355,401,735.3			
5	Defensive expenditure	3,025,929.129	Health cost 6,220,000		
	Loss due to soil erosion	2,408,547		Natural capital consumption	
	Sedimentation	90,489		EC = 6,339,366.12	
	Total EC = 6,339,366.12	EVA = NVA – EC = 349,062,369.2		ECF = 91,936,357.5	
	Total EVA = 349,062,369.2	EDP = ΣEVA – ECh = 342,842,369.2			
	Total EDP = 342,842,369.2				
	% loss in terms of NDP	3.53			
	Changes from actual green GDP loss estimate	0.03			

Source: Results from the study
(i) Stands for "other sectors"
(ii) Stands for "water resource"

Table 8.5 Simulation exercise 1 (Case 2): Environmentally adjusted national accounting of India for the year 2006–2007 (in lakh Rs.)

		Domestic production	Final consumption (households, government)	Capital formation	Rest of the world
1	Supply of products				
	897,345,362.3	(i) 790,775,859.27			106,569,503
		(ii) 3,701,692			
2	Use of products				
	897,345,362.3	(i) 396,696,119.27	(i) 269,127,205	(i) 140,015,616	(i) 91,506,422
		(ii)3,131,529	(ii) 570,163	(ii)	(ii)
3	Use of fixed capital	(i) 41,739,892.36		(i) 41,739,892.36	
4	Value added (VA/NDP)	NVA or NDP			
	GDP at factor cost 397,141,628.7	355,401,735.3			
5	Defensive Expenditure	3,025,929.129	Health cost 4,890,000		
	Loss due to soil Erosion	4,600,000		Natural capital consumption EC = 8,725,929.12	
	Loss due to soil salinity	1,100,000			
	Total EC = 8,725,929.129	EVA = NVA − EC =346,675,806.2		ECF = 89,549,794.5	
	Total EVA = 346,675,806.2	EDP = ΣEVA − ECh = 341,785,806.2			
	Total EDP = 341,785,806.2				
	% loss in terms of NDP	3.831			
	Changes from actual green GDP loss estimate	0.079			

Source: Results from the study
(i) Stands for "other sectors"
(ii) Stands for "water resource"

Table 8.6 Simulation exercise 2 (Case 1): Environmentally adjusted national accounting of India for the year 2006–2007 (in lakh Rs.)

		Domestic production	Final consumption (households, government)	Capital formation	Rest of the world
1	Supply of products				
	897,345,362.3	(i) 790,775,859.27 (ii) 3,701,692			106,569,503
2	Use of products				
	897,345,362.3	(i) 396,696,119.27 (ii) 3,131,529	(i) 269,127,205 (ii) 570,163	(i) 140,015,616 (ii)	(i) 91,506,422 (ii)
3	Use of fixed capital	(i) 41,739,892.36		(i) 41,739,892.36	
4	Value added (VA/NDP)	NVA or NDP			
	GDP at factor cost 400,108,738.4	358,368,845.1			
5	Defensive expenditure	3,025,929.129	Health cost 6,220,000		
	Loss due to soil erosion Sedimentation	2,408,547 90,489		Natural capital consumption EC = 6,339,366.12	
	Total EC = 6,339,366.12	EVA = NVA − EC = 352,029,478.9		ECF = 91,936,357.5	
	Revised total EVA = 352,029,478.9	EDP = ΣEVA − ECh = 345,809,478.9			
	Total EDP = 345,809,478.9				
	% loss in terms of NDP	3.505			
	Changes from actual green GDP loss estimate	0.059			

Source: Results from the study
(i) Stands for "other sectors"
(ii) Stands for "water resource"

Table 8.7 Simulation exercise 2 (Case 2): Simulated environmentally adjusted national accounting of India for the year 2006–2007 (in lakh Rs.)

	Domestic production	Final consumption (households, government)	Capital formation	Rest of the world
1 Supply of products				
897,345,362.3	(i) 790,775,859.27			106,569,503
	(ii) 3,701,692			
2 Use of products				
897,345,362.3	(i) 396,696,119.27	(i) 269,127,205	(i) 140,015,616	(i) 91,506,422
	(ii) 3,131,529	(ii) 570,163	(ii)	(ii)
3 Use of fixed capital	(i) 41,739,892.36		(i) 41,739,892.36	
4 Value added (VA/NDP)	NVA or NDP			
GDP at factor cost 400,108,738.4	358,368,845.1			
5 Defensive expenditure	3,025,929.129	Health cost 4,890,000		
Loss due to soil erosion	4,600,000		Natural capital consumption	
Loss due to soil salinity	1,100,000		EC = 8,725,929.12	
Total EC = 8,725,929.129	EVA = 349,642,915.9		ECF = 89,549,794.5	
Total EVA = 349,642,915.9	EDP = 344,752,915.9			
Total EDP = 344,752,915.9				
% loss in terms of NDP	3.791			
Changes from actual green GDP loss estimate	0.119			

Source: Results from the study
(i) Stands for "other sectors"
(ii) Stands for "water resource"

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Chapter 9
Review of the Case Studies

9.1 Introduction

Industrialization contributes to national economic growth; however, often it exerts considerable pressure upon natural resources of an economy. In addition, the waste generated by the industries is a major environmental concern and the disposal of effluents without appropriate treatment could affect adversely in the long run, especially health, local vegetation, and aquatic life. Thus, it is necessary for highly polluting industries to adopt a suitable waste treatment process for the clean disposal of wastewater (Biogas Forum 1999).

As discussed in Chap. 4, water quality and pollution levels are generally measured in terms of concentration or load – the rate of occurrence of a substance in water. BOD (biochemical oxygen demand) measures the strength of organic waste in terms of the amount of oxygen consumed (by the microorganism in water) in breaking it down. This is a standard water quality parameter for the presence of biodegradable organic pollutants. Moreover, a number of physical and chemical parameters (which define the water quality) such as pH, total suspended solids (TSS), total dissolved solids (TDS), and inorganic trace elements, also need to be monitored for proper assessment of water quality. Hence, it will be more convenient to integrate the data pool in some way to produce a single number to reflect the water quality status. Water quality index (WQI) measures this.

Though pollution is unavoidable as a result of industrialization, efforts should be made to minimize it. Otherwise, it may jeopardize the development that we are hoping to achieve. The Government of India is much concerned with the present state of water pollution and has taken several pollution control measures to check the increasing environmental degradation due to water pollution. However, in spite of these measures, the problem still remains. Whether it is at all useful for the industry to adopt the preventive measure by setting up effluent treatment plant or common effluent treatment plant is a matter of policy decision. To address these issues, an attempt should be taken to make a detailed study of pollution generation abatement costs and other related aspects of different industrial units of India. From

D. Chakraborty and K. Mukhopadhyay, *Water Pollution and Abatement Policy in India*, Global Issues in Water Policy 10, DOI 10.1007/978-94-017-8929-5_9,

the previous chapters, we have knowledge on different types of water pollution generation across sectors in India. The overview of estimates identifies some key sectors generating huge amount of water pollution such as group of textiles, set of chemicals, livestock, milk and milk products, leather, rubber, etc. To get a complete picture of these industrial sectors, a thorough investigation is needed. Towards that direction, a review of different case studies is presented in this chapter. Here we cover in detail studies conducted by the authors for textile, pharmaceutical, and paint industry in West Bengal. In addition, other case studies of the different parts of India have also been discussed.

9.2 Case Studies of West Bengal[1]

Water pollution is mainly generated from the industries like textile, dye and dyestuff, drugs and pharmaceuticals, and more specifically paints. Thus, the study covers three different types of industries and tries to look at the variations of treated and untreated wastewater of each. It estimates the total amount of different types of water pollution generated in different industrial units of West Bengal, evaluates the water quality status of the wastewater generated by different industries of West Bengal using the water quality Index, calculates the abatement costs of selected industries of West Bengal, and evaluates the extent of success of investment for setting up effluent treatment plants of different industrial units of West Bengal with the help of benefit–cost analysis.

9.2.1 A Brief Discussion of the Industries Surveyed

In this section, an attempt has been undertaken to introduce the different industries considered for the study. For the work, a detailed survey has been made of the following five different industries in West Bengal, India. They are: (1) Eastern Spinning Mills & India Ltd., (2) Samson Processing Industries, (3) Jenson & Nicholson (I) Ltd., (4) Infar India Pharmaceuticals, and (5) East India Pharmaceuticals.

A brief description of these industries is presented in Table 9.1.

Let us now briefly discuss the detail of these five industries, wastewater generation, and waste management practices.

[1] These case studies draw heavily from Chakraborty et al. (2008).

Table 9.1 A brief description about five industries in West Bengal

Name of the industry	Location	Type	Date of establishment	Date of establishment of effluent treatment plant	Type of product
1. Eastern Spinning Mills	Barashat, 24 Parganas (N)	Medium size textile industry	1963	1993–1994	Synthetic blended yarn
2. Samson Processing Industries	Ganganagar, 24 Parganas (N)	Small-scale textile-dyeing industry	1976	1998–1999	Colored and processed hosiery cotton fabrics
3. Jenson and Nichol (I) Ltd.	Gorifa, Naihati, 24 Parganas (N)	Large size paints industry	1926	1995–1996	Varieties of paints – red oxides primer, cement primer, plastic emulsion paint
4. Infar India Ltd.	Ganganagar, 24 Parganas (N)	Large size pharmaceutical industry	1925	1988–1989	Diosynth
5. East India Pharmaceuticals	Paturia, Durgapur	Medium size pharmaceutical industry	1979	1991–1992	Quinodochly (IP)

Source: Chakraborty et al. (2008)

9.2.1.1 Textile Industry (Eastern Spinning Mills & India Ltd.)

The *Eastern Spinning Mills* operates 24 h a day and 355 days a year. It employed over 830 persons (including both workers and management persons). Average production was about 5,148 Mt/year (1994–1995) with 7,213.6 Mt/year (1999–2000) installed capacity. This industry used 5,049.52 Mt/year (1999–2000) raw materials and 2,306.79 Mt/year (1999–2000) process chemical for yearn production. Eastern Spinning Mills uses two types of fuel, coal and oil, and their consumption quantity were 5,049.7 Mt/year (1999–2000) and 2,130 kL/year (1999–2000), respectively. To produce yearn, this industry consumed 53,250 kL/annum (1999–2000) tube well water.

Wastewater Generation

This industry has two units – a spinning unit and a dye house unit. Only the dye house unit generates wastewater, and this quantity was 145 kL/day (2000). This wastewater contained high BOD and COD levels. Table 9.2 gives a detailed description about the characteristics of this wastewater along with permissible limit of discharge, prescribed by the West Bengal Pollution Control Board (WBPCB).

Waste Management Practices

To meet the permissible limit of the WBPCB, this industry installed an effluent treatment plant (ETP) in 1993–1994 to treat all wastewater before discharge to the main sewerage system. About 210 kL of wastewater was treated every day. Table 9.3 gives a detailed description about the characteristics of this wastewater along with permissible limit of discharge. Solid wastes generated include only sludge from the ETP, and this quantity was 15.8 Mt/annum (2000). Sludge from the ETP is dumped into a sludge disposal tank inside the plant.

9.2.1.2 Textile-Dyeing Industry (Samson Processing Industries)

This *textile-dyeing* industry operates 24 h a day and 280 days a year. It employed over 110 persons/day (including both workers and management persons). There are basically three shifts for the workers, and one general shift for management and other persons. Total production of all the products was approximately 841.5 Mt/annum with 935 Mt/annum installed capacity. This industry uses a number of raw materials and process chemicals for production, and their total consumption quantity was 1,138 Mt/annum and 540.4 Mt/year, respectively. This industry uses coal

Table 9.2 Characteristics of untreated water of *Eastern Spinning Mills & India Ltd* (2000)

Parameters	Concentration	Permissible limit
COD (mg/L)	1,350	250
pH	8.5	5.5–9.0
BOD (mg/L)	310	30
Temperature °C	50–55	Room temperature
TDS (mg/L)	1,380	2,100

Source: Chakraborty et al. (2008)

Table 9.3 Characteristics of treated water of *Eastern Spinning Mills & India Ltd* (2000)

Parameters	Concentration	Permissible limit
COD (mg/L)	209.4	250
pH	7.57	5.5–9.0
BOD (mg/L)	120	30
Temperature °C	33	Room temperature
TSS (mg/L)	42	100

Source: Chakraborty et al. (2008)

as fuel, and its consumption quantity was 1,960 kL/annum. To produce products, this industry consumed 14,000 kL/annum water from deep tube well.

Wastewater Generation

The plant generated 50 kL/day wastewater. This wastewater contains high BOD and COD levels. Table 9.4 presents a detailed description about the characteristics of this wastewater along with permissible limit of discharge prescribed by the WBPCB.

Waste Management Practices

This industry built an effluent treatment plant (ETP) in 1998–1999 to treat all wastewater before final discharge to the main sewerage system. Solid waste generated in the industry consists of coal brunt ash, and this quantity was 5 t/month (approx.) (1999). Table 9.5 describes the characteristics of the treated wastewater along with the permissible limit of discharge. Solid waste is collected manually and use for low land filling.

9.2.1.3 Paints Industry (Jenson & Nicholson (I) Ltd.)

The paints industry operates 24 h a day and 300 days a year. It employed over 383 persons/day (including both workers and management persons). There are basically three shifts for the workers and one general shift for management and other persons. Total production of all the products was approximately 841.5 Mt/annum

Table 9.4 Characteristics of untreated wastewater *of Samson Processing Industries* (1999–2000)

Parameters	Concentration	Permissible limit
COD (mg/L)	–	250
Oil and grease (mg/L)	–	10
Cr^6 (mg/L)	–	0.1
pH	–	6.0–8.5
BOD (mg/L)	–	150
TDS (mg/L)	–	100

Source: Chakraborty et al. (2008)

Table 9.5 Characteristics of treated wastewater *of Samson Processing Industries* (1999–2000)

Parameters	Concentration	Permissible limit
COD (mg/L)	276.6	250
Oil and grease (mg/L)	3.8	10
Cr^6 (mg/L)	BDL	0.1
pH	8.13	6.0–8.5
BOD (mg/L)	82.5	150
TDS (mg/L)	78.0	100

Source: Chakraborty et al. (2008)

with 935 Mt/annum installed capacity. This industry uses a number of raw materials and process chemicals for production, and their total consumption quantity was 1,138 Mt/annum and 540.4 Mt/annum, respectively. This industry uses coal as fuel and its consumption quantity was 1,960 kL/annum. To produce products, this industry consumed 14,000 kL/annum water from deep tube well.

Wastewater Generation

The industry generated 680 kL/day wastewater. This wastewater contains high BOD and COD levels. Table 9.6 gives a detailed description of this wastewater composite along with the permissible limit prescribed by the WBPCB.

Waste Management Practices

Following the instruction of the WBPCB to meet its permissible limit, this industry built an effluent treatment plant (ETP) in 1995–1996 to treat all wastewater before final discharge to the main sewerage system. The ETP has been designed to treat 240 kL of contaminated water and 440 kL of cooling water per day. Table 9.7 reports the treated wastewater along with the permissible limit prescribed by the WBPCB. Solid waste generated in the industry consists of rejected materials and sludge from ETP, and this quantity was 11.9 Mt/annum (approx.) (1999–2000). Solid waste is collected manually. It is stored in polythene bags (20–25 kg) and dumped into the storage tank inside the industry.

Table 9.6 Characteristics of untreated wastewater of *Jenson & Nicholson (I) Ltd* (1999)

Parameters	Measured values (mean value)	Permissible limit
COD (mg/L)	225.51	250
Phenolic compounds (mg/L)	BDL	1.0
Oil and grease (mg/L)	3.48	10
Cr^6 (mg/L)	BDL[a]	0.1
pH	6.91	6.0–8.5
BOD (mg/L)	69.16	50
TSS (mg/L)	214.5	100

Source: Chakraborty et al. (2008)
[a]Below detection limit

Table 9.7 Characteristics of treated wastewater of *Jenson & Nicholson (I) Ltd* (1999)

Parameters	Measured values (mean value)	Permissible limit
COD (mg/L)	26.55	250
Phenolic compounds (mg/L)	BDL	1.0
Oil and grease (mg/L)	BDL	10
Cr^6 (mg/L)	BDL	0.1
pH	7.15	6.0–8.5
BOD (mg/L)	4.66	50
TSS (mg/L)	20	100

Source: Chakraborty et al. (2008)

9.2.1.4 Pharmaceutical Industry (Infar (India) Ltd.)

The pharmaceutical industry operates 24 h a day and 300 days a year. It employed over 148 persons per day (including both workers and management persons). There are basically three shifts for the workers and one general shift for management and other persons. Presently Infar (I) Ltd. mainly produces "*DIOSYNTH*". Total production of all the products was approximately 3.31 Mt/annum with installed capacity of 4.5 Mt/annum. This industry uses different types of raw materials for production, and their total consumption quantity was 6.706 Mt/annum. Infar (I) Ltd. uses oil as fuel, and its consumption quantity was 365 kL/annum. To produce products, this industry consumes 207,268 kL/annum water from deep tube well.

Wastewater Generation

This industry generated 690.9 kL/day wastewater (2000). This wastewater contains high BOD and COD levels. Table 9.8 gives a detailed description of this wastewater composite compared to permissible limits of the WBPCB.

Table 9.8 Characteristics of untreated wastewater of *Pharmaceutical Industry (Infar India Ltd.)* (1999–2000)

Parameters	Measured values	Permissible limit
COD (mg/L)	800–1,000	250
Cr^6 (mg/L)	Nil	0.1
pH	6.0–8.5	6.0–8.5
BOD (mg/L)	400–550	30
TSS (mg/L)	<100	100

Source: Chakraborty et al. (2008)

Table 9.9 Characteristics of treated wastewater of *Pharmaceutical Industry (Infar India Ltd.)* (1999–2000)

Parameters	Measured values	Permissible limit
COD (mg/L)	<200	250
Cr^6 (mg/L)	Nil	0.1
pH	6.0–8.5	6.0–8.5
BOD (mg/L)	<20	30
Oil and grease (mg/L)	<5	10
TSS (mg/L)	<60	100

Source: Chakraborty et al. (2008)

Waste Management Practices

This industry installed an effluent treatment plant (ETP) in 1998–1999 to treat all wastewater before final discharge to the main sewerage system. Table 9.9 shows the characteristics of the treated wastewater along with the permissible limit of discharge. Solid waste generated in the industry consists of requested materials and sludge from ETP. The quantities amounted to 52.8 Mt/annum (2000). Solid waste is collected from reactor and filter. It is stored in the backyard.

9.2.1.5 Pharmaceutical Industry (East India Pharmaceuticals)

The *East India Pharmaceuticals* industry operates 24 h a day, 300 days a year. It employed over 142 persons (including both workers and management persons). There are basically three shifts for the workers and one general shift is there for management persons. The main production of EIPW Ltd. is Quinodochlor (IP). Average production was around 277.89 Mt/annum. The industry uses a number of raw materials and process chemicals for production and their total consumption quantity were 303.03 Mt/annum (raw material) and 642.04 Mt/annum (process chem.), respectively. It uses steam coal and boiler compound as fuel and their consumption quantities were 460 Mt/year and 0.21 kL/year, respectively. To produce drug, this industry consumed 103,512 kL/annum water from Durgapur Project Ltd.

