Pradip K. Sikdar *Editor*

Environmental Management: Issues and Concerns in Developing Countries

Springer

Environmental Management: Issues and Concerns in Developing Countries

Pradip K. Sikdar
Editor

Environmental Management: Issues and Concerns in Developing Countries

Springer

Editor
Pradip K. Sikdar
Department of Environment Management
Indian Institute of Social Welfare and Business Management
Kolkata, India

Jointly published with Capital Publishing Company, New Delhi, India

The print edition is not for sale in Afghanistan, Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan and Sri Lanka. Customers from Afghanistan, Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan and Sri Lanka please order the print book from: Capital Publishing Company.

ISBN 978-3-030-62528-3 ISBN 978-3-030-62529-0 (eBook)
https://doi.org/10.1007/978-3-030-62529-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This book deals with the issues and concerns of natural environment and its human factor in the developing countries and discusses natural processes and systems, pollution removal technology, energy conservation, disaster management, environmental impact assessment process, economics, culture, political structure and societal equity from a management point of view. The environment is being threatened because of deforestation, destruction of natural habitats, over-consumption of natural resources, over-use of energy resources and concomitant environmental pollution. Anthropogenic activities coupled with a rapidly increasing human population are largely responsible for the extinction of many plant and animal species, while others are threatened or vulnerable. The solution to the emerging problems of environment needs a paradigmatic shift in approach from a process-based model to a socio-political-economic model. Hence, environment management should involve equality and control over use of the finite natural resources and the balance between Earth's bio-capacity and population's ecological footprint. Changes such as green technologies, human population stabilization and adoption of ecologically harmonious lifestyle are absolutely necessary and will require redesigning of political institutions, policies and even revisiting forgotten skills of sustainable practices of environmental management. These challenges should centre on environmental governance using the concepts of common property, equity and security.

The book is organized in eighteen chapters which hopefully will broaden the readers understanding of environment, its socio-political-economic models, and the inter-dependencies between environmental concerns and development pressures. The book starts with the concept of sustainable development, global degradation of the environment and its causes, the importance of the environment in some major habitats critical to the developing world's population and the way in which they are being threatened, as well as the environment friendly services they provide.

The second chapter addresses the natural and anthropogenic activities that are affecting our environment with their associated environmental problems and risks. The third chapter presents a detailed analysis of the strengths and weaknesses of ecological footprints as an effective tool for analyzing anthropogenic impact on nature and natural resources and then goes on to discuss the advantages of using the footprint family as an integrated approach for designing a more efficient indicator for sustainable utilization of natural resources.

The next two chapters deal with atmospheric and water pollution which is the greatest challenge that the developing world is facing because of the potential public health impacts. These two chapters discuss the strategies and technologies available to control atmospheric and water pollution in developing countries and measures to reduce the problems of diseases, environmental degradation and economic stagnation.

Solid waste management is a major challenge for many cities in the developing countries as a result of high annual growth in the urban population along with a rapid pace of urbanization. Chapter 6 highlights few issues of solid waste management in Indian cities and tries to highlight various management strategies including community participation and guidelines for including it as an integral part of urban planning. Chapter 7 presents a detailed discussion on engineering techniques used by man in earlier times that has been long ignored and forgotten with the advent of modern technology but can be used for sustainable living in the present time. The next chapter describes the role of energy conservation and its impact on climate change associated with greenhouse gas emissions from fossil-fuel based production facilities. Chapter 9 reviews the biophysical and socio-cultural relationships that shape urban water security from an emerging country perspective. It explores implications for including social and environmental changes and the possibilities in achieving urban water security.

The next four chapters discuss various tools that are used in environmental management. Chapter 10 reviews the application of remote sensing and geographical information system on issues like climate change, mining environment, urban mapping, land use change analysis, wetlands and watershed mapping, groundwater investigation, coastal and marine environment, mapping of invasive species, and disaster management. Chapter 11 scrutinizes key features of environmental disaster risk reduction and its management aspects. Chapter 12 discusses principles, processes and methods of environmental impact assessment and Chapter 13 reviews tools such as life cycle assessment and environmental audit, already in vogue in developed nations and which can be used proactively by organizations in developing nations to enhance their environmental management systems, thereby reducing environmental liabilities.

Chapter 14 introduces contingent valuation method of economic valuation of environmental goods which is widely used for estimating the values of natural resources and which have non-market as well as non-use values. Case studies on forestry and drinking water for the dryland region of West Bengal, India, have been discussed and in each the maximum willingness to pay (WTP) has been analysed under closed-ended and open-ended referendum. Chapter 15 discusses the relationship between geopolitics and environmental agendas through climate change, air pollution and river issues as extant in developing countries. Chapter 16 is concerned with the role of social sciences in environmental management and offers a critique of the dominant discourses that have so long held a hegemonic position in much of the exchanges between stakeholders. Chapter 17 describes the treaties, conventions, statutes, regulations and common laws that operate to regulate the interaction among human beings and the environment for the purpose of reducing adverse impacts on the environment. The final chapter of this book depicts a roadmap that seeks to provide an entirely different paradigm of environmental management for sustainable development in developing countries.

The book will serve as a guide to researchers, academics, professionals, administrators and policy makers who are concerned with environmental management and governance in developing countries. The book would also be helpful to graduate students in diverse fields like geology, hydrology, environmental science, environmental engineering, environmental management, environmental studies, economics, civil engineering, chemical engineering and irrigation engineering.

The editor conveys his appreciation to all the authors in this book for their invaluable contributions. W*ithout their effort and support this book would not have been possible. The editor is thankful to the Director of the Indian Institute of Social Welfare and Business Management for providing the infrastructural facilities, and would like to thank the publisher, Capital Publishing Company and Co-publisher Springer, for their sustained support and effort in bringing the book to fruition.*

Kolkata, India Pradip K. Sikdar

Contents

About the Contributors

Priya Banerjee, Assistant Professor, Department of Environmental Studies, Directorate of Distance Education, Rabindra Bharati University, Kolkata – 700091, India. E-mail: prya.bnrje@gmail.com

Jayanta Basu, Environment Correspondent and Columnist, The Telegraph, ABP, India; Guest Faculty, Department of Environmental Science, University of Calcutta, Kolkata – 700019, India; Director of non-profit EnGIO, Kolkata, India. Email: jayantabasu.cal@gmail.com

Jhumoor Biswas, Professor, Department of Environment Management, Indian Institute of Social Welfare and Business Management, Kolkata - 700073. E-mail: jhumoorb@yahoo.com

Surajit Chakraborty, Assistant Professor and Coordinator, Department of Environment Management, Indian Institute of Social Welfare and Business Management, Kolkata -700073. E-mail: surajitchak@rediffmail.com

Nilendu Chatterjee, Assistant Professor, Department of Economics, Bankim Sardar College, Canning, South 24 Parganas – 743329, West Bengal, India. Email: nilendu_chatterjee@rediffmail.com

Reshmi Das, UGC Assistant Professor, School of Environmental Studies, Jadavpur University, Kolkata – 700032, India. E-mail: reshmidas.sest@jadavpuruniversity.in

Anupam Debsarkar, Associate Professor, Department of Civil Engineering, Jadavpur University, Kolkata – 700032, India. Email: anupamju1972@gmail.com

Arindam Dutta, Assistant Professor and Coordinator, Department of Energy Management, Indian Institute of Social Welfare and Business Management, Kolkata – 700073, India. Email: arindamdutta190@hotmail.com

Tapas Kumar Ghatak, Member, Board of Director, CREDAI, Kolkata and Former Director, Environmental Cell, KMDA, Government of West Bengal. Email: tk.ghatak@gmail.com

Anita Chattopadhyay Gupta, Principal, Deshbandhu College for Girls, Kolkata – 700026, India. Email: anita_c_gupta@hotmail.com

Surajit Kar, Ph.D. Research Scholar, Department of Geography, University of Calcutta, Kolkata – 700019, India. E-mail: surajit15213@gmail.com

Dipanjali Majumdar, Senior Scientist, CSIR-National Environmental Engineering Research Institute, Kolkata Zonal Centre, Kolkata – 700107, India.

Meenakshi Mukherjee, M.Tech Student, School of Environmental Studies, Jadavpur University, Kolkata – 700032, India. E-mail: meenakshimukherjee1994ab@gmail.com

Subham Mukherjee, DAAD-PhD Research Scholar, Institute of Geographical Sciences, Physical Geography, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany. Email: subham.m@fu-berlin.de

Aniruddha Mukhopadhayay, Professor and Head, Department of Environmental Science, University of Calcutta, Kolkata – 700019, India. E-mail: amcu.envs24@gmail.com

Surajit C. Mukhopadhyay, Professor of Sociology, Amity Law School, Amity University, Chattisgarh, Raipur – 493225. Email: surajit62@gmail.com

Sukdeb Pal, Senior Scientist, Wastewater Technology Division, CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur – 440020, India and Assistant Professor, Academy of Science and Innovative Research (AcSIR), Ghaziabad – 201002, India. E-mail: s_pal@neeri.res.in

Abhisek Roy, Assistant Professor, Department of Civil Engineering, Meghnad Saha Institute of Technology, Kolkata – 700150, India. Email: abhisekroy22@gmail.com

Rishin Basu Roy, Research Scholar, Department of Environmental Science, University of Calcutta; Environmental Consultant, Nature Mates Nature Club, Kolkata and Freelance Naturalist, Svasara Jungle Resorts, Tadoba, Maharashtra. Email: wildrishin@gmail.com

Paulami Sahu, Assistant Professor, School of Environment & Sustainable Development, Central University of Gujarat, Gandhinagar – 382030, India. Email: paulami_sahu@cug.ac.in

Brigitta Schütt, Professor, Institute of Geographical Sciences, Physical Geography, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany. Email: brigitta.schuett@fu-berlin.de

Pradip K. Sikdar, Professor, Department of Environment Management, Indian Institute of Social Welfare and Business Management, Kolkata – 700073, India. E-mail: p_sikdar@hotmail.com

Trude Sundberg, Senior Lecturer in Social Policy and Director of Q-step Centre, University of Kent, School of Social Policy, Sociology and Social Research (SSPSSR), Canterbury, Kent, CT2 7NF, United Kingdom. Email: t.sundberg@kent.ac.uk

Biswajit Thakur, Associate Professor, Department of Civil Engineering, Meghnad Saha Institute of Technology, Kolkata – 700150, India. Email: biswajit.thkr@gmail.com

Chapter 1
Environmental Management: Issues and Concerns

Pradip K. Sikdar

1 Introduction

The purpose of this book is to highlight the issues and concerns for human environment in the developing countries incorporating natural processes and systems, pollution removal technology, energy conservation, environmental impact assessment process, economics, culture, political structure and societal equity from a management point of view and then try to find solutions to the problems based on socio-political-economic model.

This chapter introduces to the concept of sustainable development, global degradation of the environment and its causes, the importance of the environment in some major habitats critical to the developing world's population and the main way in which they are being threatened, and the environmental services they provide.

2 Definitions and Concepts

The terms 'environment', 'environment pollutant' and 'environment pollution' have been defined according to Section 2(a) of the Environmental Protection Act, 1986 as follows:

'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-organisms and property.

'Environment pollutant' means any solid, liquid or gaseous substance present in such concentration as may be, or tend to be injurious to the environment.

P. K. Sikdar (✉)
Department of Environment Management, Indian Institute of Social Welfare and Business Management, Kolkata, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_1

‘Environment pollution’ means the presence in the environment of any environmental pollutant.

A ‘habitat’ is the locality in which a species or community of plant or animal naturally lives and grows.

‘Environmental services’ refer to qualitative functions of natural non-produced assets of land, water and air (including related ecosystem) and their biota. There are three basic types of environmental services: (i) general life support services, (ii) productive services and (iii) disposal services.

The environment contains elements essential for life, health and human welfare. Some of these are being lost or modified due to modern developmental activities (ozone layer, composition of the atmosphere, natural beauty), while others are ‘finite’ and subject to irreversible loss (biodiversity). Productive services are the supply of raw materials and energy for the present production and consumption, which may be either renewable or finite. Renewable resources such as soil, forests etc. can be used sustainably or depleted from over-use and improper maintenance. Disposal services reflect the functions of the natural environment as an absorptive sink for residuals. Up to a certain level, the environment can safely assimilate waste beyond which natural systems become saturated and overloaded.

3 Sustainable Development

3.1 Definition

According to Brundtland (1987), ‘Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs’.

According to MOEF (1999), ‘Sustainable development is one that ensures that the maximum rate of resource consumption and waste discharge for a selected development portfolio would be sustained indefinitely, in a defined planning region, without progressively impairing its bio-productivity and ecological integrity’. According to this definition, development plans have to ensure sustainable and equitable use of resources for meeting the needs of the present and future generations without causing damage to environment; prevent further damage to our life-support systems and conserve and nurture the biological diversity, gene pool and other resources for long-term food security.

According to Barbier (1987), the primary objective of sustainable development is to reduce the absolute poverty of the world’s poor through providing lasting and secure livelihoods that minimise resource depletion, environmental degradation, cultural disruption and social instability.

3.2 Approaches of Sustainable Development

There are three approaches to sustainable development: (i) economic approach, (ii) ecological approach and (iii) social approach. The economic approach is that current decisions should not impair the prospects for maintaining or improving future living standards, which implies that the economic system should be managed in such a way that we can live off the dividends of our resources. The ecological approach is about maintenance of essential ecological processes and life support systems, the preservation of genetic diversity and the sustainable utilisation of species and ecosystems. The social approach is directly concerned with increasing the standard of living of the poor, which can be measured in terms of increased food, real income, education, health care, water supply, sanitation and only indirectly concerned with economic growth at the aggregate. These approaches are meant to deliver (i) economic growth and equity; not leaving any region behind, (ii) conserving natural resources and the environment; for us and future generations and (iii) social development, that is, ensure rich fabric of social and cultural diversity, ensure rights of workers, empowerment and at the same time ensure jobs, education, food, health care, energy etc.

3.3 Key Indicators of Sustainable Development

The key indicators of sustainable development were published in 1996 and then revised in 2001 and 2005. The themes of the sustainable development indicators are (1) poverty, (2) governance, (3) health, (4) education, (5) demographics, (6) natural hazards, (7) atmosphere, (8) land, (9) ocean, seas and coasts, (10) freshwater, (11) biodiversity, (12) economic development, (13) global economic partnership and (14) consumption and production patterns. There is a core set of 50 indicators, which are part of a larger set of 96 indicators of sustainable development (Table 1.1). The core set helps to keep the indicator set manageable, whereas the larger set allows the inclusion of additional indicators that enable countries to do a more comprehensive and differentiated assessment of sustainable development (United Nations, 2007).

4 Global Degradation of the Environment

The environmental degradation in industrialised countries is mostly chemical and that of developing countries is mainly physical, in the form of soil erosion and desertification. However, chemical or biological or physical degradation cannot happen in isolation without impacting the others. A report of the Czech Geological Survey on biogeochemical cycles of elements in relation to rates of weathering and

Table 1.1 CSD indicators of sustainable development

Theme	*Sub-theme*	*Core indicator*	*Other indicator*
Poverty	Income poverty	Proportion of population living below national poverty line	Proportion of population below $1 a day
	Income inequality	Ratio of share in national income of highest to lowest quintile	
	Sanitation	Proportion of population using an improved sanitation facility	
	Drinking water	Proportion of population using an improved water source	
	Access to energy	Share of households without electricity or other modern energy services	Percentage of population using solid fuels for cooking
	Living conditions	Proportion of urban population living in slums	
Governance	Corruption	Percentage of population having paid bribes	
	Crime	Number of intentional homicides per 100,000 population	
Health	Mortality	Under-five mortality rate	
	Life expectancy at birth	Healthy life expectancy at birth	
	Health care delivery	Percent of population with access to primary health care facilities	Contraceptive prevalence rate
		Immunisation against infectious childhood diseases	
	Nutritional status	Nutritional status of children	
	Health status and risks	Morbidity of major diseases such as HIV/AIDS, malaria, tuberculosis	Prevalence of tobacco use
			Suicide rate

(continued)

Table 1.1 (continued)

Theme	*Sub-theme*	*Core indicator*	*Other indicator*
Education	Education level	Gross intake ratio to last grade of primary education	Life-long learning
		Net enrolment rate in primary education	
		Adult secondary (tertiary) schooling attainment level	
	Literacy	Adult literacy rate	
Demographics	Population	Population growth rate	Total fertility rate
		Dependency ratio	
	Tourism		Ratio of local residents to tourists in major tourist regions and destinations
Natural hazards	Vulnerability to natural hazards	Percentage of population living in hazard prone areas	
	Disaster preparedness and response		Human and economic loss due to natural disasters
Atmosphere	Climate change	Carbon dioxide emissions	Emissions of greenhouse gases
	Ozone layer depletion	Consumption of ozone depleting substances	
	Air quality	Ambient concentration of air pollutants in urban areas	
Land	Land use and status		Land use change
			Land degradation
	Desertification		Land affected by desertification
	Agriculture	Arable and permanent cropland area	Fertiliser use efficiency
			Use of agricultural pesticides
			Area under organic farming
	Forests	Proportion of land area covered by forests	Percent of forest trees damaged by defoliation
			Area of forest under sustainable forest management

(continued)

Table 1.1 (continued)

Theme	*Sub-theme*	*Core indicator*	*Other indicator*
Oceans, seas and coasts	Coastal zone	Percentage of total population living in coastal areas	Bathing water quality
	Fisheries	Proportion of fish stocks within safe biological limits	
	Marine environment	Proportion of marine area protected	Marine trophic index
			Area of coral reef ecosystems and percentage live cover
Freshwater	Water quantity	Proportion of total water resources used	
		Water use intensity by economic activity	
	Water quality	Presence of faecal coliforms in freshwater	Biochemical oxygen demand in water bodies
			Wastewater treatment
Biodiversity	Ecosystem	Proportion of terrestrial area protected, total and by ecological region	Management effectiveness of protected areas
			Area of selected key ecosystems
			Fragmentation of habitats
	Species	Change in threat status of species	Abundance of selected key species
			Abundance of invasive alien species
Economic development	Macroeconomic performance	Gross domestic product (GDP) per capita	Gross saving
		Investment share in GDP	Adjusted net savings as percentage of gross national income (GNI)
			Inflation rate
	Sustainable public finance	Debt to GNI ratio	
	Employment	Employment-population ratio	Vulnerable employment
		Labour productivity and unit labour costs	
		Share of women in wage employment in the non-agricultural sector	

(continued)

Table 1.1 (continued)

Theme	*Sub-theme*	*Core indicator*	*Other indicator*
	Information and communication technologies	Internet users per 100 population	Fixed telephone lines per 100 population
			Mobile cellular telephone subscribers per 100 population
	Research and development	Gross domestic expenditure on R&D as a percent of GDP	
	Tourism	Tourism contribution to GDP	
Global economic partnership	Trade	Current account deficit as percentage of GDP	Share of imports from developing countries and from LDCs
			Average tariff barriers imposed on exports from developing countries and LDCs
	External financing	Net official development assistance (ODA) given or received as a percentage of GNI	Foreign direct investment (FDI) net inflows and net outflows as percentage of GDP
			Remittances as percentage of GNI
Consumption and production patterns	Material consumption	Material intensity of the economy	Domestic material consumption
	Energy use	Annual energy consumption, total and by main user category	Share of renewable energy sources in total energy use
		Intensity of energy use, total and by economic activity	
	Waste generation and management	Generation of hazardous waste	Generation of waste
		Waste treatment and disposal	Management of radioactive waste
	Transportation	Modal split of passenger transportation	Modal split of freight transport
			Energy intensity of transport

erosion (Paces, 1991) states that acidification increased the rate of chemical erosion and agriculture increased mostly the rate of mechanical erosion. Chemical erosion increased by a factor of 1.5 due to agriculture and by a factor of 2.9 due to acidification. Agricultural practices increased mechanical erosion by 2.7 times, while acidification due to industrial emissions increased the mechanical erosion by 1.9 times.

Major categories of contaminants of the environment are inorganic chemicals, organic chemicals, pathogenic microorganisms and radioactive nuclides.

4.1 Inorganic Chemicals

The common inorganic contaminants are chloride ion (Cl^-), heavy metals (Pb, Hg, Cd, Cr and Ni), metalloid (As), phosphorous present as phosphate ion (PO_4^{2-}). Some of the inorganic chemicals such as Pb, Cd, Hg, As etc. are highly toxic; their toxicity depends upon their speciation.

4.2 Organic Chemicals

These are substances containing carbon and its derivatives. Many of these chemicals will frequently contain hydrogen with or without oxygen, nitrogen, sulphur, phosphorus, and other elements. They exist in either carbon chain or carbon ring form. Thousands of synthetic organic chemicals are used in drugs, pesticides and food additives, which could reach man through the food chain. These include low-molecular weight chlorinated hydrocarbons such as vinyl chloride, pesticides such as toxaphene, endrin, methoxychlor, lindane (gamma-hexachlorocyclohexane) and DDT (dichlorodiphenyltrichloroethane), other contaminants such as PCBs (polychlorinated biphenyls), dioxin etc. Low-molecular weight hydrocarbons are known to cause cancer in laboratory animals. Therefore, no safe limit can be prescribed for some of these highly toxic compounds. Even in cases where 'no effect' levels in drinking water have been indicated, they are based on animal experiments and their long-term effects on human being are unknown.

4.3 Pathogenic Microorganisms

They include fungi, bacteria, viruses and even parasites that are derived from human and animal wastes and cause infectious diseases such as chickenpox, measles, typhoid, hepatitis, encephalitis. These microorganisms are contagious and transmitted by insects, animals and by taking contaminated food and water. These diseases are quite common in developing countries with poor sanitation. The standard indicator of pathogenic contamination is the number of *Escherichia coli* per 100 ml of water. The faecal coliform bacteria are not themselves pathogenic, but their presence indicates the existence of other pathogenic microorganisms such as streptococci.

4.4 Radioactive Nuclides

A radioactive nuclide is an atom that has excess nuclear energy, making it unstable. This excess energy can be emitted from the nucleus as gamma radiation or transferred to one of its electrons to release it as a conversion electron; or used to create and emit a new particle (alpha particle or beta particle) from the nucleus. Radioactive nuclides occur naturally or are artificially produced in nuclear reactors, cyclotrons, particle accelerators, radionuclide generators or nuclear weapon tests. Radioactive nuclides such as ^{137}CS, ^{222}Rn, ^{238}U, ^{235}U, ^{90}Sr, ^{131}I, ^{239}Pu etc. may cause harmful effects as radioactive contamination. They can also cause damage if they are excessively used during treatment. Exposure to radioactive nuclides can damage the functions of healthy tissue/organs or produce effects ranging from skin redness and hair loss, to radiation burns and acute radiation.

5 Causes of Environmental Destruction

There are three over lapping causes of environmental destruction (Hempel, 1996), each focusing on a particular aspect of the problem: (i) contamination (pollution), (ii) eco-simplification (lost complexity) and (iii) natural resource depletion (consumption) (Fig. 1.1).

5.1 Contamination/Pollution

Contamination refers to the presence in the environment of a material at undesirable concentrations, whereas pollution is the presence of a material in the environment at undesirable concentrations that causes harm. According to this view, environmental destruction occurs as a result of generation of unwanted material in all forms from human activities. As a result, toxic chemicals have slowly built up in forests, rivers, lakes and wetlands. The response for improving environmental quality is by setting up of poison-control centres to combat the waste products produced by modern man. Human responsibility fundamentally ends with pollution control.

5.2 Eco-simplification

Eco-simplification is the biodiversity loss as a result of extinction of species globally and also loss of species in a certain habitat arising from human development activities. The principle indicator of environmental destruction is the level of biological complexity indicated by the increasing number of threatened or endangered

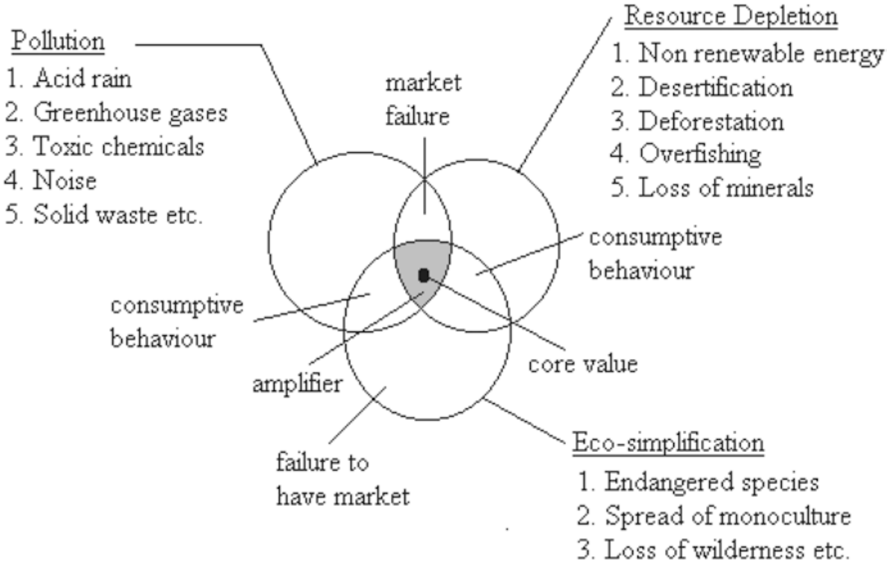

Fig. 1.1 Types of environmental destruction and their driving forces (*Source*: Hempel, 1996)

species. It has been estimated that anthropogenic extinction of about 5 lakhs to 2 million species have occurred by the end of the last century (U.S. Council on Environmental Quality, 1980) as result of deforestation, trade in endangered species, sport hunting, over-fishing and toxic pollutants. Tropical deforestation accounts for the loss of up to 6000 species a year, which is 10,000 times greater than natural extinction rates at the beginning of human civilisation (Wilson, 1989).

5.3 Natural Resource Consumption

Consumption of natural resources at a rate faster than they can be replenished leads to environmental destruction. The fundamental difference of natural resource consumption with that of contamination and eco-simplification is that the latter two are inadvertent results of human development whereas the former is intentional and targeted. According to this view to protect the environment, it is imperative to carry out 'natural resource accounting' in which un-priced ecological services are included in national income based on the cost that would be required to substitute or repair them.

The major causal factors or driving forces that are involved in the above-mentioned three types of environmental destruction are: (i) anthropocentrism, (ii) contempocentrism, (iii) technological advance, (iv) human population growth, (v) poverty, (vi) affluence, (vii) market failure and (viii) failure to have market.

Anthropocentrism and contempocentrism are the core values of environmental destruction, that is, the fundamental belief structures that influence human attitudes towards ecology. Anthropocentrism refers to the pre-occupation with human progress and domination at the expense of other species. Contempocentrism involves the pre-occupation to the present, often at the expense of future generations both human and non-human. Technological advance and human population growth are the amplifiers or the instrumental means by which human values, behaviour and possessions are expanded or extended. Technological advance represents the enormous impact for good and ill that technological developments have on the environment. Population factors involve the arrangement that human numbers are exceeding the ecological capacity. Poverty and affluence are the indicators of the tension between human need and its ecological consequences as a function of material wealth. Poverty factor involves creation of ecological poverty, a condition in which over 1 billion individuals living at or near subsistence level are devouring habitat and natural resources in their search for food, water, energy and other necessity of life. Affluence is the driving force whose 'throw away' consumer life style encourages environmental destruction through over consumption and through lack of concern of natural resource depletion. Market failure and failure to have market are the dominant economic structure and ideology that is political economy, used to explain environmental problems. Market failure involves un-priced cost of environmental harm (such as acid rain pollution) caused due to goods and services, for example, consumption of energy, food, water, building materials. Failure to have market is due to the absence of assigned property rights or to a failure to recognise economic value in vital ecological resources and services, for example, over-fishing.