Table 9.10 Characteristics of untreated wastewater of *East India Pharmaceuticals* (1999)

Parameters	Concentration	Permissible limit
1. COD (mg/L)	538.2	250
2. Phenolic compounds (mg/L)	12.4	1.0
3. pH	9.4	6.5–8.5
4. Oil and grease (mg/L)	4.8	10
5. BOD (mg/L)	80.8	100
6. TSS (mg/L)	160.4	100

Source: Chakraborty et al. (2008)

Wastewater Generation

This industry generated 302 kL/day industrial wastewater and 11 kL/day domestic wastewater, that is, total 313 kL/day liquid waste (1999). This wastewater contains high BOD and COD levels. A detailed description of this wastewater composite compared to permissible limit of the WBPCB is presented in Table 9.10.

Waste Management Practices

The industry built an effluent treatment plant (ETP) in 1991–1992 for the treatment of all wastewater before final discharge to the main sewerage system. Table 9.11 presents a detailed description of the treated wastewater along with the permissible limit of WBPCB. Solid waste generated in the industry consists of rejected materials like hand gloves, gum boot, paper containers, etc., and this quantity was about 200 kg/month. Other solid wastes are sludge from different units, ETP, etc., and this quantity was 5,000 kg/month (1999). The total amount of solid waste was 51.480 Mt/annum. Solid waste is collected manually and deposited into the storage tank inside the industry.

9.2.2 Determination of Water Quality Indices (WQI) of Wastewater of Five Industries in West Bengal

As it is known, the availability of water in terms of both quantity and quality is essential to the very existence of mankind. Earlier, people used to recognize the importance of water from quantity viewpoint. Recognition of the importance of water quality developed more slowly only in recent years. It will be more convenient to integrate the data pool in some way to produce a single number to reflect the water quality status. Water quality index (WQI) achieves that result. The WQI considered in our case is of the form

Table 9.11 Characteristics of treated wastewater of East India Pharmaceuticals (1999)

Parameters	Concentration	Permissible limit
1. COD (mg/L)	34.7	250
2. Phenolic compounds (mg/L)	0.	1 1.0
3. pH	6.7	6.5–8.5
4. Oil and grease (mg/L)	Trace	10
5. BOD (mg/L)	8.3	100
6. TSS (mg/L)	10.6	100

Source: Chakraborty et al. (2008)

$$\mathrm{WQI} = \sum_{i=1}^{n} (w_i \times q_i)$$

where

q_i = the quality of ith parameter a number between 0 and 100
w_j = the weight of ith parameter a number between 0 and 1
n = the total number of parameters

The development and formulation of WQI involves four stages:

1. Parameter selection
2. Transformation of parameter estimates to a common scale
3. Assignment of weights to all the parameters
4. Aggregation of individual parameter scores to produce a final index score

In developing water quality indices, experts (in the concerned field of water quality management) differ from each other. Here, we shall consider the systematic opinion research technique, as attempted by Robert M. Brown (as mentioned by Abbasi 1999). It has been utilized to incorporate the opinion of a large and diverse panel of experts. They were asked to rank the water quality parameters according to their significance as contributor to overall quality. The rating was done on a scale of 1 (highest) to 5 (lowest), based on the polluting effect of the parameter relative to others. Each parameter represents only a part of the overall quality; thus, parameters of even lower importance cannot be discarded since they are still part of the overall quality.

In the next step, arithmetic mean was calculated on the rating scores by the experts to arrive at the "mean of all significance rating" for each individual parameter. To convert the mean rating into weights, a temporary weight of 1.0 was assigned to the parameter which received the highest significance rating. All other temporary weights were obtained by dividing the corresponding individual mean rating of the parameters by the highest rating. Each temporary weight was then divided by the sum of all temporary weights to deduce the final weight (w_i), which must sum up to one, that is, $\sum w_j = 1$. A total weight of l is thus distributed among the parameters to reflect the relative importance of the parameters. The

Table 9.12 Water resources classification

WQI value	Class	Description
63–100	A	Good to excellent
50–63	B	Medium to good
38–50	C	Bad
Below 38	D, E	Bad to very bad

Source: Chakraborty et al. (2008)

weight hence assigned to a parameter is an indication of the degree to which water quality may be affected by that particular parameter.

The following step to the above is the transformation of parameter to a common quality scale referred commonly as individual quality rating score (q_i). The quality rating score is assigned to a particular parameter depending on an individual judgment or a consensus opinion of experts based on the water quality standards. It reflects the magnitude of violation of set of standards. The quality rating is done on a scale of 0 (highest polluting) to 100 (lowest polluting).

Finally, an overall quality rating is derived, simply by multiplying the final weights (w_i) of each individual parameter with the corresponding quality rating (q_i). The sum of ($w_i \times q_i$) gives the required single number WQI.

Now, to evaluate the water quality status of wastewater, water resource has been classified in the following way using WQI value so obtained.

The last classification of Table 9.12 (i.e., D and E – Bad to Very bad) has been decomposed to class D with WQI values above 20 and described as "Bad" and those below 20 as "Very bad" under class E.

Taking these steps as the basis, the data collected by the authors have been analyzed for assessing the water quality status of both untreated and treated wastewater generated by the different industries in West Bengal. Details of which are presented in Tables 9.13, 9.14, 9.15, 9.16, 9.17, 9.18, and 9.19.

The calculated values of WQI of untreated and treated wastewater for the aforesaid industries are presented in Table 9.20. It is evident from Table 9.20 that the water quality of treated wastewater of each industry is good.

This means that the ETP of each industry is effective in keeping the quality of wastewater within the permissible limit of discharge. It also means that there is environmental gain in the installation of ETP. Eastern Spinning Mills and East India Pharmaceuticals have gained highest environmental improvement due to the installation of ETP, because they are converting the wastewater of Class D to the wastewater of Class A by their ETP.

Table 9.13 Determination of WQI of untreated wastewater, Eastern Spinning Mills & India Ltd.

Parameter	Measured value	Permissible limit	Mean of significance	Temporary weights	Final weights (w_i)	Individual quality rating (q_i)	Overall quality rating ($w_i \times q_i$)
COD (mg/L)	1,350	250	1.4	1	0.29	5	1.45
pH	8.5	5.5–9.0	2.1	0.7	0.20	82	16.4
BOD (mg/L)	310	30	2.3	0.6	0.17	5	0.85
Temperature °C	50–55	Room temperature	2.4	0.6	0.17	7	1.19
TDS (mg/L)	1,380	2,100	2.4	0.6	0.17	80	13.6

Source: Chakraborty et al. (2008)
WQI = $\sum(w_i \times q_i) = 33.49$ (calculated from the last column)
Wastewater of class D (see tables 9.12 and 9.20 for clarification)
Bad quality wastewater (see tables 9.12 and 9.20 for clarification)

Table 9.14 Determination of WQI of treated wastewater, Eastern Spinning Mills & India Ltd.

Parameter	Measured value	Permissible limit	Mean of significance	Temporary weights	Final weights (w_i)	Individual quality rating (q_i)	Overall quality rating ($w_i \times q_i$)
COD (mg/L)	209.4	250	1.4	1	0.24	90	21.6
pH	7.57	5.5–9.0	2.1	0.7	0.17	92	15.6
Oil and grease (mg/L)	4	10	2.1	0.7	0.17	92	15.6
BOD (mg/L)	120	30	2.3	0.6	0.15	10	1.5
Temperature °C	33	Room temperature	2.4	0.6	0.15	85	12.7
TDS (mg/L)	42	100	2.9	0.5	0.12	92	11.04

Source: Chakraborty et al. (2008)

$WQI = \sum(w_i \times q_i) = 78.0$ (calculated from the last column)

Wastewater of class A (see tables 9.12 and 9.20 for clarification)

Good quality wastewater (see tables 9.12 and 9.20 for clarification)

Table 9.15 Determination of WQI of treated wastewater, Samson Processing Industries

Parameter	Measured value	Permissible limit	Mean of significance	Temporary weights	Final weights (w_i)	Individual quality rating (q_i)	Overall quality rating ($w_i \times q_i$)
COD (mg/L)	276.64	250	1.4	1	0.24	60	14.4
Oil and grease (mg/L)	3.8	10	2.1	0.7	0.17	90	15.3
Cr^{+6} (mg/L)	BDL	0.1	2.1	0.7	0.17	92	5.64
pH	8.13	6.0–8.5	2.1	0.7	0.17	92	15.64
BOD (mg/L)	82.5	150	2.3	0.6	0.14	94	13.16
TSS (mg/L)	78.0	100	2.9	0.5	0.12	94	11.28

Source: Chakraborty et al. (2008)
WQI = $\sum(w_i \times q_i)$ = 85.42 (calculated from the last column)
Wastewater of class A (see tables 9.12 and 9.20 for clarification)
Good quality wastewater (see tables 9.12 and 9.20 for clarification)

Table 9.16 Determination of WQI of untreated wastewater, Infar India Pharmaceuticals

Parameter	Measured value	Permissible limit	Mean of significance	Temporary weights	Final weights (w_i)	Individual quality rating (q_i)	Overall quality rating ($w_i \times q_i$)
COD (mg/L)	800–1,000	250	1.4	1	0.27	5	1.35
Cr^{+6} (mg/L)	Nil	0.1	2.1	0.7	0.2	92	18.4
pH	6.0–8.5	6.0–8.5	2.1	0.7	0.2	92	18.4
BOD (mg/L)	400–550	30	2.3	0.6	0.17	5	0.85
TSS (mg/L)	<100	100	2.9	0.5	0.14	94	13.16

Source: Chakraborty et al. (2008)
$WQI = \sum(w_i \times q_i) = 52.16$t (calculated from the last column)
Wastewater of class B (see tables 9.12 and 9.20 for clarification)
Good quality wastewater (see tables 9.12 and 9.20 for clarification)

Table 9.17 Determination of WQI of treated wastewater, Infar India Pharmaceuticals

Parameter	Measured value	Permissible limit	Mean of significance	Temporary weights	Final weights (w_i)	Individual quality rating (q_i)	Overall quality rating ($w_i \times q_i$)
COD (mg/L)	<200	250	1.4	1	0.24	92	22.08
	<5	10	2.1	0.7	0.17	90	15.3
Cr^{+6} (mg/L)	Nil	0.1	2.1	0.7	0.17	92	15.64
pH	6.5–8.5	6.0–8.5	2.1	0.7	0.17	92	15.64
BOD (mg/L)	<20	30	2.3	0.6	0.14	94	13.16
TSS (mg/L)	<60	100	2.9	0.5	0.12	94	11.28

Source: Chakraborty et al. (2008)
$WQI = \sum(w_i \times q_i) = 93.1$ (calculated from the last column)
Wastewater of class A (see tables 9.12 and 9.20 for clarification)
Good quality wastewater (see tables 9.12 and 9.20 for clarification)

Table 9.18 Determination of WQI of untreated wastewater, East India Pharmaceuticals

Parameter	Measured value	Permissible limit	Mean of significance	Temporary weights	Final weights (w_i)	Individual quality rating (q_i)	Overall quality rating ($w_i \times q_i$)
COD (mg/L)	538	250	1.4	1	0.24	10	2.4
Phenolic compounds (mg/L)	12.4	1.0	2.0	0.7	0.17	2	0.34
Oil and grease (mg/L)	4.8	10	2.1	0.7	0.17	92	15.64
pH	9.4	6.0–8.5	2.1	0.7	0.17	10	1.7
BOD (mg/L)	80.8	100	2.3	0.6	0.14	92	12.88
TSS (mg/L)	160.4	100	2.9	0.5	0.12	20	2.4

Source: Chakraborty et al. (2008)
$WQI = \sum(w_i \times q_i) = 35.36$ (calculated from the last column)
Wastewater of class D (see tables 9.12 and 9.20 for clarification)
Bad quality wastewater (see tables 9.12 and 9.20 for clarification)

Table 9.19 Determination of WQI of treated wastewater, East India Pharmaceuticals

Parameter	Measured value	Permissible limit	Mean of significance	Temporary weights	Final weights (w_i)	Individual quality rating (q_i)	Overall quality rating ($w_i \times q_i$)
COD (mg/L)	34.7	250	1.4	1	0.24	92	22.08
Phenolic compounds (mg/L)	0.1	1.0	2.0	0.7	0.17	92	15.6
Oil and grease (mg/L)	Trace	10	2.1	0.7	0.17	94	15.98
pH	6.7	6.0–8.5	2.1	0.7	0.17	92	15.60
BOD (mg/L)	8.3	100	2.3	0.6	0.14	98	13.72
TSS (mg/L)	10.6	100	2.9	0.5	0.12	94	11.28

Source: Chakraborty et al. (2008)

WQI $= \sum(w_i \times q_i) = 94.26$ (calculated from the last column)

Wastewater of class A (see tables 9.12 and 9.20 for clarification)

Good quality wastewater (see tables 9.12 and 9.20 for clarification)

Table 9.20 Calculated values of WQI of treated and untreated wastewater of five industries of West Bengal

	WQI values of wastewater		Class of wastewater	
Name of the industry	Untreated	Treated	Untreated	Treated
1. Eastern Spinning Mills & India Ltd.	33.49	78.0	Class D	Class A
2. Samson Processing Industries	–	85.42	–	Class A
3. Jenson & Nicholson (I) Ltd.	73.50	90.09	Class A	Class A
4. Infar India Pharmaceuticals	52.16	93.10	Class B	Class A
5. East India Pharmaceuticals	35.36	94.28	Class D	Class A

Source: Chakraborty et al. (2008)

9.2.3 Evaluation of Setting Up of Effluent Treatment Plant in Five Industries

As mentioned, following the instruction directed by the West Bengal Pollution Control Board, the different industries have set up effluent treatment plant to control water pollution. The five industries under study have also set an ETP. In this section, we will evaluate the extent of the success of setting up these plants using a well-known benefit–cost approach.

9.2.3.1 Benefit–Cost Analysis of Textile-Dyeing Industry (Samson Processing Industries)

Cost Analysis

Considering the data that has been obtained from the industry over 20 years, the cost has been calculated for the lifetime of the ETP. In calculating the total cost, both construction and operation cost aspects of the pollution abatement measures have been considered.

Construction Cost

In the evaluation of construction cost, the total investment made by the organization for purchasing and installing the equipment for the ETP has been calculated. It has been observed that the organization has made an investment of Rs. 1,159,724 in the year 1998–1999. This was the construction cost of the treatment plant for the first year, which is represented in detail in Table 9.21. It has been observed that the organization has not been taken any loan for the construction of ETP.

Operation Cost

The inputs required for the operation and maintenance of ETP are chemicals, energy, labors, water, etc. This industry has supplied the operational cost data for

Table 9.21 Construction cost of *Samson Processing Industries* (1998–1999)

Item	Cost (Rs.)
1. Equipment cost	150,000
2. Transport charge	10,540
3. Labor charge	218,292
4. Material charge	700,892
5. Consultant	80,000

Source: Chakraborty et al. (2008)

Table 9.22 Operation cost of *Samson Processing Industries* (2000–2001)

Item	Cost (Rs.)
1. Salary of operator	100,800
2. Cost of chemicals	122,452
3. Maintenance cost	18,400
4. Electricity charge	151,200

Source: Chakraborty et al. (2008)

the year 2000–2001 which is given in Table 9.22. To obtain the entire operational cost structure throughout the lifetime of the ETP, different annual inflation rates, taken from the Economic Survey published by the Government of India, have been used for each operational item. The average inflation rate has been used for the rest of the lifetime of ETP. The operational cost for each item was then calculated through the lifetime of ETP, and the sum of the different items for each year gives the total operation cost for that particular year.

Total annual cost is arrived at by adding total construction cost to the total operational cost. The present value of total cost in the future is calculated by discounting the total cost over lifetime of ETP using a 10 % discount rate, which is the market rate of interest. For this calculation, the following formula has been used:

$$P_n = \frac{Cn}{(1+r)^n} \tag{9.1}$$

where

"P_n" is the discounted cost of *n*th year.
"*Cn*" is the total cost of *n*th year.
"*n*" is the number of year.
"*r*" is the rate of discount.

The cumulative total cost has also been calculated.

Benefit Analysis

The estimation of the benefit was based on the assumption that a certain percentage of the total revenue (TR) has to be deposited to the WBPCB as a penalty if the

Table 9.23 Benefit–cost ratio of *Samson Processing Industries* for different percentage values

Values guessed (%)	∑discounted benefit	∑discounted cost	Values of BCR
0.1	257,100	7,191,287	0.04
0.25	642,740	7,191,287	0.1
0.5	1,285,480	7,191,287	0.2
1	2,570,960	7,191,287	0.3
2	5,141,920	7,191,287	0.7
3	7,712,866	7,191,287	1.1
4	10,283,820	7,191,287	1.4
4.5	11,569,300	7,191,287	1.6

Source: Chakraborty et al. (2008)

industry did not install ETP. The details of the total revenue that has been supplied by the industry are for the year 1998–1999. In this year, the industry installed an ETP and that the total revenue for the year of installation of ETP was Rs. 12,854,776. To estimate the possible percentage of the total revenue (of the year of installation of ETP) that has to be deposited as a penalty, different percentages of total revenue (of the year of installation of ETP) are used. It is assumed that these range from 0.1 % upwards. The values of different percentages assumed for the fine, along with the rupees amount, are given in Table 9.23. From here, the minimum percentage value which gives the IRR (internal rate of return) value is selected as the percentage value of fine. This amount is the benefit per year throughout the lifetime of the ETP. It has been seen that a minimum penalty of 3 % of the total revenue (of the year of installation of ETP) gives the IRR value. The present value of the benefit is then calculated over lifetime of ETP, and for this calculation, the following equation has been used:

$$\text{Benefit} = \text{deposited amountx} \times (1 + r)^n$$

where "n" is the number of year and "r" is the rate of interest which is 10 %.

Results of Benefit–Cost Analysis

Based on the processed cost and benefit data, the payback period, benefit–cost ratio, and internal rate of return have been calculated.

The *benefit–cost ratio (BCR)* is obtained by dividing the ∑(discounted benefit) to the ∑(discounted cost) throughout the lifetime of ETP. The obtained values of the BCR for different percentage values, which have been assumed as the percentage value of fine, are given in Table 9.23. The *payback period (PBR) and internal rate of return (IRR)* have been found to be in the ninth year and 16 %, respectively.

Table 9.24 Construction cost of *Jenson and Nicholson (I) Ltd.* (1995–1996)

Item	Cost (Rs.)
1. Equipment cost	937,256
2. Cost for the construction of sludge tank	50,000
3. Transport charge	40,000
4. Labor charge	772,800
5. Material charge	22,000
6. Electricity charge	1,159,200
7. Building cost	297,000
8. Consultant	110,000
9. Others and manpower	80,000

Source: Chakraborty et al. (2008)

9.2.3.2 Benefit–Cost Analysis of Paints Industry (Jenson and Nicholson (I) Ltd.)

Cost Analysis

Considering an ETP data of 20 years that has been obtained from the industry, the cost has been calculated for the lifetime of ETP. Calculation of the cost has been made similar to the *textile and dyeing industry*.