6 Environmental Issues of Major Habitats

6.1 Oceans, Seas, Small Islands, Coral Reefs and Beaches

6.1.1 Issues and Problems

The major problems in this environment are:

(i) Sea level rise due to global warming which would flood low lying coastal areas, submerge small islands and increase in the severity of coastal storm damage.

(ii) In some inland seas such as the Aral Sea in Central Asia lying between Kazakhstan in the north and Uzbekistan in the south with an area of 68,000 km^2 has been shrinking since the 1960s after the rivers that fed it were diverted by irrigation projects. By 2004, the Aral Sea was split into four lakes with surface area of 17,160 km^2. Satellite images taken by NASA in August 2014 revealed that the eastern basin of the Aral Sea had completely dried up, which is now called the Aralkum Desert. The Aral Sea is considered an example of ecosystem collapse (Keith et al., 2013). The region's fishing industry has been destroyed resulting in unemployment and economic hardship. The area is also heavily polluted, with consequential health problems including high rates of certain forms of cancer and lung diseases.

(iii) Damage to fish, wildlife, human health and amenity due to pollution in the high sea or in coastal waters from oil slicks or surreptitious dumping of hazardous waste at sea. Raw sewage, industrial waste and agro-chemicals also pollute the coastal waters.
(iv) Over-exploitation of aquatic resources is becoming an increasing problem. Fish stocks are also being depleted locally by poorly designed fishing techniques and inshore pollution.
(v) Saline water intrusion into fresh groundwater, risk from storms and rising sea level in small low-lying islands, especially coral atolls.
(vi) Dynamite blasting and excavation of beach sand are damaging reefs and beaches. Algal blooming from industrial and agro-chemical effluent is also a problem to tourism adjacent to areas of industry or intensive agriculture.

6.1.2 Environmental Services

There are many environmental services of this aquatic environment. The oceans and seas regulate the earth's climate by absorbing about one-third of the carbon dioxide emitted annually, moderates extreme events, home to numerous plant and animal species, help in element and nutrient cycling, are a source of food (fish make up the primary source of protein for a billion people worldwide), treat waste water generated from industries, agriculture and homes, provide cultural services such as tourism, recreational, aesthetic and spiritual benefits, and provide an important channel for navigation. The ocean is also a source of economic growth: the sea bed is a major source of minerals, oil and gas, and in developing goods out of biological principles (poison contained in cone snail (*Conus magnus*) contain ziconotide, an analgesic agent currently used in the medical sector). The minor products of the seas such as sea-weed, shells and live tropical fish are of considerable local economic importance. Mangrove ecosystem helps to bind soils on the coast and prevent coastal erosion. They are also natural barriers to water currents along with coral reefs and sea-weeds, and a favoured habitat for the birth and development of many species of fish. Whale faeces also provide an important environmental service. It contains high quantities of iron, which helps in photosynthesis and growth of phytoplankton, which helps in carbon sequestration and storage. The total value of the services produced by marine and coastal ecosystems is valued at US$ 29.5 trillion per year, which is worth more than the USA's gross national product in 2015 (https://ocean-climate.org/?p=3895&lang=en). These environmental services are at threat due to human intervention and may deliver fewer services. To keep supplying many services, it is essential to protect marine biodiversity and reduce to a minimum the human impact on the environmental services. Protecting marine biodiversity means protecting the climate and thus protecting humans.

6.2 Wetlands

Wetlands are '*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters*'—as defined by the Intergovernmental Treaty 'The Convention on Wetlands, 1971'. Water within these areas can be static or flowing; fresh, brackish or saline; and can include inland rivers and coastal or marine water to a depth of 6 m at low tide. In developing countries, three forms of wetlands are important—mangroves, seasonal wetlands in dry areas and deltaic environments.

6.2.1 Issues and Problems

Wetlands, one of the most productive ecosystems on the earth (Ghermandi et al., 2008) is threatened due to anthropogenic pressures such as increasing human population, large scale changes in land use/land cover, burgeoning development projects and improper use of watersheds. Loss of wetlands can be of two types: acute and chronic (Prasad et al., 2002). Acute loss takes place due to agricultural conversion, direct deforestation in wetlands, hydrologic alteration and inundation by dammed reservoirs. Chronic loss occurs as a result of degradation of water quality, groundwater depletion, introduction of exotic species (like water hyacinth and *Salvinia*) and extinction of native biota.

According to Turner (1988), the main threats to wetlands are in-filling, excavation, changes in hydrology, chemical changes and biological effects. In-filling of wetlands are mostly deliberate and occurs adjacent to urban areas and major road networks using construction and demolition waste, comprised of sand, stone, concrete, bitumen and other wastes from building sites. Wetlands are also destroyed as a part of planned city development such as Singapore and Hong Kong. Coastal wetlands are threatened by buildings and industries, mostly polluting ones that need to be sited away from the urban areas. Agriculture may also encroach wetlands by converting them to arable or livestock production. Excavation destroys wetland landscape and limits their value for other uses. Extraction of peat (e.g., Poland, Ireland) oil and gas (Nigeria, Cameroon), sand (Nigeria), bauxite, iron ore (Ivory Coast) and extraction of salt from boiling brine (Ivory Coast) has changed the landscape of the area. Wetlands are also threatened by changes in hydrology such as upstream development (construction of dam, irrigation, drainage), coastal works or construction of roads, railways etc., which disturbs the surface runoff. Untreated industrial effluents, untreated sewage, runoff from irrigated agriculture, immersion of idols, religious ritual waste have become a major threat to the survival of wetlands. High nutrient contents in the inflow water stimulate algal growth, leading to eutrophication of surface water bodies. Introduction of exotic fauna, over-hunting, over-fishing and unregulated aquaculture may also upset the delicate balance of the wetland ecosystem and cause its destruction. Global climate change is also expected to become an important driver of loss and change in wetland ecosystem.

6.2.2 Environmental Services

The key services provided by wetlands such as tanks, ponds, lakes, and reservoirs comprise carbon sequestration, flood control, water for irrigation, domestic needs and fisheries, natural protection to coastlines, silt capture, groundwater recharge, nutrient removal, toxics retention, habitat for wildlife, biodiversity maintenance, tourism and recreation, and transport.

Swamps, mangroves, peat lands and marshes play an important role in carbon cycle. They sequester carbon through high rates of organic matter inputs and reduced rates of decompositions (Pant et al., 2003). Wetland soils may contain as much as 200 times more carbon than its vegetation. Large wetlands also have micro-climatic effects. Wetlands act as a sink for contaminants in many agricultural and urban landscapes. They help to lessen the impacts of flood by absorbing water, reducing the speed at which flood water flows and trapping suspended solids and nutrient load. Lakes and ponds were built in Srinagar, Bhopal, Bengaluru, Chennai, Hyderabad etc. to control flood. In many states across India, tanks were constructed to provide irrigation water (Palanisami et al., 2010; Pant and Verma, 2010). These tanks are also used for fisheries and as source of water for bathing and domestic uses. They also help to conserve soil and bio-diversity, and regulate groundwater storage and recharge. Many lakes provide recreational and tourism, fisheries, irrigation and domestic water supply services, and also recharges groundwater body (Jain et al., 2007). Notable amongst them are: Carambolim (Goa), Chilka (Orissa), Dal Jheel (Jammu and Kashmir), Deepor Beel (Assam), Khabartal (Bihar), Kolleru (Andhra Pradesh), Loktak (Manipur), Nainital (Uttarakhand), Nal-sarovar (Gujarat) and Vembanad (Kerala). Coastal wetlands (mangrove) play a significant role protecting land from erosion, help in trapping silt and carbon sequestration. Overall, mangroves are able to sequester about 1.5 metric tonne of carbon per hectare per year (Kathiresan and Thakur, 2008). Lagoons and salt flats protect the coast by reducing the velocity of tidal waves related to hurricanes and storms. Wetlands are also breeding areas for domestic and migratory birds from western and European countries during the winter months. The creeks and channels of coastal wetlands offer network for transport in areas where roads are lacking and difficult to provide such as in the Sundarbans. Wetlands also support species diversity. Some vertebrates and invertebrates depend on wetlands for their entire life cycle while others only associate with these areas during particular stages of their life. Wetlands are also linked to the local culture (Pushkar lake in Rajasthan) and are means of livelihood of many.

6.3 Watersheds

Watershed is a hydrogeological unit draining into a single channel by a system of streams. It is all the land and water area that contributes runoff to a common point. A watershed is a complex system encompassing biological, physical, economic and social systems. About half of the world's population is affected by watershed degradation (Winpenny, 1991). The causes of watershed degradation are: deforestation and destruction of natural vegetation, overexploitation of arable lands, overgrazing, unadjusted irrigation techniques, population pressure, construction of roads, highways, housings and other civil structures.

6.3.1 Issues and Problems

Degradation of watershed leads to increased exposure of the earth to the mechanical effects of rain and runoff leading to soil erosion, reduced soil fertility and greater runoff. This results in gully erosion and flooding. As a result of high runoff, water retention is less, which reduces infiltration of water into the aquifer leading to fall in local water table and water shortages in wells and springs. The eroded soils are transported and deposited in the rivers, reservoirs, lakes and irrigation works. This increases the risk of flooding, affects fisheries and reduces the capacity of dams and irrigation systems. The quality of water in a watershed is also deteriorated because of increase in suspended solids as a result of erosion and contamination from polluted water from agricultural fields because of overuse of chemical fertilisers and pesticides.

6.3.2 Environmental Services

A healthy watershed significantly improves the quality of life of the people and the environment. The services provided are (i) ecosystem services, (ii) economic benefits and (iii) physical and mental health benefits.

Ecosystem services: They include soil formation, carbon storage, nutrient cycling, erosion/sedimentation control, water storage, water filtration, flood control, increased biodiversity, food, timber and recreation as well as reduced vulnerability to natural disasters, invasive species and the effects of climate change. These vital services are often undervalued when making land use decisions.

Economic benefits: Healthy watersheds reduce capital costs for water treatment and flood mitigation costs, increase tourism, job opportunities and property values.

Physical and mental health benefits: They include lower rates of illness, decreased stress and improved cognitive development, and higher likelihood to exercise.

6.4 Forests

Forests are the dominant terrestrial ecosystem of the earth and cover about one-third of the earth's land area, and are essential to the health of our environment. They account for 75% of the gross primary production of the earth's biosphere, and contain 80% of the earth's plant biomass. Net primary production is estimated at 21.9 gigatonnes carbon per year for tropical forests, 8.1 gigatonnes carbon per year for temperate forests and 2.6 gigatonnes carbon per year for boreal forests (Pan et al., 2013).

6.4.1 Issues and Problems

Forests are exposed to natural and anthropogenic threats. Natural threats are fire, insect disease, high wind and ice storms. Anthropogenic threats could be agribusiness, illegal logging, mining, road building, hydroelectric dams, climate change and invasive species. Agribusiness, such as palm oil plantation (Indonesia) and cattle ranching (Amazon countries), is the number one driver of deforestation that has cleared huge areas of forest into monocultures followed by illegal logging in Amazon, Central Africa, Southeast Asia and Russia.

6.4.2 Environmental Services

The key services of forests are carbon sequestration, regulation of water cycles, maintaining soil quality and reducing the risks of natural disasters such as floods. Forests also inhibit soil erosion, protect the stability of slopes and control the land surface temperature, rate of evaporation and siltation in rivers. Species diversity in forests is enormous. They are storehouse of numerous plant and animal species including medicinal plants, which store genetic material for pharmaceutical and pest control products. Forests also provide life-support system to the forest-dwellers and local people and are source of commercial products such as hardwood, essential oils, medical substance, rubber, bamboo, flowers, resins, honey, beeswax etc. Forest ecosystem has ecological links with neighbouring ecosystems. Disruption of the link may lead to degradation of the ecosystems. Lastly, forests have aesthetic and spiritual values to human.

6.5 Drylands

Drylands are areas of water scarcity with low precipitation, heat waves and droughts. The United Nations Environment Programme (UNEP) has defined drylands based on an aridity index (AI), which is the ratio between average annual precipitation and

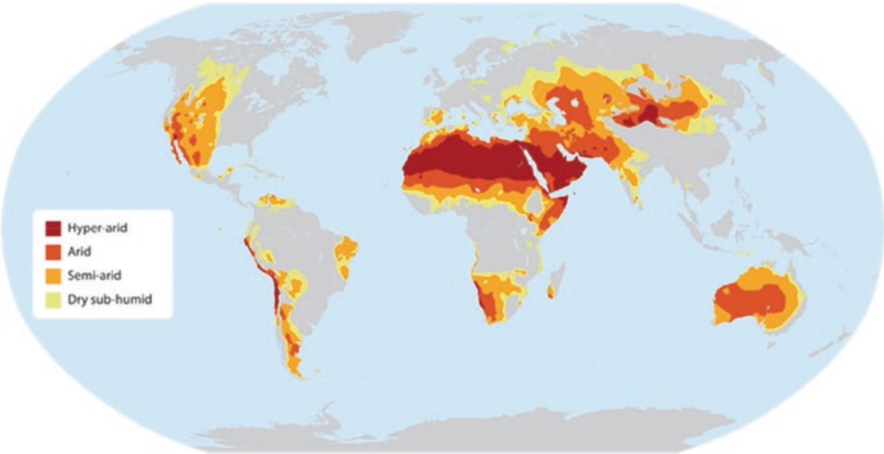

Fig. 1.2 The world's drylands and subtypes (*Source:* UNEP-WCMC, 2007)

potential evapotranspiration. If the AI of an area is <0.65, then the area is called dryland. According to UNEP, drylands can be categorised into hyper-arid lands (AI < 0.03), arid lands (AI = 0.03–0.20), semi-arid lands (AI = 0.20–0.50) and dry sub-humid lands (AI = 0.50–0.65) (Fig. 1.2). Drylands are found in most of the world's biomes and climatic zones and constitute 41% of the global land area. In the developing world, drylands are found in Africa, north east Indian Subcontinent, Central Asia, parts of Thailand, Mexico, Argentina, Bolivia and north-east Brazil.

6.5.1 Issues and Problems

Drylands are subject to wind and water erosion, intensive mineral weathering and low fertility. As a result, drylands are focus of desertification, which reduces the biological productivity of drylands. The causes of desertification are climate change, deforestation, overgrazing, poverty, population growth, migration, unsustainable irrigation practices or combination of these factors.

Climate change and human activities have profound effect on desertification in four land use/land cover classes. The soils of irrigated croplands are often degraded by accumulation of salts from evaporation of runoff water. Salt-degraded croplands are mostly found in Asia and southwestern North America. Rainfed croplands are also subjected to soil erosion by wind and rain when the lands are left uncovered after harvesting the crop. Desertification may also occur in grazing lands due to over-grazing, soil compaction and erosion. The fourth area where desertification can take place is in dry woodlands across large areas of Asia and Africa due to over-consumption of fuel-wood.

6.5.2 Environmental Services

The environmental services rendered by drylands are provisioning, regulating, cultural and supporting services (MEA, 2005). Provisioning services include goods produced or provided by the ecosystems such as food, fibre, forage, fuelwood, fruits, nuts, fibres, animal fodders, medicines, biochemicals, livestock, wildlife and fresh water. Regulating services are benefits derived from regulation of ecosystem processes such as water purification and regulation, pollination and seed dispersal, climate regulation. Non-material benefits derived from ecosystems are cultural services that include recreation and tourism, cultural identity and diversity, cultural landscapes and heritage value, indigenous knowledge systems, and spiritual, aesthetic and inspirational services. The supporting services maintain the conditions of life on the earth such as soil development, primary production and nutrient cycling.

6.6 Irrigated Farming Areas

Most of the developing world's food is from irrigated farming areas. Irrigation water comes from groundwater through motor driven wells or springs, and surface water through rivers, lakes or reservoirs. Sometimes wastewater is also used for irrigation. Use of irrigated water increased agricultural production worldwide and contributed immensely to poverty alleviation, food security, lower food price, higher employment and ushered in the Green Revolution in the developing countries in the late 1960s. Green revolution brought in high-yielding varieties of rice, chemical fertilisers and pesticides.

6.6.1 Issues and Problems

The dependence on irrigated farming has several negative environmental effects. They are increased erosion; pollution of surface water and groundwater; water logging and high nutrient levels in water resulting in algal blooms; proliferation of aquatic weeds and eutrophication in irrigation canals and downstream waterways. Poor water quality downstream of an irrigation project may render the water unfit for other users, harm aquatic species and growth of aquatic weed. All these may have serious negative ecological consequences. Large irrigation projects with reservoirs and canal system may change the hydrology or limnology of river basins. Reduction in flow of water in the river may change the landuse pattern of flood plains, cause saline water intrusion and reduces baseflow and water supply for downstream users, including municipalities, industries and agriculture. Intensive groundwater irrigation may result in the lowering of the water table, saline water intrusion in coastal areas, decreased water quality and in extreme cases land subsidence. Other possible negative impacts are salinisation of soils, increase in incidence of water-borne and water-related diseases, occupational diseases to farm workers handling dangerous chemical pesticides and air pollution from spaying pesticides. Methane from irrigated rice fields contribute in a minor way to the 'greenhouse effect'.

6.7 Industrial and Urban Concentrations

Industrial and urban concentrations, although not synonymous, can be dealt simultaneously as many cities in the world are also major industrial centres, such as Kolkata, Mumbai, Bangkok, Mexico city etc. Urbanisation process started during industrial revolution, when people moved from the rural areas to the cities for economic opportunities, better infrastructure and utilities and availability of public facilities. An urban area has high population density and infrastructure of built environment. The resources of a city are shared by the masses and individual users act independently based on their self-interest depleting resources through collective action such as in the 'tragedy of the commons'. City development provides important gains in productivity and economies in distributing public services and these have to be set off against the environmental effects of conurbations (Winpenny, 1991).

6.7.1 Issues and Problems

Rapid urbanisation leads to decline in quality of life for urban inhabitants. The poor people are forced to live in slums lacking basic public services. The living condition of the well-to-do people in the central areas is also deteriorating due to overcrowding. The need for more housing and other infrastructure results in filling up of wetlands and low-lying areas resulting in water logging. Pollution and physical barriers to root growth results in loss of urban tree cover. Overcrowded conditions lead to diseases such as tuberculosis, influenza, meningitis, mumps and measles, especially among children. Air pollution is very common in the cities of the developing countries. The main pollutants are carbon monoxide, ozone, nitrogen dioxide, sulphur dioxide, air borne lead and suspended particulate matter. The main sources of these pollutants are industrial emissions, fuel burnt for power generation or heating, burning of solid waste and exhausts from motor vehicles, especially diesel powered. The worst air pollution is observed in cities like Kolkata, Delhi, Seoul, Sao Paulo, Bangkok, Dacca etc. Air pollution causes disease like bronchitis, tuberculosis, skin and eye burning, lung cancer. Apart from diseases, air pollution also causes corrosion damage to buildings and structures, for example, the Taj Mahal in Agra, Victoria Memorial in Kolkata, the Egyptian Sphynx. Large volume of uncollected waste from households, markets, hospitals, public utilities and industry also causes air pollution, drainage congestions, groundwater pollution and multiple health hazards. Water pollution is also a menace in city life, which is caused by untreated or partially treated sewage, industrial effluent and waste water runoff from households. Polluted water spread diseases like chronic dysentery, diarrhoea etc. in people who use it for washing, cooking and bathing. Polluted surface water may also pollute the groundwater. Intensive groundwater withdrawal may also lead to land subsidence, water logging and saline water intrusion in coastal cities. Noise is also perceived as pollution. Ambient noise level in cities is high because of heavy traffic, construction and industrial activities, use of loud speakers and aircraft movement. The effects of noise pollution are hearing impairment, annoyance, psychiatric disorders, sleep disturbance, hypertension and cardiovascular disease. Another important issue in cities is creation of heat island. The main cause of the urban heat island effect is from modification of land surfaces. The rural areas have natural land surface comprising soil and vegetation, whereas urban areas land surface is covered by materials like concrete, asphalt, bricks etc. The absorption and reflectance of energy from the land surface is different in urban and rural areas resulting in warmer night in cities compared to the rural areas. The urban heat island effect is most perceptible during summer and winter.

6.7.2 Environmental Services

There are seven different urban ecosystems. They are street trees, lawns/parks, urban forests, cultivated land, wetlands, lakes/sea and streams (Bolund and Hunhammar, 1999). These systems generate a range of environmental services such as air filtering, micro-climate regulation, noise reduction, rainwater drainage, sewage treatment and recreational/cultural values.

7 Conclusions

The earth at present is sitting on the edge of a severe environmental crisis. This chapter has highlighted the current environmental issues and problems of major habitats and the environmental services they provide to make the earth habitable. The following chapters will present detail insight into the natural processes and systems, use of technologies such as remote sensing, global positioning systems (GPS) and geographical information systems (GIS) for identifying different habitats, pollution removal technology, energy conservation, disaster management, environmental impact assessment process, economics, culture, political structure and societal equity to overcome the environmental crisis the earth faces today.

References

Barbier, E.B.(1987). The concept of sustainable development. *Environ Conserv*, **14(2):** 101–110.
Bolund, P. and Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecol Econ*, **29:** 293–300.
Brundtland (1987). Our Common Future. Report of the World Commission on Environment and Development. Oxford University Press, Oxford.

Ghermandi, A., van den Bergh, J.C.J.M., Brander, L.M., and Nunes, P.A.L.D. (2008). The Economic Value of Wetland Conservation and Creation: A Meta-Analysis. Working Paper 79. Fondazione Eni Enrico Mattei, Milan, Italy.

Hempel, L.C. (1996). Environmental Governance: The Global Challenge. Island Press, Washington, USA.

Jain, S.K., Agarwal, P.K. and Singh, V.P. (2007). Hydrology and Water Resources of India. Springer, The Netherlands.

Kathiresan, K. and Thakur, S. (2008). Mangroves for the Future: National Strategy and Action Plan, India. Ministry of Environment and Forests, New Delhi.

Keith, D.A., Rodríguez, J.P., Rodríguez-Clark, K.M., Aapala, K., Alonso, A., Asmussen, M., Bachman, S., Bassett, A., Barrow, E.G., Benson, J.S., Bishop, M.J., Bonifacio, R., Brooks, T.M., Burgman, M.A., Comer, P., Comín, F.A., Essl, F., Faber-Langendoen, D., Fairweather, P.G., Holdaway, R.J., Jennings, M., Kingsford, R.T., Lester, R.E., Mac Nally, R., McCarthy, M.A., Moat, J., Nicholson, E., Oliveira-Miranda, M.A., Pisanu, P., Poulin, B., Riecken, U., Spalding, M.D. and Zambrano-Martínez, S. (2013). Scientific foundations for an IUCN red list of ecosystems. *PLoS One*, **8(5):** e62111, doi:https://doi.org/10.1371/journal.pone.0062111.

MEA (Millennium Ecosystem Assessment) (2005). Ecosystems and Human Well-being: Desertification Synthesis. World Resources Institute, Washington, DC.

MOEF (Ministry of Environment and Forest) (1999). State of the Environment Report, Ministry of Environment and Forest, Government of India.

Paces, T. (1991).Anthropogenic effects of mass balance of weathering and erosion. *In:* Selinus, O. (ed). Second International Symposium on Environmental Geochemistry. Uppsala, September 1991.

Palanisami, K., Meinzen-Dick, R. and Giordano, M. (2010). Climate change and water supplies: options for sustaining tank irrigation potential in India. *Econ Polit Wkly*, **45(26–27):** 183–190.

Pan, Y., Birdsey, R.A., Phillips, O.L. and Jackson, R.B. (2013). The structure, distribution, and biomass of the world's forests. *Annu Rev Ecol Evol Syst*, **44:** 593–622, doi:https://doi.org/10.1146/annurev-ecolsys-110512-135914.

Pant, H.K., Rechcigl, J.E. and Adjei, M.B. (2003). Carbon sequestration in wetlands: Concept and estimation. *Food Agric Environ*, **1(2):** 308–313.

Pant, N. and Verma, R.K. (2010). Tanks in Eastern India: A Study in Exploration. International Water Management Institute-TATAWater Policy Research Program and Centre for Development Studies, Hyderabad and Lucknow, India.

Prasad, S.N., Ramachandra, T.V., Ahalya, N., Sengupta, T., Kumar, A., Tiwari, A.K., Vijayan, V.S. and Vijayan, L. (2002). Conservation of wetlands of India – A review. *Trop Ecol*, **43(1):** 173–186.

Turner, R.K. (1988). The Environmental Effects of Market and Intervention Failuresin the Management of Wetlands. Report to the Environment Committee Group of Economic Experts, OECD, Paris, November.

UNEP-WCMC (2007). A spatial analysis approach to the global delineation of dryland areas of relevance to the CBD Programme of Work on Dry and Subhumid Lands. Available at https://www.unep-wcmc.org/system/dataset_file_fields/files/000/000/323/original/dryland_report_final_HR.pdf?1439378321 (Accessed on 29.01.2021)

United Nations (2007). Indicators of Sustainable Development: Guidelines and Methodologies. United Nations Publication (Third Edition), ISBN 978-92-1-104577-2.

U.S. Council on Environmental Quality (1980). The Global 2000 Report to the President 1. US Government Printing Office, Washington, D.C.

Wilson, E.O. (1989). Threats to biodiversity. *Scientific Am*, **261(September):** 108–112.

Winpenny, J.T. (1991). Value for the Environment: A Guide to Economic Appraisal. Overseas Development Institute, London.

Chapter 2
Earth Science in Environmental Management

Reshmi Das and Meenakshi Mukherjee

1 Introduction

Since the industrial revolution our environment is increasingly affected by anthropogenic impact. An in-depth knowledge of earth science and geo-ecosystems is required to protect the environment and landscapes for the future generations. Environmental management integrates knowledge from natural science disciplines such as physical geography, landscape ecology, remote sensing, bio-geochemistry, environmental geochemistry to name a few with thorough understanding of earth science. The primary earth science topic that needs to be addressed in environmental management can be divided into natural processes and anthropogenic processes. For example, volcanic eruptions, earthquakes, landslides, natural coastal processes disrupt living conditions and need constant monitoring and aftermath management from both social and environmental point of view. On the other hand, increasing population pressure is depleting freshwater and fossil fuel resources, modifying natural landscapes, producing colossal amounts of wastes and releasing toxic chemicals in the environment. Anthropogenic activities are constantly modifying our environment, which are directly impacting our food, water quality and climate. In this chapter, we will discuss both the natural and anthropogenic activities that are affecting our environment in tandem with their associated environmental problems and risks.

R. Das (✉) · M. Mukherjee
School of Environmental Studies, Jadavpur University, Kolkata, India
e-mail: reshmidas.sest@jadavpuruniversity.in

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_2

2 Freshwater

Freshwater is any naturally occurring water with salinity <0.5% and <500 parts per million (ppm) of dissolved salts. The source of freshwater is atmospheric precipitation in the form of mist, rain and snow, and are stored in ice caps, glaciers, ponds, lakes, swamps, rivers and as groundwater. There is a common misnomer that freshwater is synonymous with drinking water (or potable water). However, in reality, much of the earth's freshwater needs treatment before drinking. Human activity has threatened freshwater reserve by polluting and depleting groundwater reserve by overdrawing.