Construction Cost

In calculating construction cost, the total investment made by the organization for purchasing and installing the equipment for the setup of an ETP has been calculated. It has been observed that the organization made an investment of Rs. 3,468,256. This is the construction cost of the treatment plant for the first year, which is represented in detail in Table 9.24. The organization has not taken any loan for the implementation of the ETP.

Operation Cost

The inputs required for the operation and maintenance of the ETP are chemicals, energy, labors, water, etc. This industry has supplied the operational cost data for the year 1999–2000 which is given in Table 9.25.

The present value of total cost in the future is calculated by discounting the total cost over lifetime of ETP using a 10 % discount rate using the formula (9.1). The cumulative of total cost has been calculated.

Benefit Analysis

The model for evaluating the direct benefit was constructed based on the assumption which has already been explained in the case of textile-dyeing industry. A certain percentage of the total revenue (TR) is to be deposited to the WBPCB as a

Table 9.25 Operation cost of *Jenson and Nicholson (I) Ltd.* (1999–2000)

Item	Cost (Rs.)
1. Salary of operator	144,000
2. Cost of chemicals	197,736
3. Maintenance cost	60,000
4. Cost of water used	354,912
5. Electricity charge	276,000

Source: Chakraborty et al. (2008)

penalty if the industry avoids setting up the ETP. The details of the total revenue that has been supplied by the industry are for the year 1999–2000. Using these data, the total revenue of the industry for the year of ETP installation has been estimated by backward calculation. Different annual inflation rates for the various years have been used for this calculation. The total revenue for the year of installation of ETP is Rs. 341,488,514. The percentage of total revenue in the year of installation of ETP which has to be deposited is decided by randomly choosing different values that are assumed to be from 0.1 % onwards. The values of the different percentages assumed for the fine along with the rupee amount are given in Table 9.26. The minimum percentage value that gives the IRR value is then selected as the percentage value of fine. This amount is the direct benefit per year throughout the lifetime of the ETP. It has been seen that a minimum of 0.25 % of the total revenue (of the year of installation of ETP) gives the IRR value. The present value of the direct benefit is also calculated over the lifetime of ETP.

Results of Benefit–Cost Analysis

The obtained values of the BCR for different percentage values, which have been assumed as the percentage value of fine, are given in Table 9.26. The internal rate of return has been estimated to be 15 % and ninth year as the payback period.

9.2.3.3 Benefit–Cost Analysis of Pharmaceutical Industry (Infar India Ltd.)

Cost Analysis

Using the 10 years lifetime data that has been obtained from the industry, the total cost has been calculated throughout the lifetime of ETP. Calculation of the cost is the same like that carried out for the previous industries.

Construction Cost

For construction cost, the total investment made by the organization for purchasing and installing the equipment for the setting up of ETP has been calculated to be

Table 9.26 Benefit–cost ratio of *Jenson and Nicholson (I) Ltd.* for different percentage values

Values guessed (%)	∑discounted benefit	∑discounted cost	Values of BCR
0.1	6,949,770	15,755,151	0.4
0.25	17,374,426	15,755,151	1.1
0.5	34,748,852	15,755,151	2.2
1	69,497,703	15,755,151	4.4
2	138,995,406	15,755,151	8.8
3	208,493,109	15,755,151	13.2
4	277,990,812	15,755,151	17.6
4.5	312,739,664	15,755,151	19.8

Source Chakraborty et al. (2008)

Rs. 20,300,000. This is the construction cost of the treatment plant for the first year, which is represented in detail in Table 9.27. The organization has not taken any loan for the implementation of ETP.

Operation Cost

The input required for the operation and maintenance of ETP are chemicals, energy, labors, water, etc. This industry has supplied the operational cost data for the year 2000–2001 which is given in Table 9.28.

The present value of the total cost in the future is calculated by discounting the total cost over the lifetime of ETP using a 10 % discount rate using the formula (9.1). The cumulative total cost has also been calculated.

Benefit Analysis

The model for estimating the benefit of ETP was done based on the same assumption as explained before. The total revenue of the industry for the year of installation of ETP (1998–1999) has been computed by recursive calculation, and different annual inflation rates are used for the various years. The total revenue for the year of ETP installation is Rs. 158,192,615 (1998–1999). The percentage of the total revenue in the ETP installation year which has to be deposited is again decided by guessing the different values. The values of different percentages assumed for the fine, along with the amount of fine, are given in Table 9.29. It has been seen that a minimum fine of 2 % of the total revenue in the ETP installation year gives IRR value. Similar to the previous calculations, the present value of the benefit in the future is calculated by discounting the benefit over the lifetime of ETP using a 10 % discount rate. The cumulative total benefit has also been calculated.

Table 9.27 Construction cost *of Pharmaceutical Industry [Infar India Ltd]* (1998–1999)

Item	Rupees
Civil work	5,900,000
Mechanical equipment	8,900,000
Electrical equipment	250,000
Others	3,000,000

Source: Chakraborty et al. (2008)

Table 9.28 Operation cost *of* Pharmaceutical Industry [Infar India Ltd] (2000–2001)

Item	Rupees
Service contract	554,000
Cost of chemicals	570,000
Maintenance cost	100,000
Cost of water used	Nil
Electricity charge	1,270,000

Source: Chakraborty et al. (2008)

Table 9.29 Benefit–cost ratio *of Pharmaceutical Industry (Infar India Ltd.)* (2000–2001) for different percentage values

Values guessed (%)	∑discounted benefit	∑discounted cost	Values of BCR
0.1	1,581,926	38,761,821	0.04
0.25	3,954,815	38,761,821	0.1
0.5	7,909,631	38,761,821	0.2
1	15,819,262	38,761,821	0.4
2	31,638,523	38,761,821	0.8
3	47,457,785	38,761,821	1.2
4	63,277,046	38,761,821	1.6
4.5	71,186,677	38,761,821	1.8

Source: Chakraborty et al. (2008)

Results of Benefit–Cost Analysis

For the present industry, the tenth year has been found as the payback period. The obtained values of the BCR for different percentage values, which have been assumed as the percentage value of fine, are given in Table 9.29. The internal rate of return has been found to be 27 %.

9.2.3.4 Benefit–Cost Analysis of Pharmaceutical Industry (East India Pharmaceutical)

Cost Analysis

The lifetime of the ETP in this industry is 15 years, and the cost has been calculated considering this lifetime of ETP.

Table 9.30 Construction cost of East India Pharmaceutical (1995–1996)

Item	Rupees
1. Equipment cost	1,000,000
2. Material charge	2,285,000
3. Electricity charge	305,000
4. Building cost	520,000
5. Others	380,000

Source: Chakraborty et al. (2008)

Construction Cost

The total investment made by the organization for purchasing and installing the equipment for setup of ETP has been estimated to be Rs. 4,490,000, which is the construction cost of the treatment plant for the first year and represented in detail in Table 9.30. The organization has taken a loan of Rs. 43 lakhs for the implementation of the ETP. An interest of 16 % per year, that is, Rs. 7,092,500, was paid by the organization in each year and has been considered for the remaining years of ETP.

Operation Cost

This industry has supplied the operational cost data for the year 1998–1999 which is given in Table 9.31. Following the same procedure as previously, the entire operational cost throughout the lifetime of the ETP has been estimated by using different annual inflation rates. Details of the operation cost are given in the year 1999–2000 (Table 9.31).

Total annual cost for each year is arrived at by adding construction and interest cost to the total operational cost for that year. The present value of total cost in the future is then calculated by discounting the total cost over lifetime of ETP using a 10 % discount rate. The cumulative total cost has also been calculated.

Benefit Analysis

Similarly, the total benefit was estimated using the same assumptions as the above industries. The total revenue for the year of installation of ETP is Rs. 57,961,781. The values of different percentage assumed for the fine, along with the rupee amount, are given in Table 9.32. In this case, it is calculated that a minimum of 4.5 % of the total revenue in the ETP installation year gives IRR value. The present value and cumulative total of the benefit is calculated over the lifetime of ETP.

Results of Benefit–Cost Analysis

For the present industry, the 11th year has been found as the payback period. The obtained values of the BCR for different percentage values, which have been

Table 9.31 Operation cost of East India Pharmaceutical (1999–2000)

Item	Rupees
1. Salary of operator	204,166
2. Cost of chemicals	2,484,540
3. Maintenance cost	581,652
4. Electricity	957,760
5. Cost of water used	3,230.25

Source: Chakraborty et al. (2008)

Table 9.32 Benefit–cost ratio of East India Pharmaceutical for different percentage values

Values guessed (%)	∑discounted benefit	∑discounted cost	Values of BCR
1	8,694,270	20,003,690	0.4
2	17,388,540	20,003,690	0.9
3	26,082,801	20,003,690	1.3
4	34,777,068	20,003,690	1.7
4.5	39,124,205	20,003,690	2.0

Source: Chakraborty et al. (2008)

assumed as the percentage value of fine, are given in Table 9.32. Internal rate of return has been estimated to be 13 %.

9.2.3.5 Benefit–Cost Analysis of Textile Industry (Eastern Spinning Mills of India, Ltd.)

Cost Analysis

The lifetime of the ETP in this industry is 15 years and the cost has been calculated considering this lifetime of ETP.

Construction Cost

It has been observed that the organization has made an investment of Rs. 2,635,336 for the construction cost of the treatment plant for the first year, which is represented in detail in Table 9.33. It has been observed that the organization has taken a loan of Rs. 1,000,000 from internal resources and Rs. 16, 00,000 lakhs from the bank for the construction of the ETP at 16.5 % per annum.

Operation Cost

The industry has supplied the operational cost data for the years 1998–1999 which is given in Table 9.34. Following the same procedure as before, the entire operational cost structure throughout the lifetime of the ETP has been estimated using different annual inflation rates for each of the years.

Table 9.33 Construction cost of Eastern Spinning Mills of India, *Ltd*. (1993–1994)

Item	Rupees
1. Equipment cost	1,905,731
2. Cost for construction of sludge tank	96,670
3. Transport cost	36,468
4. Labor cost	146,099
5. Material cost	321,409
6. Electricity cost	8,959
7. Consultancy	120,000

Source: Chakraborty et al. (2008)

Table 9.34 Operation cost of Eastern Spinning Mills of India, *Ltd*. (1999–2000)

Item	Rupees
1. Salary of operator	316,560
2. Cost of chemicals	364,750
3. Maintenance cost	1,512
4. Electricity	3,024
5. Cost of water used	795,960

Source: Chakraborty et al. (2008)

Total annual cost for each year is arrived at by adding total construction cost to the total operational cost for that year, and the present value of total cost in the future is calculated by discounting the total cost over lifetime of ETP using a 10 % discount rate. The cumulative total cost has also been calculated.

Benefit Analysis

Using similar assumptions as before, the total revenue for the year for the industry was Rs. 70,200,000. It has been estimated that a minimum 0.25 % of the total revenue (of the year of installation of ETP) gives the IRR value. The present value and cumulative total value of the benefit is also calculated over lifetime of ETP.

Results of Benefit–Cost Analysis

For the present industry, two and half year has been found as the payback period. Table 9.35 presents the BCR for the different percentage values assumed as the percentage value of fine. Internal rate of return has been estimated to be 86 %.

Table 9.35 Benefit–cost ratio of Eastern Spinning Mills of India, Ltd. for different percentage values

Values guessed (%)	∑discounted benefit	∑discounted cost	Values of BCR
0.1	10,545,446	16,344,801	0.6
0.25	26,340,446	16,344,801	1.6
0.5	52,665,046	16,344,801	3.2
1	105,315,246	16,344,801	6.4
2	210,616,440	16,344,801	12.9
3	31,596,246	16,344,801	19.3
4	421,215,321	16,344,801	25.8
4.5	473,866,123	16,344,801	29.0

Source: Chakraborty et al. (2008)

9.2.4 Assessment of Effluent Treatment Plants in West Bengal

A significant number of industries in West Bengal have been producing water pollution at much higher rate than the Minimal National Standards (MINAS) approved by the West Bengal Pollution Control Board. These industries continuously discharge their wastewater into the watercourse of the Hooghly River, the municipal sewerage and cultivated lands, which poses an increasing threat to economic growth and development prospect of West Bengal economy. A limited number of these industries have put in some effort by installing ETP to minimize the water pollution they generated. The above case studies conducted by Chakraborty et al. (2008) attempted to investigate the pollution generation, abatement cost, and wastewater quality status to provide an economically viable model for evaluating the viability of the investment in ETP. Five industries in West Bengal have been chosen for the study.

It is evident from the different case studies of West Bengal that the installation of ETP caused the wastewater quality of each industry to improve. This means that the ETP of each industry is effective in keeping the quality of wastewater within the permissible limit of discharge and that there is environmental gain in the installation of ETP. Eastern Spinning Mills and East India Pharmaceuticals have experienced highest environmental gain due to the installation of ETP as they convert their wastewater from Class D to Class A using their ETP. The viability of the ETP of each industry has been evaluated based on three criteria – internal rate of return (IRR), payback period (PBP), and benefit–cost ratio (BCR). The minimum percentage of annual revenue in the year of ETP installation which gives the IRR value has been suggested as the percentage value for the fine. It is seen that this percentage value for the fine is different for different industries. Based on this minimum percentage value, the calculated values of IRR, BCR, and PBP are given in Table 9.36.

It is evident from the values of the payback period (PBP) that all the aforesaid industries could recover their full investment in the ETP within its lifetime although

Table 9.36 Values of IRR, BCR, and PBP for five effluent treatment plants in West Bengal

Name of the industry	Year of installation of ETP	Life time of ETP (years)	Assumption of percentage values on total revenue for fine	Estimated values of criteria		
				IRR	PBP	BCR
1. Eastern Spinning Mills & India Ltd.	1993–1994	15	0.25	86	2.5	1.6
2. East India Pharmaceuticals	1998–1999	15	4.5	13	11	1.9
3. Jenson & Nicholson (I) Ltd.	1995–1996	20	0.25	15	9	1.1
4. Infar India Pharmaceuticals	1998–1999	10	2	27	10	0.8
5. Samson Processing Industries	1998–1999	20	3	16	9	1.1

Source: Chakraborty et al. (2008)

the recovery rate is different for each industry. It is very fast for Eastern Spinning Mills, medium for Jenson and Nicholson (I) Ltd. and for Samson Processing Industries, and slow for East India and Infar India Ltd.

It is also clear from the table that the values of benefit–cost ratio (BCR) are greater than one for all the aforesaid industries (except Infar India Ltd.). This indicates that the installation of ETP generates benefit in excess of the investment in the ETP over the lifetime of the ETP. The profitability of benefit is high for Eastern Spinning and East India Pharmaceuticals, medium for Jenson and Nicholson (I) and Samson Processing, and low for Infar India Ltd. The internal rate of return (IRR) value for the aforesaid industries is also more than the cost of investment (10 %). This means that they can equalize total expenditure involved in ETP with its benefit by a definite rate within the lifetime of ETP. Therefore, the installation of ETP has been viable with different IRR values obtained for different industries. The Eastern Spinning has the highest IRR value (86 %) while other industries have less IRR value.

Thus the findings of the above case studies suggest that the measures to control water pollutants by setting up an ETP in five industries have been successful in West Bengal. The other industries in West Bengal which have not yet implemented these measures can learn a lesson from these exercises in setting up an ETP.

9.3 Other Case Studies in India

We shall now present several other case studies on wastewater treatment conducted in different parts of India.

9.3.1 A Case Study of Textile Industry in Pali, Rajasthan

Singh et al. (2011) made a performance evaluation of a common effluent treatment plant treating textile wastewaters. In this study, the performance of a CETP treating 3,405 m^3/day wastewater from 450 synthetic textile mills was evaluated.

CETP in the case study is located in Pali which is in the Northwestern State of Rajasthan of India and is situated on the banks of river Bandi. The total area of this town is about 12,387 km^2 with around 989 dyeing and printing units. Dyeing and printing of synthetic fabrics is the major activity along with desizing, mercerizing, kiering, and bleaching. The combined wastewater besides alkaline pH and intense color contains certain organic and inorganic chemicals from the various process operations.

Four criteria were used by the authors. These are design, operation, maintenance, and administration. Design data was collected from each operational unit of the CETP, and a scoring method was used to assess the adequacy of design. Actual operational efficiency of the CETP was evaluated by collecting samples (19 in all) at each stage of treatment. All samples were analyzed for 16 physicochemical parameters. Administration capability and adequacy of maintenance systems were evaluated using questionnaires and by conducting staff interviews.

The study has found that most of the units are designed well, although it suggests that some improvements like better mixing in equalization tank, modifications in HRT, SOR, in the clariflocculator, and increasing HRT in aeration tank, can be achieved by changing operational parameters. The lime and $FeSO_4$ tanks also have inadequate capacity and mixing that needs improvement. Existing sludge drying beds are only 27 % of the area required, and therefore further construction is required. COD and BOD in the outlet exceeded the standards for effluents for the textile industries. The two aeration tanks also need improvements in terms of performance, and this can be achieved by improving the biomass in the aeration tanks I and II and increasing the HRT. Other standards were met by the treated effluents.

Thus, the overall performance of the CETP was evaluated considering several aspects and recommendations were then made by the authors for improving its performance.

9.3.2 Case Study of Textile Industry in Tirupur and Karur, Tamil Nadu

The study by Ranganathan et al. (2007) analyzed the advanced treatment technology of wastewaters of textile-dyeing units of Tirupur and Karur, Tamil Nadu. Coimbatore district of Tamil Nadu is well known for cotton production and is also called as the Manchester of Southern India. Tirupur, one of the towns in the district, is located at the bank of river Noyyal, a tributary to river Cauvery. The quality of Noyyal river water and climatic condition of Tirupur have been ideal for dyeing operation of yarn and fabric for a long time. Presently there are 712 dyeing and bleaching industries in Tirupur that generate 87,000 m^3/day of wastewater. Out of this, a total of 281 industries are attached to a common effluent treatment plants while others have their individual effluent treatment plants.