With increasing population pressure, there is growing reliance on groundwater for farming and drinking purposes. Groundwater overdraft occurs when groundwater use exceeds recharge amount of an aquifer. This leads to a decline in groundwater level. In case of fine-grained sedimentary rocks, groundwater fills up the pores and is in part responsible for holding up the ground. Overdrawing of groundwater from such types of sedimentary bed rock results in aquifer compaction leading to land subsidence. Ground-based measurements of land subsidence can be made over small spatial scales, but remotely-sensed observations are essential for spatially comprehensive mapping of deformation over large regions. This regional scale subsidence scenario is occurring in several groundwater basins in California. Approximately, 5200 square miles of land surface has been affected by subsidence in the San Joaquin Valley alone and has been identified as the single largest human alteration of the earth's surface topography. Drought conditions exacerbate subsidence rate due to over withdrawal of groundwater by farmers. Land subsidence up to 52 mm/year has also been recorded in Northern Beijing where groundwater drawdown and geological structure control the subsidence values (Zhu et al., 2015). Inelastic compaction of aquifer system from declining water table has resulted in land subsidence in Hangzhou-Jiaxing-Huzhou Plain in China (Cao et al., 2013), New Jersey, USA (Sun et al., 1999), Emilia-Romagna coastland, Italy (Teatini et al., 2006), Mekong Delta, shared by Cambodia and Vietnam (Erban et al., 2014), Konya Closed Basin (Ustun et al., 2010) to name a few. In India, land subsidence averaging 13.53 mm/year has been reported in Kolkata city and east Kolkata wetlands due to overdraft of groundwater (Sahu and Sikdar, 2011). It is estimated that 1 metre drop in the piezometric head corresponds to a mean subsidence of 3.28 cm.

Land subsidence can have several immediate and visible as well as long-term effects. The greatest effects can be seen in infrastructural damage of manmade structures such as roads, railways, bridges, pipelines, buildings etc. that traverse a subsiding area. In California, water conveyance structures such as the California Aqueduct are gravity driven. Hence, a slight change in gradient of the land can affect groundwater flow capacity. While the above-mentioned effects are visible, which generally can be repaired, the long-term damage is caused in the aquifer capacity to hold water. Most aquifer compaction due to low piezometric surface is irreversible. Hence, even if the piezometric surface rises the aquifer does not revert back to original configuration. Additionally, land subsidence affects topography, which are manifested in wetland migration to lower elevation and erosion/deposition patterns of rivers to attain the new equilibrium.

Land subsidence in coastal region coupled with sea level rise poses a great threat to the population living in the coastal areas. For example, most part of Mekong Delta, shared by Vietnam and Cambodia lies within <2 m of current sea level. Compaction of sedimentary layers due to groundwater extraction is causing land subsidence at an average rate of 1.6 cm/year (Erban et al., 2014). Land subsidence is calculated to be ~0.88 m (0.35–1.4 m) by 2050 if pumping continues at present rates, and anticipated sea level rise will be ~0.10 m (0.07–0.14 m) by 2050. This additive effects water sea-level rise due to global climate change with the regional pumping – induced land subsidence will cause subsurface saline intrusion, damage to infrastructure and increase in the depth and duration of annual flooding.

3 Toxic Chemicals in the Environment

According to US EPA (United States Environmental Protection Agency), 10 chemicals or sources of major public health concern are air pollution, arsenic, asbestos, benzene, cadmium, dioxin and dioxin like substances, inadequate or excess fluoride, lead, mercury and highly hazardous pesticides. In this chapter, we will discuss the sources and pathways of arsenic and fluoride, both being geogenic and needs thorough understanding of earth science.

Arsenic (As) contamination in the groundwater is a serious problem in India and Bangladesh. The Ganga-Meghna-Brahmaputra (GMB) basin is one of the worst arsenic affected regions due to the presence of high concentrations of this toxic metalloid within the upper 50 m depth of aquifers. Geochemical characteristics of aquifers in regions drained by these three rivers have indicated natural groundwater arsenic contamination (Chakraborti et al., 2010). In the 1970s, UNICEF and the World Bank dug thousands of wells in the GMB plain as a solution to provide safe drinking water (Ravenscroft et al., 2005). Prior to 1970s, Bangladesh had the highest infant mortality rate in the world owing to ineffectual water treatment and sewage systems (Hunter et al., 2010). Arsenic is a Group 1 carcinogen as there is sufficient evidence for their carcinogenicity in humans. The World Health Organization (WHO) recommended maximum permissible limit for arsenic in drinking water to be 10 $\mu g\ L^{-1}$ (micrograms per litre). However, due to economic considerations most developing countries including India, still use the former WHO-recommended concentration of 50 $\mu g\ L^{-1}$ as their national standard (Ng et al., 2003).

Unlike other heavy metal pollutants such as mercury and lead, origin of arsenic in groundwater is geogenic that has been accentuated by anthropogenic perturbations. Two principal hypotheses about the origin of arsenic have been suggested. The first hypothesis suggests that the arsenic is derived from the oxidation of As-rich pyrite in the shallow aquifer as a result of lowering of water table due to over extraction of groundwater for irrigation. Arsenic is present in certain sulphide minerals such as pyrites that are deposited within the aquifer sediments (Smedley and Kinniburgh, 2002). Over withdrawal of groundwater lowers the water table below arseno-pyrite (FeAsS) deposits that gets oxidised in the vadose zone and releases arsenic as arsenic adsorbed on iron hydroxide. During subsequent groundwater recharge, iron hydroxide releases arsenic in groundwater. However, the main drawback of this hypothesis is the scarcity of source of arseno-pyrite and preservation of the sulphide mineral in the sediments during long transport (Fazal et al., 2001). A thorough search on Indian geology suggests that arseno-pyrite does not occur as an exclusive mineral deposit and present in small concentrations in base metal deposits. Moreover, the sediments of the Ganga Delta Plains had their provenance in the hills of North Rajmahal. It is highly unlikely that the long riverine transport and exposure to the atmosphere will preserve the sulphide minerals in the sediments. As an alternate hypothesis, it was suggested that arsenic was present in the ferric hydroxide coatings of the aquifer sediments under reducing conditions that got desorbed. The ferric hydroxide were either primary $Fe(OH)_3$ formed during diagenesis or secondary formed during the oxidation of pyrite (Ghosh and Singh, 2009). Irrespective of the exact nature of the source, it was ascertained that the quantity of arsenic present in groundwater (50–3200 μg/L) and adsorbed on the sediment (~8–18 ppm) are extremely large and have caused huge health implications in India and Bangladesh (Lowers et al., 2007).

In the rural affected areas of the GMB plain, besides drinking route exposure, the As contaminated groundwater, which is mainly used for irrigation purpose is also responsible for the entry of As in the food chain. Rice being a kharif crop, requires heavy rainfall for its cultivation. But during the dry season, the paddy cultivation is solely dependent on irrigation by groundwater in rural Bengal, since the sources of surface water regimes become dry during that period (Rahman et al., 2007). Prolonged use of As contaminated groundwater for irrigation practice in a particular land, results in a huge amount of As accumulation in the soil and eventually in the entire paddy plant via its root system. According to the translocation theory (Abedin et al., 2002; Liu et al., 2004), the As translocates and accumulates in paddy grains, which is the edible part of paddy. The grain is marketed either as raw or as sunned rice, which is directly prepared by hulling, or parboiled rice that is prepared by light boiling of paddy using contaminated water, followed by mechanical hulling to obtain parboiled rice. This post-harvesting treatments of the grain using As contaminated water causes additional increment of As in parboiled rice. According to a study, carried out in the fields of Deganga, North 24 Parganas, West Bengal, India, half boiled whole grain showed an increase of 43% in As concentration from that of raw whole grain, and a final increase of 61% was noticed in the full boiled whole grain. A concurrent increase of As concentrations in the water at half boiled and full boiled stages were also observed. An increase of 1.2% and 7.56% of As concentrations were found in half boiled and the full boiled water samples (Chowdhury et al., 2018, 2019). Such increment in As concentrations in the water samples after cooking of rice samples has been reported previously (Ohno et al., 2009). Besides the As contaminated groundwater used for drinking purpose, rural population is also exposed to a huge amount of As accumulating through different cereals and vegetables grown in the affected zones. This has been proved by observing the As concentrations in urine, hair and nail of the population exposed to As contamination in nine affected districts of West Bengal (Rahman et al., 2003).

Arsenic has several toxic effects on human bodies on short-term as well as long-term exposures. Biologically, the trivalent arsenite (As^{3+}) is significantly more toxic than the pentavalent arsenate (As^{5+}), including the ability to induce amplification of genes in mammalian cells. Once absorbed, As combines with haemoglobin rapidly and localises in blood within 24 h and then redistributes itself to various organs like the liver, kidney, lung, spleen and gastro-intestinal (GI) tract, with lesser accumulation in muscles and nervous tissue. After accumulation of a small dose of As, it undergoes methylation primarily in the liver to mono-methyl arsenic acid (MMA) and dimethyl arsenic acid (DMA), which are excreted along with the residual inorganic As in the urine (Kapaj et al., 2006). The most common species of inorganic As, As^{3+} and As^{5+} in the environment show their toxicity in different levels. After entering the cell, As^{5+} substitutes for phosphate in phosphorylation, which leads to the production of unstable arsenical by products like ADP-As^{5+}, which causes the disruption of ATP (adenosine 5-triphosphate) synthesis (Rosen et al., 2011). These unstable arsenical by products spontaneously hydrolyse to ADP and As^{5+}, preventing ATP production. Likewise, other metabolic processes like ATP-dependent transport, glycolysis, pentose phosphate pathway (PPP) and signal transduction pathways (two component and phosphor lay systems, chemotaxis etc.) are also disturbed. On the other hand, As^{3+} has a very strong affinity for sulphydryl groups (Silver and Phung, 2005). Arsenite reacts with cysteine groups and also glutathione, thioredoxin and glutaredoxin, which are present on the active sites of many enzymes, which control intracellular redox homeostasis, DNA synthesis and repair, sulphur metabolism, protein folding and xenobiotic detoxification. Arsine gas binds to red blood cells (RBC), causing haemolysis by damaging the membranes (Čerňanský et al., 2009). Besides, the use of As for a short period of time leads to acute toxicity while exposure for a longer period of time causes chronic toxicity, the symptoms of which are explained in details in Table 2.1.

To prevent further calamities associated with As toxicity, development of mitigation strategies for its remediation is extremely important and an absolute need of the hour (Purakayastha, 2011). Among several ways of remediation including physical processes like immobilisation, stabilisation etc. and chemical process like coagulation, co-precipitation, oxidation, ion-exchange etc., bioremediation (which includes phytoremediation and microbial remediation), is an emerging alternative and has good public acceptance (Lim et al., 2014). Phytoremediation, the use of green plants to remove or degrade contamination from soils and surface waters, has been proposed as a cheap, sustainable, effective, and environmentally friendly approach, alternative to the conventional remediation technologies (Raskin and Ensley, 2000). Phytoremediation is advantageous as this technique helps in treating a variety of contaminants over a diverse range of environment. Phytoremediation also does not require skilled technicians or highly expensive equipment, making it easier to implement. There are various mechanisms of phytoremediation like phytoextraction (which includes phytoaccumulation, phytosequestration and phytoabsorption), phytostabilisation or phytoimmobilisation, phyto-volatilisation, phytodegradation and

Table 2.1 Types of arsenic toxicity and its symptoms

Type of toxicity	*Symptoms*
Acute toxicity	Gastrointestinal (GI) signs: Vomiting (often with blood) and severe cholera like diarrhoea (may be with blood or rice-water like); dehydration and hypovolemic shock.
	Cardiovascular effects: Myocardial dysfunction, ventricular dysrhythmias, diminished systemic vascular resistance, capillary leakage.
	Central nervous system (CNS) manifestations: Seizures, encephalopathy, coma and cerebral oedema.
	After an acute poisoning Alopecia and Mees lines might occur subacutely.
Chronic toxicity	Manifests as a classic dermatitis (hyperkeratosis, 'dew drops on a dusty road' appearance), peripheral neuropathy (usually painful, symmetrical paresthesia with stocking-glove distribution), Melanosis, Keratosis, Arsenicosis.
	Hepatic and renal damage (multi-organ involvement).
	Obliterative arterial disease of lower extremities (blackfoot disease).

(Chakraborti et al., 2004)

phytofiltration (Akhtar et al., 2013; Yadav et al., 2018). Bioremediation by microbes (bacteria, fungi, yeast, algae) is an effective method, which is mainly concerned with the use of natural or engineered microbes which are capable of oxidizing, reducing, volatilising or immobilising As through bio-sorption, bio-methylation, bio-stimulation, bio-augmentation, complexation and siderophore-based amelioration (Lievremont et al., 2009). It is advantageous because it includes simple, natural processes, which are highly specific, less expensive, can be carried out on site, as well as causes complete degradation of a wide variety of contaminants (Leung, 2004).

4 Fluoride

Fluoride, an inorganic pollutant of natural origin, is an essential element required in minute quantity (0.5 mg/L) for the formation of dental enamel and mineralisation of bones of human beings. The main source of fluoride contamination of groundwater is geo-chemical in origin and it causes toxicity when ingested in higher doses (Bell and Ludwig, 1970). The tolerance limit of fluoride in drinking water as specified by WHO is 1.5 mg/L. Fluorosis has affected about 70 million people in 25 countries globally and has been reported in 62 million people drinking fluoride contaminated drinking water in India (Kannan and Ramasubramanian, 2011). In the states of Delhi, Rajasthan, Uttar Pradesh, Gujarat, Punjab, Haryana, Bihar, Orissa, Madhya Pradesh, Jammu and Kashmir, Himachal Pradesh, Andhra Pradesh, Tamil Nadu, Kerala, Maharashtra and Karnataka, high concentrations of fluoride (>1.5 ppm) have been reported (Susheela, 2001). Fluoride was first detected in India, in Nellore, Andhra Pradesh in 1937 (Shortt et al., 1937). The concentration of fluoride in groundwater depends on the physical, chemical and geological characteristics of the aquifer, the acidity and porosity of the rocks and soil, temperature and the depth of wells. Due to these large number of variables, the range of fluoride concentrations in groundwater varies from under 1.0 mg/L to >35.0 mg/L (WHO, 1984).