Textile-dyeing industries in Tirupur and Karur of Tamil Nadu (India) usually discharge effluents ranging between 80 and 200 m^3 per ton of production. Dyeing is performed either by conventional winch process or by advanced soft flow reactor process. Hypochlorite, the commonly used bleaching chemical, is being gradually phased out by alkaline hydrogen peroxide solution that generates less effluent and fewer solids in the effluents. Coloring of yarn/cloth takes place in the presence of high concentration of sodium chloride or sodium sulfate (25–75 kg/m^3) in dye solutions. Dye bath wastewaters and wash waters are the process effluents of dyeing industry which are collected separately or together and follow the advanced treatment for maximum recycling of recovered waters. After treating dye bath water by sand and nanofiltrations (NF), the permeate is used in the process for dye bath preparation and the reject of about 20–30 % is sent to multi-effect evaporator (MEE)/solar evaporation pond (SEP). Wastewaters treated using a sequence of physicochemical and biological unit processes are passed into two stages reverse osmosis (RO) membrane systems, and then the permeate is reused in the processes. The rejects of about 15–20 % of the inlet volume is either subject to nanofiltration for salt recovery or sent to evaporators. The final rejects from nanofilter systems is directed to a multi-effect evaporator system where condensed waters are recovered. The average percent removals of BOD, COD, TDS, sodium, and chloride in the advanced treatment technology are in the range of 88–98 %, 91–97 %, 80–97 %, 96 %, and 76–97 %, respectively. Multiple effect evaporators outflows of about 2–3 % of the effluent volume are allowed for solar evaporation, and the solids are disposed off. The most attractive part of water recovered from these membranes is its extremely low hardness, which is always demanded in textile sector for an improved finish and better quality dyeing. The cost of operation of MEE is about Rs. 400/m^3 of the effluent. The treatment and maintenance cost of Rs. 80/m^3 is cheaper than the water cost of Rs. 100/m^3 in Tirupur and Karur areas. Common facility for multistage evaporator would be economical. The study shows the recycling of treated wastewater, and zero wastewater discharge is found technically feasible and economically viable in the textile-dyeing industries located in the area of Tirupur and Karur, Tamil Nadu.

9.3.3 Sugar Industry in Maharashtra

The sugar industry is one of the most water-polluting industries with the recently studied pollution concentrations for some factories in India with as high as 1,154 mg/L of BOD, 5,915 mg/L of COD, and 5,759 mg/L for SS. The industry has to incur a significant cost to reduce these very high influent concentrations of pollutants to the Minimum National Standards (MINAS) of 35 mg/L of BOD, 250 mg/L of COD, and 100 mg/L for SS in India (Murty et al. 2006).

A study was conducted on sugar industry in Maharashtra by Rao et al. (2011). They considered Kumbhi Kasari Sahakari Sakhar Karkhana at Kuditre for their study. It is situated about 12 km west of Kolhapur City, a hilly area with a semiarid climatic condition. The factory has approximately 100 acres of land area, and the consumption of raw material is 127.50 kg/Mt crushed in the year 2009. It was found that more water is used in the process than the sugarcane itself. Water consumption per product output is 4.02 L/kg of sugar produced. The bagasse which is the remaining part of sugarcane after juice extraction is used as fuel for boiler in this factory.

The factory has provided and managed a well-equipped effluent treatment plant for handling 1,500 MCu/day. The plant is based on extended aeration principle and gives the desired results for maintaining effluent parameters within the consented limits stipulated by Maharashtra Pollution Control Board. The treated effluent is utilized on land for irrigation of sugarcane fields. Wastewater is also generated in the sugar factory from processing and some amount of spent lees[2] from distillery. All these wastewater are treated in the ETP of sugar factory treatment process to achieve BOD reduction from 1,000 mg/L, that is, 92 % treatment efficiency.

There are two stages of biological treatment plants. The first stage comprises an aerobic lagoon equipped with surface aerator and the second stage involves a conventional complete mix activated sludge process. The aerated lagoon in first phase is expected to reduce BOD by 50 %, that is, from 1,000 to 500 mg/L. The second stage is activated sludge process which further provides 90 % reduction in BOD resulting into an effluent having 50 mg/L of BOD.

Measures for environmental protection initiated by the sugar factory modifications in effluent treatment plant are good indicators of the environmental management arising from the spent wash[3] as well as compost. This is the best outcome towards resource conservation. Thus, the study concludes that environmental audit plays an important role to have a check on pollution control.

9.3.4 Pulp and Paper Industries in Northern India

The Central Government of India has constituted National Ganga River Basin Authority (NGRBA) as a planning, financing, monitoring, and coordinating authority for strengthening the collective efforts of the Central and State Government for

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[2] The process wastewaters of a distillery consist of fermenter sludge, spent lees, and spent wash. Spent less is usually recycled.

[3] Distillery spent wash is the unwanted residual liquid waste generated during alcohol production and the pollution caused by it is one of the most critical environmental issue (Mohana et al. 2009). Indian spentwash contains very high amounts of potassium, calcium, chloride, sulfate, and BOD as compared to spentwash in other countries (Joshi 1999).

effective abatement of pollution and conservation of the river Ganga. One of the important functions of the NGRBA is to prepare and implement a Ganga River Basin: Environment Management Plan (GRB EMP). A Consortium of seven Indian Institute of Technology (IIT) has been given the responsibility of preparing Ganga River Basin Environment Management Plan in 2010. They have done an exhaustive study (GBP 2011a) in this respect; here we are presenting that.

Pulp and paper industries, particularly the agro based, are one of the major contributors to river pollutions in Ramganga and Kali, and hence the river Ganga. It is estimated that the total wastewater discharge directly or indirectly into the river Ramganga from Uttarakhand and Uttar Pradesh is ≈162 and ≈74 MLD, respectively. This discharge not only affects the water quality of the river Ramganga but also adversely impacts river Ganga downstream of the confluence of the two rivers. Similarly, in the catchments of river Kali, 73 major industrial units discharge ≈86 MLD of wastewater bringing in an estimated 13,000 t/day of BOD load into the river system. Out of the total wastewater discharge into the river Ramganga from Uttarakhand and Uttar Pradesh, the pulp and paper sector contributes about 146 MLD (90 %) and 39 MLD (53 %), respectively. It has also been estimated that out of the total wastewater discharge into the river Kali, contribution from 15 pulp and paper industries located in Uttar Pradesh is about 37 MLD (51 %).

The experience in specifying standard for effluent treatment has been highly unsatisfactory, and the National River Ganga continues to get polluted. The pulp and paper industries located in the clusters in Kashipur, Muzaffarnagar, Meerut, and Moradabad are manufacturing a variety of unbleached and bleached grade of paper and paper products using agro residues, waste paper, and imported pulp. The main varieties of paper produced are writing and printing paper, kraft paper, duplex board, and newsprint. The scale of operation varies from 25 to 250 TPD with the use of either single or multiple paper machines. The mills having pulp mill capacity above 100 TPD and producing bleached variety of paper have already installed chemical recovery plant for black liquor, while other mills making unbleached kraft paper from agro residues are operating without chemical recovery plant. All mills generally have effluent treatment facilities comprising of primary clarifier, aeration system, and secondary clarifier. The performance efficiency of existing effluent treatment plants (ETPs), however, is highly variable and is generally unsatisfactory.

The study (GBP 2011a) assesses the identified clusters of pulp and paper industries. It captures the inventory and status of pulp and paper mills, cleaner technology, and best practices options for overall improvement, water consumption benchmarks, and strategies for minimizing water consumption and feasibility of setting up common chemical recovery plant (CCRP) and common effluent treatment plant (CETP). A survey was conducted in the study region to assess the existing water consumption for different operations in various industries. The comparison of two options for treatment of pulp and paper effluents, namely, effluent treatment at each industry (ETP) and effluent treatment in a common effluent treatment plant (CETP) for a group of industries in vicinity, is conducted. The trade-off is between the cost and efficacy of effluent treatment in a number of small-size ETP within the premises of each industry and the economy of scale and better management of CETP for a group of industries.

From the comparison of the estimated cost of treatment in ETP and CETP, the study concludes that the advantage of economy of scale is not applicable for the four clusters of pulp and paper industries under study in the Ganga Basin. In addition, the great length of conveyance system needed due to the distant location of the industries would require substantial investment on conveyance system. In addition, the pumping cost, though much less in comparison to other costs, will increase the operation and maintenance burden on each of the industries. Further, the CETP option will discourage the industry to adopt recycling of treated water due to the additional cost of conveying treated water back to the industry. This would act as a deterrent to move towards the concept of zero discharge. Based on the aforementioned information and arguments, the study has inferred that the option of collecting effluents and treating in CETP is infeasible for the identified clusters in the Ganga Basin.

They have also calculated the feasibility of zero discharge paradigm for four different categories of pulp and paper industries. The financial implications of achieving zero liquid discharge have been worked out separately for the agro based and RCF based. For the agro-based program the cost of attaining zero discharge paradigm will involve (1) cost incurred in treating black liquor in CRP or CCRP as the case may be, (2) cost of producing industry grade water from effluent without control on TDS for pulp production, and (3) cost of producing industry grade water with TDS control of the balance effluent. RCF-based program is where a part or all of the effluent may have to be tertiary treated to produce industry grade water with TDS control. Thus, the cost of attaining zero discharge paradigm will involve cost of producing industry grade water with tertiary and partly with RO treatment of the total effluent (Table 9.37).

They found that to tertiary treat trade effluent, it will increase in average the production cost for B1 (RCF-based writing and printing paper, duplex board, newsprint) and B2 (RCF-based kraft paper) categories of industry by 4–6 %. This analysis shows that the cost of tertiary treatment of the trade effluent is not prohibitive and is technically feasible. Achieving zero liquid discharge by all categories of the pulp and paper industries thus implies only an increase in cost of the paper production by a few percent of the production cost for B1 and B2 category of industry and must be enforced to save the precious resources like river Ganga in general and Ganga system in particular. The implementation of this may result in slight reduction in profit margin or alternatively the cost will be passed on to the consumers. Thus it is strongly recommended that the "polluter pays principle" must be adhered to achieve zero discharge paradigm in case of the pulp and paper industries. This will immensely help saving the rivers, in particular the river Ganga, from adverse impacts without significant impact on the industry or economy or employment opportunities. On the other hand, an increase in average production cost for A1 (agro based) and A2 (agro based) categories of industry to attain zero discharge paradigm is in the range of 17–19 %. This is on the higher side. However,

Table 9.37 Typical characteristics of water and wastewater from four different categories of pulp and paper industries

		Effluent			
		A1: Agro based	A2: Agro based	B1: RCF based	B2: RCF based
Parameters	Raw water	Writing and printing paper mills	Kraft paper mills	Writing and printing paper, Duplex board, newsprint mills	Kraft paper mills
pH	7.5–7.8	7.0–7.8	6	6.8–7.3	6
TDS mg/L	290	1,100–6,800	1,560	800–1,720	840–3,240
TSS mg/L	Nil	384–1,950	466	160–4,387	56–680
COD, mg/L	Nil	776–5,048	1,010	262–1,715	704–2,016
BOD, mg/L	Nil	450–2,234	543	180–958	593–1,058
Color, RCO	Nil	800–1,200	–[a]	–	–
Turbidity, NTU	Nil	35–19	106	2–35	22–299
Hardness, mg/L as $CaCO_3$	180–185				

Source: GBP (2011a)
[a]Mills are using RCF only at present

the study suggests that for the nation's larger interest, a zero discharge paradigm must still be enforced to protect rivers like Ganga and the Ganga system.

9.3.5 A Case Study on Tannery in Uttar Pradesh

Tare et al. (2012) conducted a study on tannery effluents in Uttar Pradesh. The study attempted a comparative assessment of the cost and quality of treatment of tannery wastewater in India by two common effluent treatment plants (CETPs) constructed for two tannery clusters, at Jajmau and at Unnao in the state of Uttar Pradesh. The Jajmau plant is upflow anaerobic sludge blanket (UASB) process-based, while the Unnao plant is activated sludge process (ASP)-based.

In Jajmau, 310 tanneries operate with an average daily rawhide processing capacity of 320 t. Approximately 295 tanneries convey 7.75 million liters per day (MLD) of effluent to the UASB-based CETP at Jajmau that was designed to treat 9 MLD of tannery wastewater. Hence, a UASB plant with an original 36 MLD capacity of treating common effluent had to be designed for treating 9 MLD of tannery wastewater. Average daily rawhide processing in Unnao is 47.5 t from a cluster of 28 tanneries. The Unnao CETP, which is an ASP-based plant, receives 1.9 MLD of tannery wastewater against a design flow of 2.15 MLD. Preliminary treatment of wastewater for removal of grit and Cr(Chromium) is performed in the tannery itself in both cases.

The capital cost for the UASB-based plant in Jajmau (Kanpur) for treatment of 36 MLD common effluents containing 9 MLD of tannery effluent was Rs. 191.5 million or Rs. 21.3 million per MLD of tannery effluent treated. The capital costs for the ASP-based plant in Unnao for treatment of 2.15 MLD of tannery effluent were Rs. 19.3 million or Rs. 8.96 million per MLD of tannery effluent treated. The annual operation and maintenance costs for the Jajmau plant were Rs. 8.6 million or Rs. 0.98 million per MLD of tannery effluent treated/year. Similar costs for the Unnao plant were Rs. 4.8 million or Rs. 2.25 million per MLD of tannery effluent treated/year.

To compare the two CETPs of different sizes, the capital and O&M costs were normalized in the study. The results were in favor of the UASB plant at Jajmau, Kanpur because of the "efficiencies of scale" between two plants. The ASP-based Unnao CETP is of smaller capacity (2.15 MLD), while Jajmau plant is of larger capacity (36 MLD). This is despite the fact that cost calculations for UASB-based treatment assume income from power generation as per design of the plant although the actual power generation based on the field performance is much less. The UASB-based plant at Jajmau is constructed on an area of 12.5 ha. Hence, 1.4 ha of land is required per MLD of tannery effluent treated in this plant while the land requirement for the ASP-based plant at Unnao is 0.95 ha per MLD of tannery effluent treated.

The performance of the ASP-based CETP was close to the predicted performance. On the other hand, the performance of the UASB-based CETP was much poorer than the designed performance values. The researchers have tried to explain the reasons for this problem. They argued that the poor performance can be attributed partially to the presence of high levels of SO_4^{2-} (sulfate ion) in tannery wastewater. It was also noticed that despite the existence of Cr removal facilities in almost all tanneries discharging their effluents to the CETPs, high Cr concentrations, on the order of 55 mg/L, were observed in wastewater influent to both CETPs.

The cost of treatment of tannery effluent has been normalized in the primary sedimentation facility in the UASB-based CETP. Installation of such a facility, as argued by the authors, will ensure that only the sludge captured in the primary sedimentation tank is Cr-contaminated, while the UASB reactor sludge is free of Cr contamination. UASB treatment has resulted in partial reduction of BOD and COD of domestic wastewater, while TSS, sulfide, and Cr concentration have increased. However, the effluent quality after UASB treatment still does not satisfy Indian standards for discharge of treated domestic wastewater into natural bodies of water. Moreover, the sludge from the 36 MLD UASB-based CETP is contaminated with Cr and, hence, is hazardous. Disposal of such sludge is problematic. The study suggests that it is correct to classify the entire sludge generated by the UASB-based CETP as a byproduct of the tannery wastewater treatment process.

Treatment of tannery effluents in CETPs involves collection, conveyance, and treatment followed by final disposal of treated effluents and sludge to natural bodies of water or on land. It is expected that the construction and operation of CETPs will result in beneficial impacts on the environment as there will be an overall improvement in parameters determining environmental quality, as compared with the situation before the construction of CETPs. Installation of both CETPs has resulted in a reduction in organic loading to surrounding bodies of water. However, such CETPs also tend to convert distributed streams of pollutant loading into one large stream while also producing toxic sludge. In the case of the two CETPs studied, the Cr-contaminated sludge produced from both CETPs is being disposed off without proper care with the assumption that trivalent Cr is relatively nontoxic.[4] As far as treatment of tannery effluent is concerned, it is normally argued that anaerobic treatment options are more advantageous compared to aerobic wastewater treatment process in tropical and developing countries. However, the comparative assessment of CETPs from this study does not lead to a same conclusion.

Comparison in terms of total annualized cost, sludge production, and land requirements indicates that the normalized values of these parameters, that is, per MLD of tannery effluent treated, were higher in the case of the UASB-based process compared to the ASP-based process. The study concludes that UASB treatment may not be suitable for wastewater treatment in the area studied.

9.3.6 A Case Study on Tannery at Pammal in Tamil Nadu

The study was conducted on tanneries at Pammal in Chennai district, Tamil Nadu, by Vasudevan et al. (2012). The purpose of the study was to evaluate the performance of the CETP for tannery effluent in terms of BOD, COD, TSS, TDS, and by water tracer studies using rhodamine. The treatment plant treats tannery effluent from tannery industries located in and around Pallavaram municipality. The treatment system adopts the activated sludge process. Wastewater was collected from the equalization tank, primary clarifier, aeration tank, secondary clarifier and treated effluent and was characterized for pH, TDS, TSS, COD, BOD, chloride, sulfate, and chromium as per standard methods of wastewater analysis. The wastewater was collected at a regular time interval of 2 h for 48 h and was analyzed for the concentration of the tracer.

Physiochemical characteristics of the tannery effluent from the equalization tank of the CETP are as follows: pH of the wastewater ranged from 7.0 to 8.1., TDS from 500 to 2,000 mg/L, TSS was in the range of 1,000–2,000 mg/L, COD from 3,500 to 5,000 mg/L, BOD from 1,100 to 1,600 mg/L, chloride from 1,000 to 2,000 mg/L sulfate from 40 to 50 mg/L, and chromium from 0.01 to 0.02 mg/L. Raw effluent characteristics were above the CPCB tolerance limit for effluent discharge.

BOD of the wastewater in the various treatment units varied from a high of 1,400 mg/L to a low of 40 mg/L. There was a considerable reduction in the BOD during the treatment process. BOD removal during the study varied from 95 to 98 %

[4] However, there are reports indicating the possibility of trivalent Cr being oxidized to hexavalent Cr. 30 Hexavalent Cr is reported to be highly toxic and, hence, environmental impacts of sludge disposal should be properly assessed.

and the treatment system was able to achieve a maximum BOD removal of 98.5 %. BOD removal of 98.5 % can be attributed to the decomposition and mineralization of organic and inorganic compounds. BOD is the most important parameter in the treatment process design and effluent discharge or reuse. Higher BOD removal may be mainly due to the higher volumetric loading rate higher than 0.3–0.7 kg BOD/m^{3}day. Similar removal efficiency for BOD was reported by others for a CETP in the treatment of tannery effluent.

COD of the tannery effluent in the various unit of CETP also showed a reduction up to 200 mg/L. COD of the wastewater in the various treatment units varied from a high of 5,940 mg/L to a low of 200 mg/L. A maximum COD removal of 96.63 % was achieved during the study period. Similarly about 95 % COD removal was observed during the treatment of tannery effluent by using halophilic bacterial consortium. COD/BOD ratio of the treated effluent was about 3.5 which shows a substantial portion of the organic matter is nonbiodegradable. This nonbiodegradable organics may due to the high dye content in the tannery effluent which can be removed by using UV-ozonation.

TSS of the tannery effluent in the various unit of CETP also showed a reduction ranging from 2,000 to 60 mg/L. A maximum removal efficiency of 96.58 % was observed during the study. TDS of the tannery effluent in the various units of CETP did not show that much reduction compared to the other parameters. TDS of the wastewater in the various treatment units varied from 8,200 to 5,100 mg/L. A removal efficiency of only 8.6 % was observed. The plant is originally designed to treat water with TDS of little above 2,100 mg/L, whereas the TDS level of the wastewater at present is 5,000–7,000 mg/L which is mainly due to the use of the salts in the tanneries. Generally TDS cannot be reduced in the biological wastewater treatment system. The norms for the discharge of trade effluent as prescribed by Tamil Nadu Pollution Control Board (TNPCB) are 2,100 mg/L. Hence, it is suggested that to reduce the TDS level to 2,100 mg/L (TNPCB standard), a reverse osmosis process is used. The parameters like BOD, COD, and TSS in the treated effluent were found to be higher than those prescribed by the TNPCB for most of the time during the study period. The BOD and TSS removal efficiency have increased due to the addition of lime, alum, and polyelectrolyte in the primary clariflocculator.

Suitable remedial measures can be adopted to improve the performance of the treatment plant. All individual units in the CETP were checked for their efficiency in the design for treating the wastewater, and no flaws were found and hence the performance of the CETP based on the design is found to be satisfactory. However, the effluent flow into the equalization tank and the primary clarifier should be admitted equally in order to get an even distribution of suspended solids. Based on the study regarding the performance of the CETP, the following conclusions and recommendations were made. The volumetric loading was found to be in the range of 0.46–0.65 kg BOD/m^{3}day. The normal range is from 0.30 to 0.7 kg BOD/m^{3}day. The loading rates have been considerably increased due to the presence of the more fleshing organic matters in the tannery effluent, which has resulted in lower BOD removal efficiencies in this study. The removal efficiency can be increased by increasing the concentration of microorganisms and maintaining the food to micro organism (F/M) ratio at 0.18 and maintaining higher mean cell residence time.

The study by Vasudevan et al. (2012) revealed that the wastewater treatment of tannery can be improved by optimizing some major wastewater treatment plant operating parameters like volumetric loading rate, F/M ratio, and MLVSS (mixed liquor volatile suspended solids). For improving the TDS removal, it is recommended by them to go for reverse osmosis since TDS cannot be removed by biological treatment system.

9.3.7 A Case Study on Tannery in North Arcot District, Tamil Nadu

Sankar (2000) made a thorough study of the economies of CETPs using data on the basis of a field study from five CETPs which were in operation in the tannery clusters of Ranipet and Vaniyambadi in North Arcot district of Tamil Nadu.

The size of the CETP in terms of number of members varies from 10 to 110, and in terms of volume of effluent, from 200 to 4,000 m^3 or kilo liters per day (KLD). The length of the sewerage varies from 1.5 to 8.00 km. All CETPs comply with the standards for pH, sulfide, and total chromium. The CETP at SIDCO phase 1 violates the standards for four parameters, BOD, COD, SS, and TDS while that at Melvisharam violates the standards for SS and TDS. For all five CETPs, the TDS values at the outlets are far above the norm of 2,100 mg/L.

The study has attempted to estimate the tentative cost of TDS removal by two methods available – membrane separation–reverse osmosis (RO) process and high rate transpiration system (HRTS). The total cost per KLD effluent treated varies from Rs. 4.27 to 22.45 for RO plants. The study has also compared the RO options with RTS options which show that RTS is a lower cost option. However, there are several problems in adopting RTS options such as availability of land near the plants and also uncertainties regarding the impact of using the wastewater on soil quality and product from the trees. Therefore, the study suggests that although the RO process is costlier, it enables recovery of 80 % of the used water and social benefit of recovering and reusing the water is high.

Sankar (2000) has also estimated the pollution abatement cost per KLD of effluent treated. He found that with the RO options, the abatement cost varies from Rs. 20.76 for the largest CETP to Rs. 6,618 for the smallest CETP. On the other hand, with the RTS options the corresponding variation is from Rs. 18.02 to Rs. 45.26. He has also computed the economic costs of pollution abatement per kg of hides and skins processed and computed as a percent of sales and shows that it is less than 1 %. The conversion cost of 1 kg of raw hides and skins to the finished leather is in the range of Rs. 28–35. Thus, the study found that the abatement cost as percentage of the conversion cost ranges from less than 1 to about 3 %. Finally the study concludes that for plants with design capacity of less than 400 KLD, CETP is a cost-effective option for full compliance with the standards. Given the domestic regulatory pressures and external pressures, it suggested that the tanners must use CETP as an institutional mechanism for solving the environmental problems caused by them.

From the case studies, we find that different industries have adopted different measures depending on capacity. The findings from West Bengal studies reveal that measures to control water pollutants by setting up ETP in five industries have been successful. While the experiences from leather industry in North and South India show similar results, they have used CETP to control water pollution. On the other hand, a typical cluster of pulp and paper industry in northern India observes the feasibility of the ETP compared to the CETP.

9.3.8 Experiences from Common Effluent Treatment Plants in India

After independence, the industrial sector in India has expanded dramatically, including the major water-polluting industries such as the petrochemical, pharmaceutical, pesticide, paint, dye, petroleum, fertilizer, asbestos, caustic soda, inorganic chemicals, and general engineering industries. Small-scale industries (SSIs) have also played an important role in overall industrial development in India, and the growth of SSI units has been promoted by the government to achieve an economically sustainable development, even though small industries are often highly polluting.

The industrial control regime in India is based on the standards and regulation approach. Source-specific concentration-based standards have been laid down for polluting units, and the penalties for noncompliance with the standards are fine, imprisonment of officials responsible for noncompliance, disconnection of electricity/water supply, and closure of the units. The standards are the same for large and medium units as well as for small units. While most of the large and medium polluting units have been able to erect and operate effluent treatment plants (ETPs), this option does not appear to be viable for many small units because of their small size and technical, financial, and managerial constraints.

It is difficult for each industrial unit to provide and operate an individual wastewater treatment plant because of the scale of operations or lack of space or/and technical manpower. The volume of pollutants emitted by SSIs clusters may be more than an equivalent to a large-scale industry because of the inefficient production technologies adopted by SSIs. To deal with the effluent in these SSIs, the concept of common effluent treatment plan (CETP) was introduced with a hope that not only it would help the industries in pollution abatement but also as a step towards a cleaner environment (CPCB 2005). Common effluent treatment plants are being suggested as a cost-effective option for compliance with the standards for small and medium polluting units in industrial clusters. This would require improvements of infrastructural facilities (e.g., pipeline for connection and delivery of the effluent) (CPCB 2005).

Accordingly, the Ministry of Environment and Forests (MoEF) initiated and promoted the CETP scheme for treatment of effluents generated from SSI units located in clusters through liberal financial assistance. The CETP scheme was instituted initially for a period of 10 years with effect from the year 1991, but the MoEF has decided to continue financial assistance under the scheme beyond this period. Most of the 88 CETPs constructed and commissioned so far were financed under the CETP scheme of the Government of India.

Of the 88 CETPs that have been constructed and commissioned so far in the country, the Central Pollution Control Board has studied the performance of 78 CETPs operating throughout the country. It is observed that only 20 of the 78 CETP studied (i.e., 25.6 %) complied with the prescribed limits for general parameters pH, BOD, COD, and TSS even as 15 of these were not able to comply with the prescribed limit for TDS. Thus, only 5 (i.e., 6.4 %) CETPs were complying under all general parameters including TDS.

The experiences of the functioning of CETPs have raised a number of industry-specific problems across various effluents. Some of them as indicated by the CPCB study can be briefly reported.

The efficacy of CETP based on activated sludge process employed for treatment of tannery effluent was analyzed for the efficiency to reduce chromium and other contaminants. It is expected that the construction and operation of CETP will result in beneficial impacts on the environment. CETP uses activated sludge process where a flocculent mixture of an aerobic population of microorganism and waste-water are aerated. For the safe discharge of wastewater into water bodies after treatment, concentration of Cr has to be brought down below the permissible levels. Tanneries may use a combination of chemical and microbial processes to produce ecolabeled leather/leather products (CPCB 2005).

High TDS in treated effluent is observed to be a widespread problem. The CPCB study found that 69 out of the 78 CETPs did not comply with TDS standards. TDS concentration of the wastewaters is mainly due to the inorganic ions in the water supply and those added during the use of water in industries such as tanneries, pharmaceutical units, chemical manufacturing units, and dye and dye intermediates units. In all such cases, the best approach for reduction of TDS is to try reduction at the source by adopting a cleaner technology for minimizing net input of chemicals in addition to practicing recovery and recycling of chemicals.

High TDS in the raw influent reaching CETPs and, as a result, in treated effluent of CETPs is a major cause of concern, more so because it is generally caused by high salinity which requires costly treatments such as reverse osmosis (RO) and nanofiltration systems followed by multistage evaporator systems (MSES). Area-specific thoughtful approach is required to tackle this problem. First attempt should be reduction in release of TDS contributing chemicals from problem industries by adopting cleaner production technologies and recovery and recycling of chemicals from the waste streams. Second option should be treatment of waste stream for TDS at the level of individual industry. Treatment of TDS at the CETP should be the last option unless some special conditions demand so. State Pollution Control Boards should investigate all the TDS-related problem areas and compel the industries/ CETPs for its solution. The State Pollution Control Boards may consider prescribing location-specific regulations for the control of TDS at the industry level (CPCB 2005).

It is observed from the unit-wise performance data of various CETPs that poor performance of primary- and secondary-settling units is an important factor responsible for overall poor performance of CETPs. The efficiency of treatment by the physicochemical process is decided by the TSS concentration in the effluent of primary settling unit. Treatment schemes of almost all the CETPs employ primary settling as one treatment unit and a secondary biological treatment in most of the schemes. Sublevel performance of primary and secondary settling units has been observed in a large number of CETPs.

In most cases, the CPCB study found that these settling units are not complying with the prescribed standards (an effluent having <50 mg/L TSS). The study noted that there is scope for improvement of the performance of CETPs by paying attention to the performance of settling units. Things which require investigations include optimizing the chemical doses, proper flocculation, proper sludge withdrawal frequency and duration, avoiding short-circuiting in the tank, assessing surface overflows, solids loading, and weir loading, and adjusting optimum recirculation rate in secondary settling tank.

In two CETPs in Andhra Pradesh, the dissolved air floatation (DAF) units were not able to give any significant reduction in organic matter or suspended solids. Replacing the DAF unit with a primary settling unit in Pattancheru CETP may be considered for improving efficiency of primary treatment and reducing operational costs. An effective primary physicochemical treatment is also expected to improve overall COD removal efficiency as high COD and TDS in treated effluent is a major problem in these two CETPs of Andhra Pradesh. Most of the CETPs in textile units of Tirupur and Karur have employed a treatment scheme with physicochemical treatment followed by sand filtration and stabilization tank. Only a few have adopted treatment scheme with additional biological secondary treatment. CETPs of the former type require special efforts in optimizing chemical dozing for their greater dependency on physicochemical treatment.

Dual media filter (DMF) unit, which has been employed in treatment schemes of CETPs in Delhi, and at few other places and sand filter unit, which has been employed in CETPs of textile units in Tamil Nadu, are normally used to improve suspended solids level from near 50 mg/L in primary settling unit's effluent to near 10 mg/L. Incidentally, it also reduces the organic matter associated with the suspended matter being removed. It may also remove a small fraction of organic matter associated with colloidal matter that is coagulated and filtered during filtration. However, filter units should not be depended upon to perform more than the expected function as explained because if a DMF or a rapid sand filter unit is over loaded, it will require frequent backwashing.

Activated carbon filter (ACF) unit, which has been employed in treatment schemes of CETPs in Delhi and at few other places, is only meant for removing trace organics, such as pesticides, phenols, and heavy metals, which escape the primary treatment and therefore should not be loaded with bulk organic matter. However, ACF as a terminal treatment unit can be said to be a misfit because very frequent replacement or regeneration of the bed is neither easy nor economically affordable.

Treatment schemes of Odhav CETP (Gujrat), Nandesari CETP (Gujrat), Sarigam CETP (Gujrat), Dhareshwar CETP (Gujrat), and Sachin-II CETP (Gujrat) have three-stage treatment and that of Tarapur CETP (Maharashtra) has four-stage treatment, but these plants were still not meeting standards. This reflects gross neglects in operation. If biological treatment units are properly operated and full attention is paid to the proper settling at different stages of treatment as explained above, performance of these plants could be greatly improved.

The concept of CETP was adopted as a way to achieve end-of-pipe treatment of combined wastewater at a lower unit cost than that could be achieved by individual industries. It is also used to facilitate discharge, monitoring, and enforcement by environmental regulatory agencies. Thus, the investment of substantial government finances in the CETP scheme was justified on the basis of potential benefits in terms of pollution reduction and environmental improvements. However, it has not been successful because of the heterogeneous nature of the effluent from different industries. It has only compounded the toxic content to larger volumes. Moreover, with the changing nature of effluent, many toxic substances like organochlorines, polychlorinated biphenyls (PCBs), and heavy metals have found their way into the waste stream. The various standards formulated for inlet and outlet effluent have not mentioned these toxic chemicals and other volatile fugitives. The management of persistent organic pollutants (POPs) and inorganic residues in fluid form goes beyond the capacity of primary and secondary treatment in CETPs. Reverse osmosis, granulated activated carbon, ultrafiltration, ion exchange, and other tertiary treatment methods which could be effective in this case are not used by CETPs mainly for economic reasons. This concept has also faced many operational and institutional problems as many participating industries started withdrawing from the scheme. With the growing pace of industrialization in India, these CETPs are not always able to meet the need of the industrial clusters. This has resulted in bypassing the treatment and directly discharging the untreated effluent in water bodies.

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Chapter 10
Summary and Conclusion

Almost all the countries of the world are concerned with the environmental problems, and environmental considerations are becoming a part of the overall development policy of every nation. The rapid growth of population, urbanization, and industrialization are aggravating the problem by putting more pressure on water resources.

The water resources of India considering both ground- and surface water as one system is about 1,869 km^3 (Table 1.1 in Chap. 1). However, due to topology and uneven distribution of water resources over space and time, only about 1,123 km^3 of the total potential of 1,869 km^3 is actually available for use (Table 1.1). Availability of water is a paramount issue in India with demand for water exceeding supply by as much as 30 % (CWC 2010). Agriculture, industry, and domestic uses are competing for the limited supply. The agricultural sectors, which contribute 26 % (approximately) to the national GDP, continue to dominate water use with 70 % of total water consumption (Table 1.2 in Chap. 1). Industrial production has increased in India because of the opening up of the economy since 1991 which contributes approximately 24 % to GDP, and the demand on water resources from the industrial sector has increased to 13.90 % of total water consumption (Table 1.2). This is followed by the remaining household sector which claims 15.40 % of water resources (Table 1.2). Apart from the pressure from the growing economy, available water resources are being overexploited by the rapid growth of population. This has reduced the per capita availability of water resources in the country.

One of the biggest challenges that the country faces today is to resolve massive environmental problems, which include industrial pollution, that is, pollution of air, water, and soil due to industrial production; vehicular emissions; and hospital waste and domestic sewage disposal, which needs immediate attention and calls for appropriate measures.

An economy consists of a large number of industries. These industries do not exist in isolation from each other, rather are interrelated. The interdependence arises from the fact that the output of a sector is generally required as input by another sector. Though some sectors do not produce pollution directly, they produce rather indirectly in a very significant way depending on the degree of

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interdependence among sectors of the economy. There have been several studies, but a quantitative analysis involving interdependence between water pollution and economic activities is only few. The purpose of this study is to contribute to this area. With detailed and recent data, an in-depth quantitative study linking the economy and water pollution by different sectors of the Indian economy has been done. This study spreads along ten chapters including summary and conclusion.

Chapter 1 provides a discussion on the link between environment and development and deals with the problem of water pollution and development. An accounting of water resources with consumption and availability has also been offered for India. It is observed from this discussion that it is very difficult to prepare an accurate national picture of India's water resources because accurate field data are almost nonexistent. Till now we have no arrangements in India to compile and publish on an annual basis comprehensive data regarding various aspects of water which are important for policy analysis and program formulation. Attention should be given in this direction. Finally, a brief review of literatures primarily focusing on water pollution and its effect and on quality indices and wastewater treatment is presented and identifies the gap in the literature for India.

Chapter 2 reviews the status of water pollution in India and other Asian countries. Due to trade liberalization, especially after the 1990s, all emerging Asian countries are affected to some extent with environmental pollution. Wastewater generation primarily depends on the treatment strategies, and some countries have already taken reasonable measures to wipe out the problem while others not.

Chapter 3 formulates a pollution model based on the input–output approach to link the generation of water pollution with rest of the economy. Further, a modified model including a clean water sector has also been developed to explore the impact on the economy.

Chapter 4 deals with the data used in this work. The major data required for the work are the input–output table of India; the different types of water pollutants generated by the different industries of India; and the abatement cost for various water-polluting industries. The study has used the input–output table of India for the year 2006–2007 recently prepared by the CSO (2011). The input–output table of 2006–2007 consists of 130*130 sectors. For our study, the table has been aggregated to 38 sectors.

From the publications of the Central Pollution Control Board and various other water pollution information sources, ten types of water pollution parameters which are being discharged by the different industries of the Indian economy are identified. These are suspended solids (SS); dissolved solids (DS); chloride; sulfide; zinc; phenol oil and grease; biochemical oxygen demand (BOD); chemical oxygen demand (COD); and other pollutants such as nitrogen, chromium, cyanide, alkalinity. Detailed analysis of cost data concerning pollution abatement activities by different industries of the Indian economy has also been presented. A large number of industries do not conduct systematic effluent treatment, but we were able to collect the pollution data for 31 sectors. Secondly, we have estimated the abatement cost for the treatment of water pollution for each individual sector. However, the cost data could only be collected for 16 sectors. The issue with data limitation is also discussed in the chapter.

In the process of conducting all the experiments with the methodologies mentioned in Chap. 3, certain problems relating to the inadequacy of data were faced, which made us suggest the following recommendations. Firstly, the lack of appropriate and required data on different types of water pollutants generated by different industries of the Indian economy points towards the need for a detailed, adequate, and recent up-to-date data on water pollutants. For example, data on water pollution generated by the different types of chemical industries were not available in the required form despite of this sector having extensive linkages with other sectors in the economy. Availability of detailed data on this sector would have given a better result as indirect pollution will be generated by other sectors of the economy. Secondly, since most of the industries until now have no systematic approach towards effluent treatment, they are unable to provide any practical data on the pollution abatement costs. As a result, detailed breakup of the total cost of pollution abatement activity has been possible to analyze for only 16 industries. Experiments in this study, showing the effect of pollution control cost on output and prices of different goods and services, have been attempted based on the available set of data, but for a more effective and socially useful results, the study calls for a detailed, complete, and recent dataset on cost of abatement of all the industries of the economy. These are some of the areas which institutions like the CPCB and state pollution control boards should keep in mind and take steps towards collecting the data for socially applicable experiments. Universities and research institutes should be entrusted to make some detailed micro-survey on these issues to provide a detailed data.

Chapter 5 reports the results based on the model calibrated in Chap. 3. It focuses mainly on the sectoral pollution coefficient across each parameter identified for the study. Analysis of direct and indirect coefficient of each pollutant has also been discussed. The direct water pollution coefficients count the direct effect of pollution generation within a sector, and the total (direct plus indirect) includes the indirect effect of pollution generation among other related sectors.