The primary anthropogenic sources of fluoride include fertilisers, combusted coal and industrial waste with phosphate fertiliser (Farooqi et al., 2007). However, fluoride may enter into human body systems through water, food, cosmetics (like toothpaste), drugs and medicines (containing NaF), organofluoride compounds like Freons (CFC, Teflon) etc. (Hiyama, 2013). Groundwater is primarily contaminated due to weathering and leaching of F^- containing minerals present in the rock bed which act as potential geogenic source of fluoride (Handa, 1975; Edmunds and Smedley, 2005; Sreedevi et al., 2006). The most common rock forming mineral containing fluoride is CaF_2 as it is abundantly available on the earth's crust. Moreover, since fluoride ions (F^-) and hydroxyl ions (OH^-) are both negatively charged and have the same ionic radius, F^- can easily replace OH^- in most of the rock forming minerals. According to one hypothesis, the main reason behind the leachability of F^- from the minerals containing fluoride is the production of carbonate ion (HCO_3^-) in the soil. Occurrence of carbonates and bicarbonates in the soil is due to formation of CO_2 from weathering of common rock forming minerals. This CO_2 reacts with rainwater to form carbonate ion.

$$CO_2 + H_2O = H_2CO_3$$

$$H_2CO_3 = H^+ + HCO_3^-$$

$$HCO_3^- = H^+ + CO_3^{2-}$$

This alkaline water may be able to mobilise fluoride from its minerals like CaF_2.

$$CaF_2 + 2HCO_3^- = CaCO_3 + 2F^- + H_2O + CO_2 \left(\text{Handa, 1975; Banerjee, 2015}\right)$$

The primary mechanism of fluoride toxicity begins with the binding of fluoride with calcium ions leading to hypocalcaemia, further leading to osteoid formation. On binding with Ca, it disrupts glycolysis, oxidative phosphorylation, coagulation and neurotransmission. It may lead to hyperkalemia due to extracellular release of potassium by inhibiting Na^+/K^+ ATP-ase. Fluoride may further lead to hyper salivation, vomiting and diarrhoea by inhibiting cholinesterase (Chouhan and Flora, 2010). Fluoride, being highly electronegative has affinity towards uracil and amide bonds, thus damaging the structure of DNA leading to genotoxic effects (Li et al., 1987; Dhar and Bhatnagar, 2009). It also suppresses the activity of enzymes like DNA polymerase, affecting replication and repair (Aardema and Tsutsui, 1995). Fluoride concentration within the range of 0.5–1.5 mg/L prevents tooth decay, but above 1.5 mg/L, it has adverse effects on health as described in details in Table 2.2.

Fluorosis is the pathological condition that arises due to long-term exposure of elevated levels of fluoride. Dental fluorosis results in porous and opaque enamel resembling white chalk colour instead of the normal creamy white translucent

Table 2.2 Adverse health effects of different fluoride concentration ranges

Concentration of fluoride (mg/L)	*Adverse health effects*
1.5–4.0	Dental fluorosis
4–10	Skeletal fluorosis
>10	Crippling fluorosis

colour. The enamel and dentin become structurally weak and prone to breakage with deposition in the roots of the teeth or the pulp chamber giving rise to yellowish spots, specks and blotches with brown pits (Dhar and Bhatnagar, 2009). Skeletal fluorosis mainly leads to increase of bone density, brittleness of bones, rheumatic pain, arthritis in bones and muscles with bending of the vertebral column due to fluoride uptake of 4–8 mg/L. This is followed by sporadic pain, stiffness of joints, headache and weakness of muscles (Ghosh et al., 2013). Fluoride, on long-term exposure causes neurological damage especially in children resulting in crippling fluorosis, which leads to an irreversible and hopeless state of disorder, which further results in loss of work and livelihood, social aloofness and loss of will to live due to inability to meet high medical costs (Mullenix et al., 1995; Guan et al., 1998). Therefore, it can be said that fluoride if not ingested in the right proportion, can take the shape of a widespread threat to the people worldwide.

Various mechanisms of removal of fluoride from groundwater have been reported of which, coagulation (Reardon and Wang, 2000), ion exchange (Singh et al., 1999), adsorption (Raichur and Basu, 2001), precipitation, membrane technology (like reverse osmosis) are common. For adsorption, activated carbon, silica gel, calcite and alumina are mainly used as adsorbents. It is a very cost-effective method and can remove fluoride with upto 90% efficiency (Muthukumaran et al., 1995; Yang et al., 1999). In coagulation, fluoride ions in the water are precipitated by limewater ($Ca(OH)_2$).

$$CaO + H_2O = Ca(OH)_2$$

$$Ca(OH)_2 + 2F^- = CaF_2 + H_2O \left(\text{Azbar and Türkman, 2000}\right)$$

In Nalgonda method, F^- contaminated water on treatment with alum and lime slurry, results in flocculation, which is then followed by sedimentation and filtration.

$$Al_2(SO_4)_3 \cdot 18H_2O = 2Al^{3+} + 3SO_4^{\;2-} + 18H_2O$$

$$2Al^{3+} + 6H_2O = 2Al(OH)_3 + 3H^+$$

$$Ca(OH)_2 + 2H^+ = Ca^{2+} + 2H_2O$$

$$Al(OH)_3 + F^- = Al - F(\text{complex})$$

$$Ca(OH)_2 + F^- = CaF_2 \text{ (Parker, 1975; Meenakshi and Maheshwari, 2006)}$$

By ion-exchange process, fluoride can be removed from water by a strongly alkaline anion-exchange resins with ammonium ion and the reaction takes place as follows (Meenakshi and Maheshwari, 2006):

$$\text{Matrix} - NR_{3+}Cl^- + F^- \rightarrow \text{Matrix} - NR_{33+}F^- + Cl^-$$

Besides, defluoridation of groundwater can be done by several ways like chemical, electrode and solar defluoridation. In chemical defluoridation, calcium chloride ($CaCl_2$) reacts with Na_2HPO_4 to produce TCP (tri calcium phosphate). This TCP reacts with F^- to form a strong chelate, hence separating the F^- from water (Zhang et al., 2011). In electrode defluoridation, direct current is passed through F^- contaminated water resulting in anodic dissolution of aluminium, producing poly aluminium hydroxide (nAl(OH)$_3$), which on reaction with F^- produces Al-F complex, followed by sedimentation and filtration (Mameri et al., 1998). Solar defluoridation follows the same principle as the previous one, except for the use of photovoltaic cells (PVC) instead of passing current through fluoride contaminated water (Andey et al., 2013).

5 Fossil Fuel and Mining

Fuel formed by natural processes from the remains of dead organisms (such as oil and natural gas) and plants (such as coal) through anaerobic decomposition are collectively termed as fossil fuels. Typically, it takes millions of years to form fossil fuel from the biomass. In spite of continuing formation of fossil fuels, they are considered non-renewable resources as humans are rapidly depleting the viable reserves and it takes millions of years to form new reserves.

The environmental impacts of fossil fuel mining and combustion are multifarious. Fossil fuel combustion produces the most important greenhouse gas carbon dioxide (CO_2) along with nitrogen oxides, sulphur dioxide (SO_2), volatile organic compounds (VOCs), particulate matter (PM) and heavy metals. While CO_2 is the key component in global temperature rise, nitrogen oxides and SO_2 cause acid rain, VOCs and PM cause health effects such as asthma, respiratory diseases etc. Carcinogenic heavy metals such as arsenic, cadmium and chromium are emitted from fossil fuel combustion and adhere to the breathable and respirable size fraction of PM. The respirable size fraction, $\leq PM_{2.5}$ are readily trapped by the alveoli of the lungs and mixes with the blood stream (Dockery and Pope, 1994). Particulate-bound transition metals are known to generate reactive oxygen species (ROS) within cells through Fenton and Haber Weiss reactions (Betha et al., 2013). Evidences indicate that ROS is the key player in normal cell signal transduction and cell cycling. Mercury is a by-product of coal combustion (Sun, 2019) and gets deposited in the environment after emission. Inorganic mercury is converted to methyl mercury, known to be a neurotoxin by sulphate reducing bacteria under anaerobic conditions that bioaccumulates and biomagnifies in food chain (Benoit et al., 1999).

Coal (and minerals, metals and gemstones) are mined and extracted from the earth. Mining generates large amount of wastes that are discharged in the environment. Mining is of two types: surface mining and underground mining. During surface mining, the covering vegetation and if necessary, layers of bed rocks are removed. Surface mining causes loss of biodiversity, erodes the soil, reduces the fertility, alters landscape and generates huge quantities of wastes called tailings. Tailings are generally toxic and produced as slurry and are commonly dumped into water bodies polluting the water and destroying the biota. Besides the above-mentioned environmental hazards acid mine drainage (AMD) in some instances is the primary pollutant of surface water. According to United States Environmental Protection Agency (US EPA), in the mid-Atlantic region AMD degraded >4500 stream miles destroying aquatic life and restricting stream use for recreation and public drinking water purpose. AMD is highly acidic water with elevated levels of dissolved metals drained from surface or deep coal or metal mines and coal refuse piles. When sulphide minerals such as pyrite (FeS_2) come in contact with air or water, they get oxidised to sulfuric acid (H_2SO_4) and acidify groundwater and nearby surface water, which in turn solubilise metals. The overall reaction involved in the formation of AMD is as follows:

$$4FeS_2 + 15O_2 + 14H_2O = 4Fe\left(OH\right)_3 + 8H_2SO_4$$

Precipitation of ferric hydroxide causes bright orange colour to water and rock. AMD can be treated either through chemical treatment such as by calcium oxide (CaO) or anhydrous ammonia or by passive treatment through creation of limestone channel or wetlands. CaO is alkaline in nature and increases the pH of AMD. This causes many of the metals to precipitate as carbonates and hydroxides. Ammonia is a strong base and once injected into AMD reacts rapidly and increases the pH. Often AMD is treated in free-flowing channel lined with coarse limestone that precipitates metals and adds alkalinity to the water. Wetlands act as natural sinks of metals. The dense plant root system catches the suspended solids and flocculated particles as they pass through the wetlands. However, the best method to treat AMD is prevention. This can be done by using proper reclamation method, which prevents air and/or water from reaching the pyrite material.

Hazards are associated with oil and gas exploration, storage and combustion. During oil drilling, there are risks of blowouts, encountering unanticipated high overpressure, drill pipe and hole shearing by mobile salt etc. When crude oil is released uncontrollably or accidentally an oil well blowout occurs. During the blowout even a small spark coming in contact with the oil can lead to catastrophic disasters. Sometimes the weight of the overlying sedimentary rocks along with the interstitial pore fluids exert enormous pressure and result in compaction of the oil-bearing formation. Unless there exists a communication with the surface, this situation results in unanticipated high overpressure in the oil-bearing formation and can cause a well to blow out or become uncontrollable during drilling. The enormous pressure of rock formations around an oil reservoir is counteracted by the use of mud around the drilling site, which helps to balance the hydrostatic pressure. If this balance is upset, water, gas or oil can infiltrate the wellbore or even the drill itself and this can quickly escalate into a blowout if not promptly identified and addressed. To manage such an infiltration, the drill entry point is immediately isolated by closing the well. A heavier fluid is injected to reach a balance by increasing the hydrostatic pressure. Ultimately, the infiltrated fluid or gas is evacuated in a controlled and safe manner. Salt formations encountered during drilling operations pose a serious threat. Salt is an exceptional rock as it flows by creep in the subsurface (Weijermars et al., 2014). The load-factor tolerance and drag forces of wellbore casing is carefully calculated using a range of salt viscosities and creep rates. Before designing a well casing passing through salt, the probable range of creep forces of moving salt needs to be considered when calculating safety margins and load-factor tolerance of the well casing.

The largest hazard during transportation and storage of oil is the oil spill, which is the release of liquid petroleum hydrocarbon into the marine ecosystem due to human error. Oil spill on land can also occur. Crude oil can be spilled from drill rigs, offshore platforms, tankers etc. Spill can also occur from refined petroleum products such as gasoline and diesel and heavier fuels such as bunker fuels used by large ships. Till date, the most disastrous oil spill was off the coast of Alaska in 1989. This occurred when Exxon Valdez, an oil tanker owned by Exxon Shipping Company, hit an underwater reef (Prince William Sound's Bligh Reef) at midnight and spilled millions of gallons of crude oil and is considered one of the worst human-caused environmental disasters. Due to the remoteness of the location, clean-up efforts were delayed. Three decades after the oil spill, Prince William Sound appears to have recovered on the surface, but digging a shallow hole into certain Alaskan beaches brings up oil to the surface. Oil penetrates into the mammalian fur and bird feathers, reducing their buoyancy in the water, insulating ability and making them more vulnerable to temperature fluctuations. During preening, the oil on skin and feathers is ingested and affects the liver function and causes kidney damage.

Cleaning an oil spill is a humongous effort and depends on the accessibility of the spill site, type of oil spilled, the temperature of the water etc. Physical clean ups of oil spills such as vacuum and centrifuge method, dredging, beach raking can be expensive. Instead bioremediation with the bacteria such as *Alcanivoraxor* and *Methylocella silvestris* have proved to be helpful in breaking down and removing oil.

6 Landslide

Landslide is the movement of a mass of rock and debris along a hill slope under the direct influence of gravity. In most cases, landslides are triggered by natural causes such as earthquake, volcanic eruption, forest fire, excessive rainfall and weathering and erosion of the rocks that make up the hill slope. However, human causes can also trigger landslides.