The results show that the amount of total pollution generation per unit of the product (Appendix 5.A.2) is significantly higher for all industries compared to the direct pollution generation coefficient (Appendix 5.A.1). For example, direct pollution generation coefficient of leather industries is found to be 0.0001749, 0.0002525, 0.0002542, 0000526, and 0.0002102 for SS, DS, chloride, BOD, and COD, respectively, per lakh rupees of output, whereas the total pollution coefficient of this industry is 0.0005678, 0.0003623, 0.0003184, 0.0002287, and 0.0009229 for SS, DS, chloride, BOD, and COD, respectively, which is much higher compared to direct coefficients. Thus, one cannot simply look at the size of the direct water pollution coefficients but must also consider the size of the total coefficients (direct plus indirect) for better insight.

A significant number of industries (livestock, chemical industries, beverages, leather, cotton textiles, miscellaneous textile, paper, and milk and milk Products) in India are producing water pollution above MINAS by several times. We have seen in Chap. 4 that a number of industries are able to control their water pollution emission. The pollution abatement activities involve costs, which, in turn, will affect the price and output of the different industries. To analyze the effect of these costs, a clean water sector was added to the economy.

The chapter further computes the new set of output and prices due to the implementation of the clean water sector into the economy and identifies the most effected sector. The analysis shows that the demand for the output of all the different sectors has changed and the price of all the sectors has increased. We find that chemical, mining, and electricity are key sectors which have extensive linkages in the demand for clean water. It is evident from the study that the inorganic chemicals sector experiences the highest percentage increase in output (12.63 %), followed by organic chemicals (5.93 %); electricity, gas, and water (5.47 %); and mining and quarrying (3.16 %). Any shift in cost has an effect on prices.

The direct cost of clean water production is not the whole story. Since many industries are affected by the cost of purchased intermediate goods and services, prices have also risen unevenly across the economy. The pattern of final consumption has also been affected. This study shows that the percentage price increase is high for electricity, gas, and water supply(9 %), construction(6.54 %), agriculture (5.96 %), fertilizer, oil and vanaspati, sugar, petro coal tar products, organic heavy chemicals, pesticides, inorganic heavy chemicals, cotton textile, livestock, etc. Final consumers, that is, the households, ultimately bear the burden of pollution generation, either through a price increase – due to the production of clean water or tax imposed by the government on producers – or through a health treatment cost when pollution is not treated. For the household, the relationship between the real cost and real benefits remains nevertheless the same. Having paid for clean water production or tax imposed by the government indirectly, household will spend less on health treatment cost directly.

The chapter also identifies the total amount of different types of pollution in the total final demand and its different components for the industries. The total coefficients as derived in this chapter provide policy makers with one way of assuming the impact of alternative environmental management strategies on pollution generation.

Chapter 6 offers detailed information regarding water pollution content in trade. It starts with the discussion on two controversial hypotheses in the trade and environment literature, known as pollution haven and factor endowment. It investigates the two hypotheses using water pollution parameters for India for the year 2006–2007. Research on India in this area is very thin. In light of this, the chapter highlights the trend and pattern of trade in India for the last 10 years and more (1998–2011). The result in relation to pollution haven and factor endowment has been analyzed in detail. India is exporting more water pollution-intensive goods while importing less. Therefore, India is a pollution haven, particularly for a number of water pollution parameters (dissolved solids, chloride, sulfide, BOD, and COD for the year 2006–2007). On the other hand, the result based on Leontief and Leamer approaches for the factor endowment hypothesis reveals that India is exporting labor-intensive goods and importing capital-intensive goods. The chapter attempts to explain these results with regard to the composition of exports and imports. Thus, the findings of water pollution content in India's trade with the ROW have thrown further insight on trade and environment debate.

Chapter 7 primarily deals with the simulation exercises on some pollution abatement policies. The water-polluting firms in Indian industry are supposed to meet the standards set for pollutants by the Central Pollution Control Board. A sample of water-polluting industries in India shows that some firms have effluent treatment plants and a few firms are also using process changes in production and input choices to achieve effluent standards. However, unfortunately, most of them are not complying with the standard. The laxity of formal environmental regulations by the government and the use of command and control instruments could be regarded as factors responsible for large variations in complying with the pollution standards by firms (Murty and Kumar 2011).

In this chapter, we suggested two pollution abatement policies and evaluated the impact of these policies on output and prices. Two scenarios are developed. In Chap. 4, we have calculated the abatement cost for 16 key industries in the economy. If the existing industries having CETP or ETP could maintain the standards, then the total abatement cost will increase. This additional cost to achieve the standards can be treated as pollution tax. These pollution tax rates will be different for different industries. For this study we could estimate abatement cost only for 16 industries (milk and milk products; livestock; mining; sugar; tea, coffee, and beverages; food products; cotton textile; jute, hemp, mesta textiles; miscellaneous textiles; paper and paper products; paints, varnishes, and lacquers; leather and leather products; rubber and rubber products; inorganic chemicals; organic chemicals; and other chemicals). This additional cost borne by the 16 industries will have an impact on the whole economy. In the second scenario, a pollution tax based on the total pollution tax for 16 industries, which is 0.76 % of gross value added for India for the year 2006–2007, is imposed on all the sectors. Although the tax rate was the same, the volume of tax was different across sectors because of the differences in value added. We have focused on the impact of these two abatement policies on outputs and prices in the Indian economy (Tables 7.1,7.2,7.3 and 7.4). We received a similar pattern of changes in both outputs and prices for both policies in some sectors, namely, inorganic and organic chemicals, electricity, mining, sugar, and cotton textile.

We have also calculated the future load of water pollution in the context of India's growth strategy which will be useful to the policy makers and academic community. Here we have attempted three scenarios to estimate the gross output including clean water in the year 2016–2017. It is expected that the total output of the economy will increase as with the economic growth, but the sectoral growth rates would likely to vary. We are expecting the sectoral output changes not only due to the increase in growth rate of the economy but also due to the implementation of clean water activities in the economy. Three different growth rates have been applied to calculate the future impact on the Indian economy at the end of current 12th Five-Year Plan. Firstly, we considered business as usual growth, if the economy follows the current trend; secondly a promising high level growth has taken into account following the announcement by the Planning Commission of

India at the end of the 11th Five-Year Plan; and thirdly we followed a reasonable growth path as suggested by the RBI and other expert forecaster in India (details in Chap. 7). We have noticed that the sectoral impacts differ according to scenarios. Analysis across the scenarios reveals that water pollution-generating sectors will grow rapidly, though the abatement activities will continue to increase the output of clean water sector. In this context, we have also computed the total volume of pollution across the ten identified water pollutants. The volume of pollution is reasonable in third scenario compared to other two scenarios.

It is observed from the study that the whole economy will be impacted due to pollution control. The government can use a variety of regulatory and economic instruments to reduce water pollution. Some contributions have been made in the form of policy suggestion in this study from which it is evident that the price system would also differ if instead of voluntary action or obeying a special law, each industry undertakes to eliminate pollution at its expense and pays off an appropriate proposed tax for pollution generation. From the study, it is apparent that the price of the product will be more costly if sectors are taxed than that provided by the pollution control schemes currently undertaken. Pollution control schemes should be imposed on all the sectors producing water pollution, and penal measures must be taken on the industries not implementing them. The size of penal measures in the form of tax on a sector should be proportional to the amount of pollution generated by that industry above MINAS.

Conventional national accounts focus on market transaction and use as indicators that reflect important factors in welfare generation, but they do not measure welfare itself. However, new scarcities of natural resources now threaten the sustained productivity of the economy while production and consumption activities may impair environmental quality by overloading natural sinks with wastes and pollutants. By not accounting for the private and social costs of the use of natural resources (water resources) and the degradation of the environment due to water pollution, conventional accounts may send wrong signals of progress to decision makers who may then set society on a non-sustainable development path. Such adjustments will give a more realistic indication of wealth creation and consumption of goods and services. Thus, environmentally adjusted domestic product (EDP) must be done along with NDP annually.

Chapter 8 measures the EDP as well as welfare loss for India due to water pollution. The current exercise has compiled part of the SEEA framework. Three categories of adjustments to the national accounts have been proposed to reflect the cost and benefits of human activity on the environment. These are (a) depletion of natural capital, (b) environmental degradation, and (c) defensive expenditure. A significant number of industries in India are producing water pollution above the environmental standard by several times. These industries are discharging wastewaters on to land and water in an alarming proportion, degrading land and water resources. This degradation is hazardous to the health, fertility of land, aquatic life, etc. We have considered health hazards, damages to crops, and defensive expenditure to arrive at green GDP estimate in India for the year 2006–2007. The defensive expenditure in this study is the cost of wastewater treatment, while damages to crops are the loss of agricultural output due to soil erosion and land degradation (replacement of soil nutrient cost and sedimentation cost). Health data used to estimate the health impacts of inadequate water supply, sanitation, and hygiene have been taken from two different sources (Parikh 2004; World Bank 2012).

We have applied two different estimates to calculate the environmentally adjusted national income accounting. Case 1 is based on the estimates accounted in Gundimeda et al. (2005, 2007) and Parikh (2004), while Case 2 is based on World Bank study (2012). In addition, we also estimated the defensive expenditure in this study. These two estimates differ in terms of (1) loss due to soil erosion, (2) sedimentation as well as soil salinity, and (3) health cost.

The loss in terms of NDP is 3.56 % and 3.91 %, respectively, for Cases 1 and 2 as discussed in Chap. 7(Tables 8.2 and 8.3). With the implementation of pollution control policies, the loss in NDP is 3.53 % (Table 8.4) and 3.83 % (Table 8.5), which are marginally less than the regular EDP estimates. The loss in terms of NDP is further reduced when a flat pollution tax rate of 0.76 % is imposed in the economy. It will be 3.50 % according to Case 1(Table 8.6) and 3.79 % for Case 2 (Table 8.7), which is further lower compared to actual GDP loss quoted as 3.56 % and 3.91 %, respectively (Tables 8.2 and 8.3). It should be noted that where environmental costs are growing faster than GDP, EDP growth rates will be below that of GDP. Therefore, data on depletion, degradation, and defensive expenditure should be available annually to allow work in this direction along with GDP or NDP calculation. Based on our study considering only "water resources," we have seen that in India (2006–2007), NDP loss is in the range of 3.50–3.91 %. If other natural resources are accounted for, then the situation is expected to be worse. Hence, there is a need for further research in this field.

Chapter 9 reviews a number of case studies across the different states in India. It includes textile, pharmaceutical, and paint industry from West Bengal; textile and dye industry in Rajasthan and Tamil Nadu; sugar industry in Maharashtra; pulp and paper industry in Northern India; and tannery industry in Uttar Pradesh and Tamil Nadu. From these case studies, we find that different industries have adopted different measures depending on their capacity. There is a controversy regarding the construction of CETP or ETP plant in India, and these case studies provide further insight in this regard. The findings from the West Bengal studies reveal that measures to control water pollutants by setting up environmental treatment plant (ETP) in five industries have been successful. While the experiences from leather industry in North and South India show similar results, they have used CETP to control water pollution. On the other hand, a typical cluster of pulp and paper industry in Northern India shows the feasibility of ETP compared to that of CETP.

In general, the performance of CETPs has been found to be very unsatisfactory largely because of poor operation and maintenance. Therefore, the State Pollution Control Boards should conduct regular and automatic monitoring of CETPs to ensure proper operation and maintenance, failing which they should initiate action against negligent agencies and willful defaulters (CPCB 2005). Achieving standards for treated effluent quality from CETPs are dependent on meeting the designed criteria of inlet quality to CETPs that inter alia depends on effluent quality from each industry (CPCB 2005). In addition, all CETPs and ETPs should adopt the following measures: (a) to employ qualified and well-trained staff for operation and maintenance; (b) to interlock manufacturing processes with ETP operation; (c) to set up separate energy meters if not done; (d) to convert open anaerobic lagoons to closed systems with gas recovery; and (e) to implement the guideline developed by the CPCB for health and safety of worker in the industry.

In spite of data constraints and limitations as discussed in Chap. 4, the study provides several interesting findings which should be taken into consideration by academicians and policy makers. An important finding as discussed in Chap. 5 indicates that policy makers should note that the total pollution coefficients (direct and indirect) should be considered as an alternative environmental management strategies and not just direct pollution coefficient. Water pollution abatement activities will have a significant impact on the Indian economy, leading to the expansion of output and increasing prices. While the increase in output is beneficial to the economy, consumers will be affected severely due to the price increase. Moreover, the industries will likely lose their competitive advantage due to the price rise of the outputs from both buyers and sellers end.

The pollution content in the foreign trade of India also reveals significant result. The present researcher and others have already done some work in the area of trade and environment focusing on air pollution not water pollution (Mukhopadhyay and Chakraborty 2006). For an emerging economy like India, trade sector plays an important role in generating GDP and employment. The current attempt signifies that as our economy is more export oriented after 1991 policy reforms, the results from Chap. 6 are of serious concern to us. Since exporting industries such as cotton textiles are water pollution intensive, an emphasis on export growth will likely to create more water pollution as evident from Chap. 7.

Another important finding from the estimates of EDP due to water pollution shows a significant reduction in NDP due to the degradation of water resources (Chap. 8). This study strongly suggests that if other natural resources could be accounted, then NDP reduction would be greater.

10.1 Water Pollution Abatement Policy Options

10.1.1 Recent Initiatives by MOEF

The CAG report (2011) on Performance Audit of Water Pollution in India examines the broad framework of policy, programs, institutions, and initiatives taken by MoEF to address water pollution in India. They assess the risks to health and environment and sustainability of measures to address water pollution in India. On the basis of the findings, the report made several important conclusions which are worth noting.

(a) Adequate assessment has not been made on the risks of polluted water to the health of living organisms and the impact on environment; (b) adequate policies, legislations, and programs have not been set up and effective institutions have not been put into place for pollution prevention, treatment, and restoration of polluted water in rivers, lakes, and groundwater and monitored efficiently and effectively; (c) adequate mechanisms have not been put in place by the government to sustain measures to tackle water pollution; (d) programs for the control of pollution have not succeeded in reducing pollution levels in groundwater and surface water and restoring water quality; and (e) funds were not utilized in an efficient manner to further the aim of reduction of water pollution (CAG 2011).

On the basis of the assessment, recently they made several recommendations, some of which can be briefly summarized as follows:

1. MoEF/states, in the policy on water pollution, need to consider prevention and control of water pollution as well as ecological restoration of degraded water bodies.
2. MoEF/CPCB in conjunction with Ministry of Water Resources and all the states should initiate steps to draw up a comprehensive inventory of all rivers, lakes, and groundwater sources in the country. It should also undertake a survey to list all the important species associated with each river and lake in India. This information should be available to the public.
3. To prepare planning for reduction of pollution of all rivers and lakes in the country, MoEF should take into account the basin approach.
4. It is also recommended that MoEF needs to establish enforceable water quality standards for lakes, rivers, and groundwater that would help protect human and ecosystem health. Penalties should be levied for violations of water quality standards. Further, MoEF, along with Ministry of Agriculture, should develop standards for pollutants like nitrogen, phosphorus, etc., which arise from agricultural practices because the use of pesticides and fertilizers from agricultural sources is one of the biggest nonpoint source of pollution.
5. There is a need to strictly enforce the provisions of the acts and review the existing levels of penalty in various acts relating to control and prevention of water pollution.
6. Legislations should be introduced by MoEF/states to specifically prevent water pollution which takes into account pollution from both point and nonpoint sources.
7. The Water Quality Assessment Authority at the central level and the Water Quality Review Committee in the states should be revitalized and strengthened so that it can act as a cross-sectoral nodal body for water pollution issues.
8. The role of civil society should be emphasized. States should involve citizens in proposing and monitoring programs to control pollution. Citizens monitoring committee and local level monitoring committees need to be constituted for more effective implementation.

In response to these recommendations, MoEF in May 2011 constituted a committee to consider the recommendations/observations made in the report and prepare a roadmap for implementation of the recommendations/observations accepted. The committee consists of representatives from the CPCB, the Ministry of Water Resources, the Ministry of Urban Development, and the CAG. The committee proposed, inter alia, a time-bound action plan in this regard (CAG 2011).

10.1.2 Other Policy Suggestions

The prevention and mitigation of extensive levels of water pollution that cause damage to human health and natural and productive assets at the local and regional levels call for a proper set of abatement policies and policy implementation instruments.

Policy options to address the water pollution problem fall into two general categories: command and control (CACs) and market-based economic instruments (EIs). Economic instruments make use of market mechanisms and provide one important approach to address this challenge. They encompass a broad array of policy tools, ranging from pollution taxes and marketable permits to deposit–refund systems and performance bonds. When economic instruments are applied on water management and control or reduction of water pollutants, they increase the returns from pollution abatement activities as evident from Chap. 7. Findings of the chapter reveal that the implication of economic instruments like pollution tax leads to expansion in output.

On the other hand, the application of economic instrument also results in the rise in prices to achieve clean water. This encourages the design of new and improved abatement technologies. In this connection we would like to mention that the foremost attempt should be made to achieve clean water, and for that technological innovation is a must. Increase in the research and development expenditure has to be taken by the different industries and the government involving scientists, social scientists, and technologists. Cost-effective new technology practices may have demonstrated environmental benefits relative to current practice.

For example, the ideal method to abate diffuse chemical pollution of waterways is to minimize or avoid the use of chemicals for industrial, agricultural, and domestic purposes. Adapting practices such as organic farming and integrated pest management could help protect waterways (Scheierling 1995). Chemical contamination of waterways from industrial emissions can also be reduced by cleaner production processes (UNEP 2002).

For proper water management, Indian industries should be encouraged to set up water recovery or desalination plants to meet their demands. Consequently, the industry has not only started adopting measures to minimize waste but also has been looking for various means by which they can recover and recycle their wastewater. Some industries, such as Rashtriya Chemicals and Fertilizers Ltd., have successfully experimented to recover and reuse water from their regenerate waste streams using reverse osmosis and are in the process of setting up large-capacity plants (GBP 2011b). This should be a lesson for other industries. The membrane processes with their variety and flexibility have assumed a greater significance in water recovery and reuse. Regarding effluent water treatment for reuse in industries, the membrane technology is most suited for Indian conditions and is being rapidly adopted. It is suggested that in the future, all process industries will have water-recycling plants and coastal industries may adopt seawater desalination plants by using either processed waste heat or reverse osmosis membranes. As a result domestic water requirements would be met with existing resources, while industrial requirements are supplemented by desalination. This has already been demonstrated in review of case studies in Chap. 9. We suggest in-depth research in this area to be encouraged by the government and industries in collaboration with research institutes and universities.