Mining, deforestation, clear cutting, land use, water management and vibration are some of the human-induced causes of slope failure. Vibrations emanating from blasting activities during mining can weaken soils in areas susceptible to landslides. During timber harvesting along a slope, old trees are cleared that decimates the existing root structure that binds the soil and prevents weathering. Most of the landslide occurs during or after heavy rainfall. Heavy water laden slopes readily succumb to the forces of gravity. Hence, water supply and wastewater drainage patterns need to be carefully designed for heavily built towns on hill slope to prevent future landslides.

The best way to manage landslide is to prevent it from destroying properties and lives. Before construction on hill slopes, soil type analysis and ground assessment should be done for the property to determine how susceptible it would be to ground movements. If the area is prone to past landslides, chances are high for future occurrences. Such areas should be avoided. Planting trees and vegetation help stabilise soil on slopes. In many cases, there are structural deformation symptoms before a land slide. Close monitoring of such occurrences such as tilting of fences, utility poles or trees, seepage of groundwater in new locations, ground bulging at the base of the slope, new cracks developing in bricks, plasters and foundations can hint towards slope instability and eventual failure.

7 Volcanoes

Although volcanic eruptions are more predictable than earthquakes, there is very little if anything that man can do to prevent or alter the hazardous events happening. Some of the hazards associated with volcanic eruptions are volcanic earthquakes, directed blast, tephra, volcanic gases, lava flows, pyroclastic flows and lahars.

Earthquakes are caused by stress changes in solid rock due to injection of magma into surrounding rocks. Volcanic activity related earthquakes can produce ground cracks, ground deformation and damage to manmade structures. During a volcanic eruption, the rock fragments that are ejected into the atmosphere are called tephra. How far the tephra will travel away from a volcano depends on the height of the eruption column, air temperature, wind direction, speed etc. Tephra produces a wide range of hazards. The electrically charged ejected material often produces lightning in the atmosphere and there are reports of human casualty by lightning from volcanic eruption clouds. Ballistically shot large tephra from the volcano can hit people and cause injury and death and cause property damage. Tephra can damage crops and cause famine. After the eruption of Tambora, Indonesia in 1851, that ejected 151 km^3 of ash into the atmosphere, 80,000 people died due to famine. The fine particles of the pyroclastic flow, the ash, have multifarious hazards. Ash fall can disrupt electricity and telephone communication lines, bury roads, start fires, clog drainage and sewage systems. Ash can trigger respiratory problems and decreases visibility.

Accumulation of ash on the roof of flat-topped buildings lead to roof collapse. An erupting volcano releases water vapour and gases into the atmosphere. The gases include carbon dioxide (CO_2), sulphur dioxide (SO_2), hydrochloric acid (HCl), hydrogen fluoride (HF), hydrogen sulphide (H_2S), carbon monoxide (CO), hydrogen gas (H_2), ammonia (NH_3), methane (CH_4) and silicon tetrafluoride (SiF_4). These gases when leached from the atmosphere produce acid rain. Lava flows are the least hazardous of all processes in volcanic eruptions because they do not move very fast decreasing chances of human casualty. The distance a lava flow will travel depends on the flow temperature, viscosity of the lava that depends on silica content, extrusion rate and slope of the land. For example, a cold lava flow will not travel far and neither will one that has a high silica content. On the contrary a basalt flow like those in Hawaii have low silica contents and low viscosities so they can flow long distances. The primary hazard of lava flow is property damage. The Hawaiian town of Kalapana was destroyed by lava flows in the 1980s. Lava flows buried cars and burnt homes and vegetation. Electricity and water connections were cut off from the community. Pyroclastic flows and lahars are the greatest volcanic hazards. More people have died due to these hazards than any other volcanic hazard. When the rock masses erupted from a volcano mixes with water and discharged gas, they become fluidised and move downhill in response to gravity. Pyroclastic flows can burn and destroy manmade structure and vegetation. When pyroclastic flow mixes with excess water they form lahars. During 1991 Mount Pinatubo eruption, the pyroclastic flows transformed into lahars as they moved along river valleys.

People living in arears close to volcano relies on the monitoring network. The United States, Italy and Japan are the leaders in this field. For example, the 1991 Pinatubo eruption at Philippines could be precisely predicted by USGS due to increasing SO_2 emission and accordingly areas close to the summit were evacuated. After an eruption, the ash stays in the air and environment for long. To prevent breathing of volcanic ash and fumes, people wear masks with filters or place wet cloth over their nose and mouth. Past old pyroclastic flow deposits are likely places of new flow trajectories if the volcano erupts. Hence, it’s advisable to avoid habitation building on old pyroclastic flow paths.

Several methods such as building retention basins, tunnels, concrete structures etc. have been used to stop or detour lahar flows. However, very often they have succumbed to the furious nature. Like most other disaster management strategies, the best preventive measure is to establish a warning system with seismometers to detect a signal as lahars move down the valleys.

8 Earthquakes

Earthquake is sudden rapid shaking of the ground surface. Ground shaking can occur due to several reasons. The most common and widespread are the movements along tectonic plate boundaries. The earth’s crust is composed of seven large lithospheric plates and numerous smaller plates. The continuous movement of the tectonic plates cause built up of pressure along the plate boundaries. When stress is sufficiently great it is released in a sudden jerky movement resulting in seismic waves that propagate through the ground to the surface and cause the ground to shake. Earthquakes caused by plate tectonics are called tectonic quakes. Earthquake can also occur due to active volcanism or caused by human activity. Volcanism-related earthquakes are not as powerful as tectonic quakes with shallow hypocentre and they are generally felt in the vicinity of the epicentre. Human activities or errors such as tunnel construction, dam failure etc. can cause ground shaking however they are not as intense or wide spread as tectonic earthquakes.

Disaster related to earthquake can cover hundreds of thousands of square kilometres. The ground shaking causes structural damage, loss of life and injury to innumerable people. In summary, one severe earthquake can disrupt the social and economic structure of the affected area. For example, on 26th December 2004, an earthquake measuring 9.3 on the Richter scale in the Indian Ocean caused severe damage to Banda Aceh, Sumatra. The damage was not because of ground shaking but generation of tsunami waves that killed at least 230,000 people from >10 countries around the Indian Ocean including Indonesia, Sri Lanka, India and Thailand. It is impossible to prevent earthquake; however, it is possible to mitigate the effects and to reduce loss of life, injuries and damage. Community awareness and participation through earthquake drills and public awareness programs are the first steps in earthquake mitigation. Japan is considered to be the leader in earthquake disaster management as it sits on one of the most seismically active plate boundaries of the earth. All buildings in Japan are required to have an earthquake resistant structure. For example, skyscrapers abide by strict building codes that rest on Teflon to allow the building foundation to slide ever-so-slightly during a tremor. Aftermath of earthquakes are managed by Japan Medical Association Teams and Disaster Medical Assistance Teams and work round the clock over a broad area during the initial 72 h that is considered as the golden hour to save life and trapped people under collapsed structure. Besides providing medical assistance in the affected areas, critical patients are air lifted from the disaster areas and transported to nearby medical centres. As for tsunamis, steps have been taken in the Pacific to establish a warning system as tsunamis have a unique wave frequency.

There has been increasing efforts to predict an earthquake to minimise the loss of lives and properties. An earthquake does not happen all of a sudden, instead they tend to form a complex network of interacting faults. Close monitoring of seismic activities on the fault network can lead to successful earthquake prediction. For example, in Indonesia, Neural Network for Earthquake Prediction Based on Automatic Clustering for earthquake prediction is used to closely monitor motion at plate boundaries. In spite of continued efforts, earthquakes are much less predictable than volcanic eruptions.

9 Radon Exposure

Radon (Rn) is a colourless and odourless gas produced as an intermediate short-lived product during radioactive decay of uranium (U) and thorium (Th) to lead (Pb). The three radioactive isotopes ^{238}U, ^{235}U and ^{232}Th decay to ^{206}Pb, ^{207}Pb and ^{208}Pb with half-lives of 4.468 billion years, 704 million years and 14 billion years. During these decay reactions, radon is produced as short-lived intermediate product. Radon itself is the immediate decay product of radium. The most stable radon isotope is ^{222}Rn with a half-life of only 3.8 days. However, as uranium and thorium are two most abundant radioactive elements in the earth's crust with long half-lives, radon is continuously produced. International Agency for Research on Cancer labelled radon gas as carcinogenic to humans. After inhalation, radon emits radiation that damages the inside of our lungs and increases the risk of lung cancer (Field et al., 2000).

In this section, we will discuss natural accumulation of radon in buildings and occupational health hazard of miners from radon exposure. Radon emission will depend on the bedrock nature. For example, igneous and metamorphic rocks such as granite, gneiss and schist have high concentrations of uranium and thorium as compared to limestone. Hence, buildings built on granitic or schistose bed rock or used as building materials will have more radon exposure. Entry points of radon into buildings are through cracks in solid foundations and walls, cavities inside walls etc. Ground floor and basement are most affected. Radon accumulation can vary from one room to the other in the same floor and building and can change with wind conditions and atmospheric inversion. Commercially available radon testing kits are easy to use and cheap and are recommended to use before purchasing a house particularly with basement. The kit includes a collector that the user hangs in the lowest habitable floor of the house for 2–7 days. As the half-life of radon is only 3.8 days, the gas built up can easily be mitigated by improving ventilation system of the house. In the 1940s and 1950s, miners in uranium and other hard rock mines were exposed to radon and reports of lung cancer among non-smoking miners poured in from Czech Republic, Australia and United States. Since then mining conditions have been improved by redesigning the ventilation system, and in the present-day radon gas levels inside uranium mines have fallen to levels similar to the concentrations inhaled in some homes.

10 Conclusions

The estimated growth of world population is >90 million per year, of which 93% is in developing countries. The ever-increasing demands for food, space and better living conditions cannot be supported by the earth's natural resources without degrading human life quality. With the growing population, there will be growing need for land, food, freshwater, fossil fuel and industrial growth. To provide food, existing agro system will need more fertilisers and pesticides for better yield further polluting the environment. Excessive use of groundwater for drinking and agriculture are depleting water table and causing water pollution. Treated surface water should be explored as an alternative source. Finding alternate sources of energy to generate electricity has become a mandate in the present world. To reach the global warming goal of well below 2 °C as set by the Paris Agreement, decreased emission of greenhouse gases from industries and vehicle exhausts is required. Land clearing for agriculture and mining degrades ecosystems, leads to extinction of thousands of species and de-stabilises natural ecosystems. Natural disasters such as volcanic eruptions and earthquakes are unavoidable. A large part of the earth's population lives in seismically active zones and around active and dormant volcanoes. These people rely on prediction networks for evacuation and general preparedness post an earthquake or volcanic eruption to handle the aftermath. In summary, a sound knowledge of the science behind the natural and human induced environmental disaster is essential to better understand the causes, deal with the crisis and find mitigation ways to alleviate the lives of tens of thousands of people affected by the situation.

References

Aardema, M.J. and Tsutsui, T. (1995). Sodium fluoride-induced chromosome aberrations in different cell cycle stages. *Mutat Res*, **331(1):** 171.

Abedin, M.J., Cotter-Howells, J. and Meharg, A.A. (2002). Arsenic uptake and accumulation in rice (*Oryza sativa* L.) irrigated with contaminated water. *Plant Soil*, **240(2):** 311–319.

Akhtar, M.S., Chali, B. and Azam, T. (2013). Bioremediation of arsenic and lead by plants and microbes from contaminated soil. *Res Plant Sci*, **1(3):** 68–73.

Andey, S., Labhasetwar, P.K., Khadse, G., Gwala, P., Pal, P. and Deshmukh, P. (2013). Performance evaluation of solar power based electrolytic defluoridation plants in India. *Int J Water Resources Arid Environ*, **2(3):** 139–145.

Azbar, N. and Türkman, A. (2000). Defluoridation in drinking waters. *Water Sci Technol*, **42(1–2):** 403–407.

Banerjee, A. (2015). Groundwater fluoride contamination: A reappraisal. *Geosci Front*, **6(2):** 277–284.

Bell, M.C. and Ludwig, T.G. (1970). The supply of fluoride to man: Ingestion from water, fluorides and human health. WHO Monograph series 59. World Health Organization, Geneva.

Benoit, J.M., Gilmour, C.C., Mason, R.P. and Heyes, A. (1999). Sulfide controls on mercury speciation and bioavailability to methylating bacteria in sediment pore waters. *Environ Sci Technol*, **33:** 951–957.

Betha, R., Pradani, M., Lestari, P., Joshi, U.M., Reid, J.S. and Balasubramanian, R. (2013). Chemical speciation of trace metals emitted from Indonesian peat fires for health risk assessment. *Atmos Res*, **122:** 571–578.

Cao, G., Han, D. and Moser, J. (2013). Groundwater exploitation management under land subsidence constraint: Empirical evidence from the Hangzhou-Jiaxing-Huzhou Plain, China. *Environ Manage*, **51:** 1109–1125.

Čerňanský, S., Kolenčík, M., Ševc, J., Urík, M. and Hiller, E. (2009). Fungal volatilization of trivalent and pentavalent arsenic under laboratory conditions. *Bioresource Technol*, **100(2):** 1037–1040.

Chakraborti, D., Rahman, M.M., Das, B., Murrill, M., Dey, S.P., Mukherjee, S.C., Dhar, R.K., Biswas, B.K., Chowdhury, U.K., Roy, S., Sorif, S., Selim, M., Rahman, M. and Quamruzzaman, Q. (2010). Status of groundwater arsenic contamination in Bangladesh: A 14-year study report. *Water Res*, **44(19):** 5789**–**5802.

Chakraborti, D., Sengupta, M.K., Rahman, M.M., Ahamed, S., Chowdhury, U.K., Hossain, A., … and Quamruzzaman, Q. (2004). Groundwater arsenic contamination and its health effects in the Ganga-Meghna-Brahmaputra plain. *J Environ Monit*, **6(6):** 74.

Chouhan, S. and Flora, S.J.S. (2010). Arsenic and fluoride: Two major ground water pollutants. *Indian J Exp Biol*, **48(7):** 666–678.