In addition, some economic instruments will actually raise revenue for governments, providing an important source of finance to priority sectors for pollution abatement activities. The choice of the most appropriate economic instrument is influenced by a wide range of factors including environmental laws already in place, the power and technical capability of government bodies involved, and the broad economic conditions within the country itself. It is, therefore, important to recognize that there is no precise formula for deciding when to apply a particular EI. However, there are certain patterns as to when and under what conditions EIs can be successfully employed. For example, where emissions of pollutants of concern are emitted from many different industrial sources, there are likely to be widely varying costs to abate the pollution (Chap. 4). In these circumstances, there are often large efficiency gains from imposing pollution taxes, as seen in Chap. 7 in simulation exercise 2. In the second simulation exercise, spreading the taxes across all sectors of the economy results in more tax benefits and less price increase when compared to focusing taxes only on selected sectors (simulation 1).

Economic instruments that subsidize the technological improvement can benefit water quality. Various subsidy options which can be thought of in this regard are listed below:

(a) Grant-based subsidies: soft loans, direct funding, provision of hard currency at below market rates
(b) Financing-based subsidies: soft loans, revolving funds, sectoral funds, green funds, public interest rate subsidies or loan guarantees
(c) Tax-based subsidies: tax credits, tax breaks, tax exemptions, tax differentiation, accelerated write-offs
(d) Risk-based subsidies: subsidized insurance or reinsurance, liability caps, public sector indemnification

It is widely known that command and control measures do not provide necessary incentives to polluters for the choice of least cost methods of pollution control. However, a combination of factors seems to explain the current dominance of CAC approaches throughout the world despite the benefits of EIs. These include a lack of understanding of how EIs work to protect the environment and how to choose the appropriate instrument; political interests that seek to minimize control costs via regulation; and a preference for keeping the status quo. Opportunities for much greater environmental and economic gains are, therefore, lost (UNEP 2004).

The Government of India has so far resorted to CAC measures for controlling industrial pollution in India. The actual use of fiscal incentives in the country has been rather limited, even though the need to employ economic and fiscal policy instruments for the control of pollution and management of natural resources has gained recognition since the 1990s (Datt et al. 2004). Fiscal instruments, such as pollution taxes or marketable pollution permits, provide incentives to factories for adopting the least cost pollution abatement technologies. There have been no serious attempts in India to use such instruments for the abatement of industrial pollution (Kumar and Managi 2009, 2010; Murty and Kumar 2011).

From the above analysis of the two approaches, we conclude that the use of economic instruments together with existing command and control approaches will bring great benefit. The efficiency improvements associated with economic instruments must nevertheless be balanced against the constraints posed by current policies and institutional capabilities.

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Appendix A: Extended Input Output Table Including the Clean Water Sector for the Year 2006–2007 (Figures are in Lakh Rupees)

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Extended input–output table (figures are in lakh Rs.) (including the "Clean Water" sector) for the years 2006–2007

	sectors	1	2	3	4	5	6	7	8	9	10	11
1	Agriculture	9121421.796	548.243	1029112.000	1807443.724	526.141	0.000	42.578	16892.652	131669.938	189660.084	4259271.218
2	Other agriculture	64315.474	796162.390	770.000	392.525	0.269	0.000	65.521	1945377.757	2106892.951	749528.313	358794.923
3	Milk and milk products	11498.504	0.000	21673.000	0.250	0.000	0.000	0.009	2996.481	4210.949	2952.922	1378683.568
4	Llivestock	1793941.160	722439.028	0.000	10319.071	92.051	0.000	50.154	442.260	2546.851	547.288	269203.967
5	Fishing	3934.345	0.004	0.000	0.000	246158.000	0.000	0.033	875.566	1440.226	473.800	471744.132
6	Coal and lignite	143.696	11.669	0.000	1362.670	0.005	11356.000	25867.819	1733.676	6389.632	8729.265	11572.517
7	Minning and quarrying	22.445	0.908	0.000	1675.521	0.000	0.000	89496.402	19.425	260.277	1063.968	16468.025
8	Sugar	6838.583	0.027	0.000	168.158	0.036	0.000	50.090	69185.301	2438.008	643201.212	660805.405
9	Oil and vanaspati	8261.678	0.563	87671.000	184986.306	0.306	0.000	45.242	1550.144	418603.465	1458.782	368603.098
10	Tea, Coffee and beverages	274.905	0.001	0.000	27.282	0.000	0.000	138.363	1088.956	119.920	600900.394	28814.286
11	Food products	54270.064	21.072	482.000	21847.814	11466.765	0.000	140.347	2516.315	12194.193	573467.511	1032268.051
12	Cotton textile	7.915	1617.572	486.000	799.529	0.001	0.000	34.783	2.540	538.638	52.551	223.963
13	Woolen and silk textile	0.671	364.757	0.000	189.213	0.000	0.000	48.802	0.229	136.605	774.777	118.677
14	Jute hemp mesta textile	57594.245	49.425	0.000	150.071	47894.978	4.000	3337.905	2024.402	1712.519	21112.925	16302.553
15	Miscellenous textile products	548.502	3282.711	0.000	109.512	92386.017	84.000	177.812	3325.035	2719.898	33781.863	25965.202
16	Wood and wood products	1645.660	366.460	0.000	481.553	6893.039	30089.000	4929.610	15378.903	24479.799	24754.561	111524.097
17	Paper andpaper products	9298.141	4285.374	0.000	1042.942	0.372	6496.000	2713.735	19313.804	11490.205	148574.335	279053.586
18	Leather and leather products	0.201	0.490	0.000	1267.703	0.000	0.000	71.235	0.015	9.985	196.171	29.300
19	Rubber products	360.223	6689.952	0.000	79.890	0.019	9313.000	14880.106	0.010	17.965	180.259	253.824
20	Plastic products	934.114	624.203	0.000	1215.005	0.000	4.000	1777.105	26701.627	29204.313	220775.460	106030.943
21	Petroleum and coal tar products	1068422.638	229704.926	0.000	1794.484	159517.450	42221.000	176669.155	60418.866	47745.970	90899.948	213236.843
22	Inorganic heavy chemicals	544.044	101.473	0.000	2511.616	0.003	0.000	11569.505	12335.484	11682.899	46762.086	86746.145
23	Organic heavy chemicals	222.001	24.654	0.000	1585.663	0.001	0.000	1983.088	1594.612	6926.030	67177.417	47697.339
24	Fertilizers	3946936.464	746938.697	0.000	109.099	193.670	0.000	8.234	13.644	562.797	223.449	50695.011
25	Pesticides	491597.077	208360.749	0.000	71.645	25.664	0.000	274.480	2.180	101.570	3981.154	6894.618
26	Paints, varnishes and lacquers	6.762	77.504	0.000	157.827	0.000	0.000	1084.490	52.925	191.084	474.048	1455.251
27	Other chemicals	2844.525	43.766	127.000	11368.723	9975.053	293837.000	184240.751	1399.570	162074.036	237982.620	105337.692
28	Synthetic fibers, resin	4.494	25.327	0.000	1078.751	0.000	0.000	500.231	0.562	228.142	61.851	1619.884
29	Other non metallic mineral products	131.092	21.400	0.000	478.284	0.000	0.000	68812.344	286.328	33.736	5677.891	1438.260
30	Iron and steel	1.778	9.322	0.000	375.100	6856.000	2.000	7296.694	574.432	71.335	298.780	276.093
31	Machinery and metal products	219359.318	18073.390	66.000	7717.919	7401.913	257009.000	449730.010	100529.303	12500.413	69743.988	116320.150
32	Electrical machinery	756.220	1983.544	0.000	1042.206	0.040	323.000	2790.383	12149.817	265.145	50.628	54.558
33	Transport equipment	22558.977	17679.949	0.000	27.607	98693.465	39406.000	5716.080	6418.247	13.689	17.638	268.148
34	Other machinery	5955.982	10097.110	0.000	1501.798	0.315	21371.000	6737.518	9087.149	340.842	2053.115	6075.072
35	Construction	728830.516	122297.824	799.000	5125.026	42.371	30402.000	379447.791	98932.532	2221.534	34129.593	215990.682
36	Electricity gas and watersupply	912264.068	57879.955	0.000	1995.694	51.959	130441.000	130945.206	8047.961	22914.762	90596.492	163420.866

37	Transport services and communication	1640406.325	363419.510	217383.000	359774.585	67258.798	165152.000	162928.783	62214.028	155890.324	798478.252	990489.032
38	Other services	2216063.573	416441.890	822532.000	1360251.277	56470.588	170524.000	369533.518	810327.604	955149.957	934949.426	3200769.563
39	Clean water			100283.05	42593.79			23087.47	157504.37	39588.41	209368.87	3124.10
	Total Input	22392218.18	3729645.84	2181101.00	3790526.04	811905.29	1208034.00	2104135.91	3293810.34	4135990.60	5605744.82	14604516.54
	NIT	-3561562.56	-566608.74	-2197.00	32914.06	-202611.83	90587.00	156051.68	158765.71	85725.45	330128.74	199884.75
	Total Input+NIT	18830655.61	3163037.10	2178904.00	3823440.10	609293.46	1298621.00	2260187.59	3452576.05	4221716.05	5935873.55	14804401.30
	Gross Value Added	38798540.85	12596817.37	12259726.00	4765383.74	3406010.54	3338194.48	6926717.46	649436.68	825543.97	2560810.25	2044283.49
	Other Gross Value Added			20856.91	13049.96			7630.07	50295.53	12641.68	56765.44	706.27
	Total	57629196.46	15759854.47	14438630.00	8588823.84	4015304.00	4636815.48	9186905.05	4102012.73	5047260.01	8496683.80	16848684.79

Extended input–output table (figures are in lakh Rs.) (including the “Clean Water” sector) for the years 2006–2007

	Sectors	12	13	14	15	16	17	18	19	20	21	22
1	Agriculture	1,098.851	106.532	152.007	514.858	785.492	23,686.762	2,662.974	529.859	6,324.793	1,976.692	16,543.787
2	Other agriculture	1,391,570.277	184,441.873	128,164.050	319,855.660	389,508.595	249,251.658	79,075.105	343,940.968	108,241.008	907.860	7,593.912
3	Milk and milk products	217.297	0.083	11.426	17.196	2.159	396.590	15.491	0.240	66.333	1.507	61.158
4	Livestock	862.928	32,412.628	27.598	23,636.417	8,105.967	510.202	276,817.278	37,463.265	13,654.366	839.199	8,193.284
5	Fishing	73.843	0.001	0.165	5.875	1.006	242.226	5.296	0.042	16.832	0.018	0.369
6	Coal and lignite	5,540.972	9,328.142	3,113.208	6,107.696	8,144.435	58,194.668	944.622	7,357.568	7,420.043	219,112.426	82,854.036
7	Mining and quarrying	1,261.903	5,773.430	655.089	29,806.367	791.037	5,718.929	1,044.107	53,610.298	11,743.061	18,754,636.659	178,234.555
8	Sugar	132.708	0.593	113.628	8.250	111.575	276.457	8.591	8.898	3,078.796	513.721	10,465.782
9	Oil and vanaspati	168.132	14.620	10.647	64.534	73.173	123.850	16.468	46.788	409.580	99.523	6,277.974
10	Tea, coffee, and beverages	6.095	401.898	17.485	62.485	3,193.329	89.122	53.343	164.536	3,296.117	259.560	17,712.108
11	Food products	6,286.757	1,522.218	220.344	2,133.527	982.705	11,192.833	515.724	827.215	4,663.085	853.772	15,539.840
12	Cotton textile	875,790.814	176,189.830	488.487	1,777,105.191	3,583.855	3,350.220	4,544.324	16,808.422	5,851.935	121.207	1,397.237
13	Woolen and silk textile	237,170.837	593,161.692	12,540.515	793,676.652	979.696	2,288.652	8,491.093	6,254.061	4,856.425	226.186	8,611.815
14	Jute hemp mesta textile	5,558.510	12,379.298	7,594.424	34,861.643	4,497.510	3,566.965	1,186.567	10,315.425	2,595.428	1,614.455	5,578.382
15	Miscellaneous textile products	16,488.546	72,504.249	209.280	377,448.937	3,786.180	11,535.587	8,024.727	36,111.119	11,541.573	2,028.196	7,014.824
16	Wood and wood products	13,084.856	15,355.005	756.137	43,668.893	35,060.307	94,950.769	4,037.014	11,220.127	18,167.978	9,727.585	21,651.413
17	Paper and paper products	19,462.691	59,708.539	3,147.437	63,926.305	31,170.305	1,539,008.827	4,673.946	10,422.579	62,598.607	13,980.208	46,200.538
18	Leather and leather products	1,211.065	3,810.309	9.863	66,743.237	1,104.435	353.150	431,270.022	45,566.042	14,450.048	139.023	9,038.943
19	Rubber products	679.801	2,680.971	32.176	18,289.845	10,567.089	1,922.596	2,943.396	152,750.450	14,218.392	1,525.093	11,789.509
20	Plastic products	22,071.514	106,699.877	1,362.399	122,311.460	33,677.435	68,831.814	14,534.826	35,455.579	805,352.755	26,984.619	52,250.116
21	Petroleum and coal tar products	114,844.606	144,116.738	3,437.089	131,007.342	13,897.250	99,296.748	18,553.017	87,838.601	94,617.566	1,020,990.973	276,603.786
22	Inorganic heavy chemicals	48,484.584	110,433.523	1,303.852	43,640.614	8,770.628	143,316.950	1,948.164	139,586.403	107,970.613	244,890.569	414,637.204
23	Organic heavy chemicals	23,799.125	256,443.285	4,361.042	63,175.045	50,255.047	35,329.584	1,385.697	39,105.147	290,820.150	30,150.515	456,444.493
24	Fertilizers	29.594	6.072	1.129	5.859	689.246	3.782	1.379	6,192.946	65.682	94.669	69,110.335
25	Pesticides	14.524	294.941	0.181	114.644	8,316.646	75.271	5.285	372.201	2,186.595	3,621.128	38,576.186
26	Paints, varnishes, and lacquers	37,499.899	34,933.402	1,516.412	28,634.785	4,019.446	63,280.522	20,738.447	25,915.160	39,959.759	4,851.217	17,900.774

27	Other chemicals	21,254.834	76,256.783	20,228.157	150,493.770	9,328.245	180,955.078	51,724.834	71,464.530	356,917.399	214,187.630	207,460.115
28	Synthetic fibers, resin	34,778.248	490,475.962	84.770	365,930.793	11,416.751	20,161.174	12,613.494	819,880.028	1,006,701.462	6,075.871	106,695.935
29	Other nonmetallic mineral products	157.850	986.237	590.144	2,505.520	1,946.139	7,834.181	1,807.330	3,385.317	5,141.100	6,790.764	16,675.419
30	Iron and steel	243.879	503.174	363.676	8,020.379	50,447.315	15,925.023	3,739.702	97,923.499	58,017.098	2,330.026	7,973.127
31	Machinery and metal products	92,278.864	76,848.299	8,502.837	381,332.412	55,613.195	37,954.062	26,360.672	126,570.459	120,514.025	48,927.143	61,505.308
32	Electrical machinery	471.027	1,914.324	254.553	16,903.172	28,432.817	28,051.419	5,793.507	31,193.337	31,666.996	928.245	4,236.748
33	Transport equipment	3.037	8.686	122.839	2,373.782	6,471.695	282.651	1,248.395	30,534.330	5,170.989	135.209	70.704
34	Other machineries	9,330.072	16,137.004	482.183	97,202.894	8,701.135	30,052.683	14,896.342	11,870.035	29,478.720	11,941.257	15,957.449
35	Construction	104,529.114	45,727.637	2,624.713	254,615.235	7,540.705	64,550.746	6,894.828	14,657.896	15,825.536	194,928.938	31,196.011
36	Electricity gas and water supply	376,137.698	150,152.706	34,726.542	166,747.625	28,137.455	160,356.316	22,521.096	74,071.850	134,378.791	359,386.918	171,846.507
37	Transport services and communication	1,095,042.309	343,182.985	19,946.811	752,635.294	107,186.213	448,506.495	131,526.840	200,063.908	236,578.507	746,419.881	224,926.257
38	Other services	1,159,555.576	881,337.191	128,007.776	1,979,455.057	257,038.935	527,801.460	340,549.975	417,962.751	474,932.401	892,918.824	465,922.146
39	Clean water	3,428,551.22		198.06	81,960.59		5,349.82	2,643.51	6,134.46		15,050.38	2,167.85
	Total input	5,717,193.24	3,906,250.74	385,181.07	8,125,039.25	1,194,335.15	3,939,226.02	1,503,173.92	2,967,441.88	4,109,490.55	22,825,117.29	3,094,748.09
	NIT	143,745.73	198,892.05	10,473.77	69,063.85	63,015.06	428,301.92	55,290.08	175,735.09	384,884.73	1,556,800.90	276,034.44
	Total Input + NIT	5,860,938.98	4,105,142.78	395,654.84	8,194,103.10	1,257,350.21	4,367,527.94	1,558,464.00	3,143,176.97	4,494,375.28	24,381,918.19	3,370,782.53
	Gross value added	1,889,902.37	1,020,184.70	209,836.24	3,062,744.17	949,014.87	1,560,852.10	654,120.81	839,236.10	1,055,720.53	4,922,062.02	1,033,796.21
	Other gross value added	2,143,202.86		340.82	2,517.79		2,951.65	1,727.37	2,760.67		11,311.86	1,391.08
	Total	7,750,841.35	5,125,327.49	605,491.08	11,256,847.26	2,206,365.08	5,928,380.04	2,212,584.80	3,982,413.07	5,550,095.80	29,303,980.20	4,404,578.74

Extended input–output table (figures are in lakh Rs.) (including the "Clean Water" sector) for the years 2006–2007

	Sectors	23	24	25	26	27	28	29	30	31	32	33
1	Agriculture	14,467.260	569.801	5,882.401	11,119.052	179,833.758	13,556.255	1,975.313	79.618	7,586.125	2,256.818	1,006.693
2	Other agriculture	36,772.081	6,938.314	907.366	8,703.002	564,221.363	6,501.453	7,606.155	2,336.740	7,768.864	6,989.668	5,536.785
3	Milk and milk products	157.412	7.979	733.602	561.957	18,504.652	5.954	37.620	0.190	1,592.248	90.667	0.001
4	Livestock	6,766.978	70.693	1,811.726	2,391.490	37,511.550	15,107.663	861.905	144.219	6,281.244	9,459.912	6,082.298
5	Fishing	1.370	0.057	231.192	184.678	4,745.606	0.105	9.688	0.269	537.565	81.844	0.001
6	Coal and lignite	27,452.311	32,309.862	2,047.398	15,199.302	24,479.775	1,585.448	307,678.532	2,134,795.926	887,348.863	47,889.785	27,578.474
7	Mining and quarrying	70,373.443	547,330.805	9,556.784	49,522.516	217,793.869	48,028.467	976,393.642	1,011,172.611	881,568.570	135,896.374	24,590.954
8	Sugar	7,489.499	646.515	1,347.681	3,379.416	54,515.072	3,095.371	512.825	462.808	7,923.255	712.391	22.558
9	Oil and vanaspati	7,398.948	757.927	590.274	8,262.251	57,513.741	395.983	235.795	8.963	576.118	68.106	157.389
10	Tea, coffee, and beverages	16,827.016	1,113.258	1,867.369	5,206.488	14,605.600	3,442.409	988.891	1,821.165	3,915.653	852.062	150.732
11	Food products	14,208.759	2,682.547	3,502.828	8,737.455	108,871.118	7,498.369	1,970.667	172.668	8,811.623	2,184.163	486.395
12	Cotton textile	1,481.234	4.235	62.843	331.619	8,008.363	5,274.514	7,090.635	422.460	2,642.373	1,463.282	7,319.514
13	Woolen and silk textile	11,539.316	3.890	40.101	251.871	2,649.252	15,544.213	5,214.595	1,014.824	12,493.897	52,045.172	11,539.163
14	Jute hemp mesta textile	4,518.326	2,028.843	1,638.663	3,542.306	32,349.202	2,982.863	8,400.078	2,671.557	8,999.349	16,153.523	4,814.161
15	Miscellaneous textile products	6,065.339	3,308.808	2,016.242	5,381.779	40,287.437	3,473.911	13,358.618	3,737.972	35,338.478	48,824.921	6,776.463
16	Wood and wood products	19,559.319	16,208.444	9,862.241	22,656.431	142,870.308	10,273.655	63,145.686	20,882.163	143,935.694	149,733.959	40,304.680
17	Paper and paper products	43,548.238	527.157	4,885.307	12,170.147	123,676.799	18,698.124	93,512.618	23,114.848	107,566.404	197,739.873	30,689.982
18	Leather and leather products	5,692.118	133.871	395.713	3,139.855	3,585.189	201.570	849.927	2,605.188	7,323.201	27,731.523	51,217.650
19	Rubber products	7,497.780	167.008	1,039.318	3,812.216	7,876.989	10,805.410	2,697.144	8,615.625	94,998.833	69,068.995	234,042.097
20	Plastic products	54,273.863	22,792.635	6,857.353	47,392.805	322,340.886	35,640.076	204,370.994	45,710.887	250,922.091	740,773.620	140,688.985
21	Petroleum and coal tar products	156,193.629	777,444.252	28,141.621	64,792.181	285,668.693	186,937.645	622,627.176	742,537.740	494,424.904	326,035.609	133,628.762
22	Inorganic heavy chemicals	307,588.477	669,118.849	108,641.168	288,424.623	641,875.118	232,362.005	93,521.337	126,594.502	328,306.790	223,170.726	24,730.270
23	Organic heavy chemicals	474,439.774	221,552.093	117,113.672	160,564.179	1,427,803.660	675,301.421	17,746.654	12,602.905	56,030.861	106,128.558	27,135.475
24	Fertilizers	17,004.317	381,744.510	2,408.208	198.282	1,059.250	2,935.654	325.193	20.053	97.876	66.677	41.633
25	Pesticides	57,532.044	5,895.570	176,134.160	8,196.270	31,524.478	393.924	2,470.295	5,963.693	2,662.889	6,170.804	45.723
26	Paints, varnishes, and lacquers	19,020.379	256.025	2,957.621	105,518.166	18,674.250	11,347.680	42,640.050	43,350.916	81,276.014	135,315.096	98,318.333
27	Other chemicals	251,261.449	48,356.830	50,177.765	350,880.513	3,287,113.364	347,716.419	43,406.032	30,613.242	103,098.518	211,900.960	70,392.710
28	Synthetic fibers, resin	109,755.202	662.529	4,816.752	93,892.342	77,929.897	470,257.443	27,919.350	18,117.005	135,875.902	709,575.999	174,414.797
29	Other nonmetallic mineral products	4,364.194	703.579	1,060.169	8,658.941	12,141.974	1,496.563	788,172.252	61,293.455	89,860.635	318,290.110	30,199.117

30	Iron and steel	3,189.375	335.446	3,733.530	15,578.223	45,043.037	2,630.627	54,989.575	3,597,817.113	4,771,565.560	3,589,508.501	1,571,927.544
31	Machinery and metal products	50,484.919	5,338.347	19,586.279	54,729.643	205,419.582	31,353.746	92,028.041	4,294,160.498	7,579,447.479	6,231,291.226	1,897,072.654
32	Electrical machinery	2,984.982	3,277.757	1,389.118	5,505.356	61,682.207	8,107.931	3,723.952	122,551.607	1,147,722.462	8,893,528.429	707,369.377
33	Transport equipment	14.375	159.234	76.202	144.575	990.071	29.847	726.432	77,163.883	125,528.415	26,441.111	1,610,045.914
34	Other machineries	16,704.859	1,254.717	4,011.065	15,339.268	132,743.295	9,151.366	42,428.831	26,299.566	327,766.758	431,887.225	220,063.779
35	Construction	20,229.237	45,860.026	4,800.546	10,066.287	143,090.982	13,651.775	468,012.452	92,808.346	659,957.012	611,915.290	151,744.100
36	Electricity gas and water supply	141,420.198	78,768.171	24,227.893	60,089.691	280,274.628	47,158.516	630,284.704	1,379,352.751	746,205.493	463,228.551	392,408.939
37	Transport services and communication	156,951.629	295,841.257	34,715.122	124,677.296	746,366.932	171,508.519	718,097.000	1,788,484.578	1,567,800.452	2,760,637.745	593,292.273
38	Other services	383,210.604	453,232.448	130,088.303	284,250.272	1,485,300.200	305,145.261	917,186.846	3,012,791.381	3,543,185.343	3,718,209.920	2,449,841.124
39	Clean water	9,561.58		17,868.19	12,262.95	191,722.93			123,702.80			
	Total input	2,528,440.25	3,627,404.29	769,355.60	1,863,452.74	10,850,942.15	2,719,598.16	6,263,217.50	18,692,293.94	24,238,943.81	30,273,319.19	10,745,677.50
	NIT	252,985.61	227,968.73	71,617.00	180,094.40	1,038,265.57	281,570.65	441,548.34	985,532.71	2,209,503.42	2,893,927.25	1,094,534.14
	Total input + NIT	2,781,425.87	3,855,373.02	840,972.60	2,043,547.14	11,889,207.72	3,001,168.80	6,704,765.84	19,677,826.65	26,448,447.23	33,167,246.45	11,840,211.63
	Gross value added	931,454.71	924,721.40	333,718.50	613,320.99	4,594,027.04	1,017,877.39	3,037,768.93	6,262,365.17	8,135,483.76	4,263,980.32	3,345,666.88
	Other gross value added	7,128.96		14,338.33	6,254.11	68,145.00			92,975.02			
	Total	3,712,880.58	4,780,094.42	1,174,691.09	2,656,868.13	16,483,234.76	4,019,046.19	9,742,534.77	25,940,191.82	34,583,930.99	37,431,226.76	15,185,878.51

Extended input–output table (figures are in lakh Rs.) (including the "Clean Water" sector) for the years 2006–2007

	Sectors	34	35	36	37	38	39 Clean water
1	Agriculture	12,227.388	1,066,039.796	4,362.946	959,630.000	3,485,134.325	
2	Other agriculture	14,387.775	365,912.572	50,865.558	40.000	176,643.826	
3	Milk and milk products	3,184.697	100.132	456.574	0.000	537,636.154	
4	Livestock	22,600.731	601,505.144	121.738	0.000	756,121.594	
5	Fishing	1,083.905	34.134	154.965	0.000	15,941.843	
6	Coal and lignite	19,004.293	2,365.658	1,696,075.946	4,164.000	19,167.142	
7	Mining and quarrying	476,661.144	3,729,783.599	375,521.057	11.000	35,153.813	
8	Sugar	1,680.278	107.693	884.058	0.000	392,574.488	
9	Oil and vanaspati	1,443.337	74.648	629.500	18,469.000	479,262.162	
10	Tea, coffee, and beverages	356.563	33.134	785.385	127.000	632,167.893	
11	Food products	2,803.200	131.193	1,210.380	1,150.000	964,075.266	
12	Cotton textile	7,599.796	274.022	910.334	6,825.000	23,132.111	
13	Woolen and silk textile	14,762.389	100.383	2,618.979	5,752.000	13,944.090	
14	Jute hemp mesta textile	3,843.946	87,987.897	222.344	551.000	43,744.392	
15	Miscellaneous textile products	9,196.999	4,392.564	2,262.325	66,747.000	81,196.637	
16	Wood and wood products	46,385.629	924,812.898	6,340.217	9,770.000	136,558.989	
17	Paper and paper products	50,918.812	87,860.328	69,113.138	510,058.000	994,416.787	
18	Leather and leather products	12,493.769	100.686	442.353	5,186.000	6,100.951	
19	Rubber products	17,284.547	7,857.550	3,815.799	1,638,388.000	40,544.192	
20	Plastic products	183,253.498	307.923	2,725.386	401,320.000	72,465.641	
21	Petroleum and coal tar products	57,552.843	3,355,402.843	1,658,558.481	12,678,247.000	944,386.830	
22	Inorganic heavy chemicals	25,640.072	345.440	10,049.297	1,178.000	39,712.706	2,629,273.35
23	Organic heavy chemicals	18,196.402	275.727	8,451.069	0.000	97,822.187	
24	Fertilizers	71.929	9,090.681	1,495.108	0.000	6,639.286	
25	Pesticides	283.682	2,296.014	3,571.034	3,612.000	4,447.775	
26	Paints, varnishes, and lacquers	21,324.095	1,080,483.333	1,054.570	310,432.000	11,029.889	
27	Other chemicals	40,916.539	426.645	60,072.711	10,107.000	2,470,901.951	
28	Synthetic fibers, resin	168,838.588	240.125	2,577.659	1,184.000	48,938.875	
29	Other nonmetallic mineral products	29,054.494	9,570,373.288	1,324.692	63,179.000	32,997.964	
30	Iron and steel	320,464.890	10,272,678.681	18,916.742	1,959.000	200,503.549	

31	Machinery and metal products	580,560.601	2,349,270.232	254,789.825	747,270.000	417,877.237	
32	Electrical machinery	371,898.864	2,060,272.456	629,587.215	1,381,860.000	1,333,466.362	
33	Transport equipment	10,005.800	29,055.479	20,636.162	2,059,967.000	351,880.898	
34	Other machineries	3,359,668.228	710,733.559	344,013.692	1,248,464.000	1,870,686.916	
35	Construction	91,869.658	3,790,499.949	496,904.734	1,798,697.000	3,492,218.604	
36	Electricity gas and water supply	75,675.995	1,264,353.224	5,391,854.467	1,132,523.000	700,414.311	1,290,062.70
37	Transport services and communication	832,682.670	5,373,350.319	1,157,715.312	6,016,714.000	6,750,682.539	
38	Other services	1,201,728.218	9,444,405.034	2,237,701.150	7,728,031.000	17,186,712.087	
39	Clean water			560,046.32			
	Total input	8,107,606.26	56,193,334.98	14,518,792.90	38,811,612.00	44,867,302.26	3,919,336.05
	NIT	489,649.91	2,467,927.18	−1,792,890.01	2,687,900.00	1,459,992.05	
	Total input + NIT	8,597,256.17	58,661,262.16	12,725,902.90	41,499,512.00	46,327,294.31	3,919,336.05
	Gross value added	3,506,342.62	31,961,741.07	6,542,631.10	30,972,762.78	167,193,500.37	
	Other gross value added			392,928.50			2,909,919.86
	Total	12,103,598.80	90,623,003.23	19,268,534.00	72,472,274.78	213,520,794.68	6,829,255.91

Extended input–output table (figures are in lakh Rs.) (including the "Clean Water" sector) for the years 2006–2007

	Sectors	IIUSE	PFCE	GFCE	GFCF	CIS	EXP	Less IMP	TFUSE	Total
1	Agriculture	22,376,698.53	33,366,015.00	341,400.00	0.00	551,057.00	1,856,444.00	862,418.00	35,252,498.00	57,629,196.53
2	Other agriculture	10,486,982.61	5,115,590.00	61.00	0.00	715,826.00	350,911.00	909,516.00	5,272,872.00	15,759,854.61
3	Milk and milk products	1,985,875.00	12,180,376.00	256,404.00	0.00	15,160.00	835.00	20.00	12,452,755.00	14,438,630.00
4	Livestock	4,668,943.84	3,165,944.00	83,746.00	210,053.00	215,174.00	279,838.00	34,875.00	3,919,880.00	8,588,823.84
5	Fishing	747,979.00	2,620,591.00	0.00	0.00	10,142.00	651,617.00	15,025.00	3,267,325.00	4,015,304.00
6	Coal and lignite	5,724,427.48	29,264.00	6,326.00	0.00	−81,805.00	16,434.00	1,057,831.00	−1,087,612.00	4,636,815.48
7	Mining and quarrying	27,741,641.05	96,490.00	27,381.00	0.00	−98,011.00	5,011,045.00	23,591,641.00	−18,554,736.00	9,186,905.05
8	Sugar	1,872,759.73	2,148,026.00	0.00	0.00	557,503.00	186,911.00	663,187.00	2,229,253.00	4,102,012.73
9	Oil and vanaspati	1,654,330.01	3,913,652.00	0.00	0.00	170,165.00	568,142.00	1,259,029.00	3,392,930.00	5,047,260.01
10	Tea, coffee, and beverages	1,340,880.80	6,491,045.00	36,541.00	0.00	412,611.00	274,922.00	59,316.00	7,155,803.00	8,496,683.80
11	Food products	2,881,908.79	12,579,254.00	361,492.00	0.00	276,160.00	1,450,727.00	700,857.00	13,966,776.00	16,848,684.79
12	Cotton textile	2,941,837.35	3,726,087.00	0.00	0.00	96,846.00	1,196,535.00	210,464.00	4,809,004.00	7,750,841.35
13	Woolen and silk textile	1,819,405.49	3,029,794.00	0.00	0.00	149,907.00	690,447.00	564,226.00	3,305,922.00	5,125,327.49
14	Jute hemp mesta textile	464,380.08	98,548.00	25.00	0.00	38,186.00	35,323.00	30,971.00	141,111.00	605,491.08
15	Miscellaneous textile products	1,041,439.26	4,152,444.00	328,493.00	41,359.00	337,578.00	5,696,111.00	340,577.00	10,215,408.00	11,256,847.26
16	Wood and wood products	2,251,523.08	217,040.00	59,815.00	345,428.00	−702,909.00	136,065.00	100,597.00	−45,158.00	2,206,365.08
17	Paper and paper products	4,705,065.04	1,049,235.00	477,334.00	0.00	521,446.00	251,875.00	1,076,575.00	1,223,315.00	5,928,380.04
18	Leather and leather products	702,470.80	972,696.00	1.00	0.00	−4,281.00	709,176.00	167,478.00	1,510,114.00	2,212,584.80
19	Rubber products	2,397,686.07	391,462.00	17,148.00	522,429.00	210,168.00	694,370.00	250,850.00	1,584,727.00	3,982,413.07
20	Plastic products	4,208,635.80	626,549.00	34,450.00	286,368.00	308,186.00	507,058.00	421,151.00	1,341,460.00	5,550,095.80
21	Petroleum and coal tar products	26,608,415.20	5,991,164.00	421,402.00	0.00	−2,883,377.00	2,765,552.00	3,599,176.00	2,695,565.00	29,303,980.20
22	Inorganic heavy chemicals	4,558,495.74	0.00	1,189.00	0.00	977,915.00	315,738.00	1,448,759.00	−153,917.00	4,404,578.74
23	Organic heavy chemicals	4,799,644.58	0.00	12,809.00	0.00	−337,796.00	2,115,956.00	2,877,733.00	−1,086,764.00	3,712,880.58
24	Fertilizers	5,245,080.42	0.00	0.00	0.00	−95,527.00	3,040.00	372,499.00	−464,986.00	4,780,094.42
25	Pesticides	1,076,087.09	0.00	213.00	0.00	38,157.00	235,307.00	175,073.00	98,604.00	1,174,691.09

26	Paints, varnishes, and lacquers	2,265,748.13	59,202.00	0.00	0.00	501,402.00	98,041.00	267,525.00	391,120.00	2,656,868.13
27	Other chemicals	9,746,844.76	4,202,981.00	446,211.00	0.00	2,393,534.00	1,467,769.00	1,774,105.00	6,736,390.00	16,483,234.76
28	Synthetic fibers, resin	4,923,330.19	0.00	0.00	0.00	−259,314.00	781,281.00	1,426,251.00	−904,284.00	4,019,046.19
29	Other nonmetallic mineral products	11,137,869.77	64,734.00	410.00	37,424.00	−238,846.00	475,196.00	1,734,253.00	−1,395,335.00	9,742,534.77
30	Iron and steel	24,732,089.82	0.00	0.00	1,902,962.00	−43,409.00	2,677,797.00	3,329,248.00	1,208,102.00	25,940,191.82
31	Machinery and metal products	27,105,538.99	1,650,270.00	198,475.00	13,819,246.00	766,722.00	4,359,980.00	13,316,301.00	7,478,392.00	34,583,930.99
32	Electrical machinery	16,904,189.76	3,884,440.00	438,829.00	14,556,786.00	3,787,607.00	4,398,425.00	6,539,050.00	20,527,037.00	37,431,226.76
33	Transport equipment	4,550,087.51	1,784,930.00	264,943.00	9,158,257.00	77,471.00	2,601,398.00	3,251,208.00	10,635,791.00	15,185,878.51
34	Other machineries	9,070,486.80	1,493,171.00	157,557.00	9,299,189.00	1,078,705.00	16,790,354.00	25,785,864.00	3,033,112.00	12,103,598.80
35	Construction	14,253,636.23	2,174,614.00	738,351.00	73,456,402.00	0.00	0.00	0.00	76,369,367.00	90,623,003.23
36	Electricity gas and water supply	16,005,262.00	2,162,804.00	1,100,468.00	0.00	0.00	0.00	0.00	3,263,272.00	19,268,534.00
37	Transport services and communication	38,378,927.78	25,730,354.00	1,495,736.00	2,199,789.00	0.00	5,435,510.00	768,042.00	34,093,347.00	72,472,274.78
38	Other services	73,319,514.68	81,852,565.00	34,798,664.00	4,717,571.00	0.00	26,420,292.00	7,587,812.00	140,201,280.00	213,520,794.68
39	Clean water	396,696,119.28	227,021,331.00	42,105,874.00	130,553,263.00	9,462,353.00	91,506,422.00	106,569,503.00	0.00	3,025,929.30
	Total input	396,696,119.28	227,021,331.00	42,105,874.00	130,553,263.00	9,462,353.00	91,506,422.00	106,569,503.00	394,079,740.00	790,775,859.28
	NIT	15,073,441.83								
	Total input + NIT	15,073,441.83	394,079,739.79	0.00	0.00	0.00	0.00	0.00	0.00	15,073,441.83
	Gross value added	379,006,297.96								
	Other gross value added	411,769,561.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	411,769,561.11
	Total									

PFCE private final consumption exp., *GFCE* govt. final consumption exp., *GFCF* gross fixed capital formation, *CIS* change in stock, *EXP* exports, *Less IMP* imports, *TFUSE* total final use