Chowdhury, N.R., Ghosh, S., Joardar, M., Kar, D. and Roychowdhury, T. (2018). Impact of arsenic contaminated groundwater used during domestic scale post harvesting of paddy crop in West Bengal: Arsenic partitioning in raw and parboiled whole grain. *Chemosphere*, **211:** 173–184.

Chowdhury, N.R., Joardar, M., Ghosh, S., Bhowmick, S. and Roychowdhury, T. (2019). Variation of arsenic accumulation in paddy plant with special reference to rice grain and its additional entry during post-harvesting technology. *In:* Ground water development-issues and sustainable solutions. Springer, Singapore, pp. 289–303.

Dhar, V. and Bhatnagar, M. (2009). Physiology and toxicity of fluoride. *Indian J Dental Res*, **20(3):** 350.

Dockery, D.W. and Pope, C.A. (1994). Acute respiratory effects of particulate air pollution. *Annu Rev Public Health*, **15:** 107–132.

Edmunds, W.M. and Smedley, P.L. (2005). Fluoride in Natural Waters Essentials of Medical Geology. (Alloway, B.J. and Selinus, O. (eds)).

Erban, L.E., Gorelick, S.M. and Zebker, H.A. (2014). Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam. *Environ Res Lett*, **9:** 084010.

Farooqi, A., Masuda, H., Kusakabe, M., Naseem, M. and Firdous, N. (2007). Distribution of highly arsenic and fluoride contaminated groundwater from east Punjab, Pakistan, and the controlling role of anthropogenic pollutants in the natural hydrological cycle. *Geochem J*, **41(4):** 213–234.

Fazal, M.A., Kawachi, T. and Ichion, E. (2001). Extent and severity of groundwater arsenic contamination in Bangladesh. *Water Int*, **26(3):** 370–379.

Field, R.W., Steck, D.J., Smith, B.J., Brus, C.P., Fisher, E.L., Neuberger, J.S., Platz, C.E., Robinson, R.A., Woolson, R.F. and Lynch, C.F. (2000). Residential radon gas exposure and lung cancer: The Iowa Radon Lung Cancer Study. *Am J Epidemiol*, **151:** 1091–1102.

Ghosh, A., Mukherjee, K., Ghosh, S.K. and Saha, B. (2013). Sources and toxicity of fluoride in the environment. *Res Chem Intermed*, **39(7):** 2881–2915.

Ghosh, N.C. and Singh, R.D. (2009). Groundwater arsenic contamination in India: Vulnerability and scope for remedy. Proceedings of the workshop on Arsenic Contamination in Groundwater – Source, Migration and Mitigation: Future Research Needs. 23rd–24th July, 2010, IISWBM, Kolkata, India.

Guan, Z.Z., Wang, Y.N., Xiao, K.Q., Dai, D.Y., Chen, Y.H., Liu, J.L., … and Dallner, G. (1998). Influence of chronic fluorosis on membrane lipids in rat brain. *Neurotoxicol Teratol*, **20(5):** 537–542.

Handa, B.K. (1975). Geochemistry and genesis of fluoride—Containing ground waters in India. *Groundwater*, **13(3):** 275–281.

Hiyama, T. (2013). Organofluorine Compounds: Chemistry and Applications. Springer Science & Business Media.

Hunter, P.R., MacDonald, A.M. and Carter, R.C. (2010). Water supply and health. *PLoS Med*, **7(11):** e1000361.

Kannan, S. and Ramasubramanian, K.V. (2011). Assessment of fluoride contamination in groundwater using GIS, Dharampuri District, Tamil Nadu, India. *Int J Eng Sci Technol*, **3(2):** 1077–1085.

Kapaj, S., Peterson, H., Liber, K. and Bhattacharya, P. (2006). Human health effects from chronic arsenic poisoning—A review. *J Environ Sci Health A*, **41(10):** 2399–2428.

Leung, M. (2004). Bioremediation: Techniques for cleaning up a mess. *Bioteach J*, **2:** 18–22.

Li, Y., Heerema, N.A., Dunipace, A.J. and Stookey, G.K. (1987). Genotoxic effects of fluoride evaluated by sister-chromatid exchange. *Mutat Res Lett*, **192(3):** 191–201.

Lievremont, D., Bertin, P.N. and Lett, M.C. (2009). Arsenic in contaminated waters: Biogeochemical cycle, microbial metabolism and biotreatment processes. *Biochimie*, **91(10):** 1229–1237.

Lim, K.T., Shukor, M.Y. and Wasoh, H. (2014). Physical, chemical, and biological methods for the removal of arsenic compounds. *Bio Med Res Int*, **2014:** Article ID 503784.

Liu, W.J., Zhu, Y.G., Smith, F.A. and Smith, S.E. (2004). Do iron plaque and genotypes affect arsenate uptake and translocation by rice seedlings (*Oryza sativa* L.) grown in solution culture? *J Exp Bot*, **55(403):** 1707–1713.

Lowers, H.A., Breit, G.N., Foster, A.L., Whitney, J., Yount, J., Uddin, M.N. and Muneem, A.A. (2007). Arsenic incorporation into authigenic pyrite, Bengal Basin sediment, Bangladesh. *Geochim Cosmochim Acta*, **71(11):** 2699–2717.

Mameri, N., Yeddou, A.R., Lounici, H., Belhocine, D., Grib, H. and Bariou, B. (1998). Defluoridation of septentrional Sahara water of North Africa by electrocoagulation process using bipolar aluminium electrodes. *Water Res*, **32(5):** 1604–1612.

Mullenix, P.J., Denbesten, P.K., Schunior, A. and Kernan, W.J. (1995). Neurotoxicity of sodium fluoride in rats. *Neurotoxicol Teratol*, **17(2):** 169–177.

Muthukumaran, K., Balasubramanian, N. and Ramakrishna, T.V. (1995). Removal of fluoride by chemically activated carbon. *Indian J Environ Protect*, **12(1):** 514–517.

Ng, J.C., Wang, J. and Shraim, A. (2003). A global health problem caused by arsenic from natural sources. *Chemosphere*, **52(9):** 1353–1359.

Ohno, K., Matsuo, Y., Kimura, T., Yanase, T., Rahman, M.H., Magara, Y. and Matsui, Y. (2009). Effect of rice-cooking water to the daily arsenic intake in Bangladesh: Results of field surveys and rice-cooking experiments. *Water Sci Technol*, **59(2):** 195–201.

Parker, L. (1975). Fluoride removal—Technology and cost estimates. *Ind Wastes (Chicago)*, **21(6):** 23–27.

Purakayastha, T.J. (2011). Microbial remediation of arsenic contaminated soil. *In:* Detoxification of Heavy Metals. Springer, Berlin, Heidelberg, pp. 221–260.

Rahman, M.A., Hasegawa, H., Rahman, M.M., Islam, M.N., Miah, M.M. and Tasmen, A. (2007). Effect of arsenic on photosynthesis, growth and yield of five widely cultivated rice (*Oryza sativa* L.) varieties in Bangladesh. *Chemosphere*, **67(6):** 1072–1079.

Rahman, M.M., Mandal, B.K., Chowdhury, T.R., Sengupta, M.K., Chowdhury, U.K., Lodh, D. and Chakraborti, D. (2003). Arsenic groundwater contamination and sufferings of people in North 24-Parganas, one of the nine arsenic affected districts of West Bengal, India. *J Environ Sci Health A*, **38(1):** 25–59.

Raichur, A.M. and Basu, M.J. (2001). Adsorption of fluoride onto mixed rare earth oxides. *Sep Purif Technol*, **24(1–2):** 121–127.

Raskin, I. and Ensley, B.D. (2000). Phytoremediation of Toxic Metals. John Wiley and Sons.

Ravenscroft, P., Burgess, W.G., Ahmed, K.M., Burren, M. and Perrin, J. (2005). Arsenic in groundwater of the Bengal Basin, Bangladesh: Distribution, field relations, and hydrogeological setting. *Hydrogeol J*, **13(5–6):** 727–751.

Meenakshi and Maheshwari, R.C. (2006). Fluoride in drinking water and its removal. *J Hazard Mater*, **137(1):** 456–463.

Reardon, E.J. and Wang, Y. (2000). A limestone reactor for fluoride removal from wastewaters. *Environ Sci Technol*, **34(15):** 3247–3253.

Rosen, B.P., Ajees, A.A. and McDermott, T.R. (2011). Life and death with arsenic: Arsenic life: An analysis of the recent report "A bacterium that can grow by using arsenic instead of phosphorus". *Bioessays*, **33(5):** 350–357.

Sahu, P. and Sikdar, P.K. (2011). Threat of land subsidence in and around Kolkata City and East Kolkata Wetlands, West Bengal, India. *J Earth Syst Sci*, **120:** 435–446.

Shortt, H.E., Pandit, C.G. and Raghavachari, R.S.T. (1937). Endemic fluorosis in the Nellore district of South India. *Indian Med Gazette*, **72(7):** 396.

Silver, S. and Phung, L.T. (2005). Genes and enzymes involved in bacterial oxidation and reduction of inorganic arsenic. *Appl Environ Microbiol*, **71(2):** 599–608.

Singh, G., Kumar, B., Sen, P.K. and Majumdar, J. (1999). Removal of fluoride from spent pot liner leachate using ion exchange. *Water Environ Res*, **71(1):** 36–42.

Smedley, P.L. and Kinniburgh, D.G. (2002). A review of the source, behaviour and distribution of arsenic in natural waters. *Appl Geochem*, **17(5):** 517–568.

Sreedevi, P.D., Ahmed, S., Madé, B., Ledoux, E. and Gandolfi, J.M. (2006). Association of hydrogeological factors in temporal variations of fluoride concentration in a crystalline aquifer in India. *Environ Geol*, **50(1):** 1–11.

Sun, H., Grandstaff, D. and Shagam, R. (1999). Land subsidence due to groundwater withdrawal: Potential damage of subsidence and sea level rise in southern New Jersey, USA. *Environ Geol*, **37:** 290–296.

Sun, R. (2019). Mercury stable isotope fractionation during coal combustion in coal-fired boilers: Reconciling atmospheric Hg isotope observations with Hg isotope fractionation theory. *Bull Environ Contam Toxicol*, **102(5):** 657–664.

Susheela, A.K. (2001). Treatise on Fluorosis. Fluorosis Research and Rural Development Foundation, India. *Fluoride Open URL*, **34(3):** 181–183.

Teatini, P., Ferronato, M., Gambolati, G. and Gonella, M. (2006). Groundwater pumping and land subsidence in the Emilia-Romagna coastland, Italy: Modeling the past occurrence and the future trend. *Water Resource Res*, **42:** W01406.

Ustun, A., Tusat, E. and Yalvac, S. (2010). Preliminary results of land subsidence monitoring project in Konya Closed Basin between 2006–2009 by means of GNSS observations. *Nat Hazards Earth Syst Sci*, **10:** 1151–1157.

Weijermars, R., Jackson, M.P.A. and Dooley, T.P. (2014). Quantifying drag on wellbore casings in moving salt sheets. *Geophys J Int*, **198:** 965–977.

World Health Organization (1984). Fluorine and Fluorides. World Health Organization, Geneva.

Yadav, K.K., Gupta, N., Kumar, A., Reece, L.M., Singh, N., Rezania, S. and Khan, S.A. (2018). Mechanistic understanding and holistic approach of phytoremediation: A review on application and future prospects. *Ecol Eng*, **120:** 274–298.

Yang, M.M., Hashimoto, T., Hoshi, N. and Myoga, H. (1999). Fluoride removal in a fixed bed packed with granular calcite. *Water Res*, **33(16):** 3395–3402.

Zhang, Z., Tan, Y. and Zhong, M. (2011). Defluorination of wastewater by calcium chloride modified natural zeolite. *Desalination*, **276(1–3):** 246–252.

Zhu, L., Gong, H., Li, X., Wang, R., Chen, B., Dai, Z. and Teatini, P. (2015). Land subsidence due to groundwater withdrawal in the northern Beijing plain, China. *Eng Geol*, **193:** 243–255.

Chapter 3
Ecological Footprint: Indicator of Environmental Sustainability

Priya Banerjee and Aniruddha Mukhopadhayay

1 Introduction

> '*In our way of life… with every decision we make, we always keep in mind the Seventh Generation of children to come… When we walk upon Mother Earth we always plant our feet carefully, because we know that the faces of future generations are looking up at us from beneath the ground. We never forget them*'
> (Oren Lyons, Faithkeeper, Onondaga Nation, Earth Day 1993 Pledge)

No one knows what the world would be like by 2050. However, it is apprehended that mankind would be faced with several environmental and social challenges. Few such challenges include providing food for the global population, elimination of poverty and inequality and provision for a life of acceptable quality for all, generation of sufficient energy for maintaining all economic activities without triggering detrimental environmental consequences and arresting the decline of biodiversity while ensuring harmonious co-existence between other species. These are some of the major questions that are recently being addressed by mankind under the broad concept of 'sustainable development' (Chambers et al., 2014).

The Brundtland report, published in the year 1987, defined *sustainable development* as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs'. Maintaining a lifestyle exceeding available ecological resources will definitely cause degradation of this planet and in turn hamper human well-being. On the other hand, living an unsatisfactory and inequitable lifestyle resulting from insufficient availability of natural resources will lead to conflicts and resultant degradation of social fabric (Chambers et al., 2014). In order to achieve sustainability, humanity must ensure a good life for every individual within

P. Banerjee (✉)
Department of Environmental Studies, Directorate of Distance Education, Rabindra Bharati University, Kolkata, India

A. Mukhopadhayay
Department of Environmental Science, University of Calcutta, Kolkata, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_3

the capacity of the biosphere for doing so. Hence, sustainable development may be defined most practically as 'improving the quality of life while living within the carrying capacity of supporting ecosystems' (IUCN, 2009). Achievement of sustainable development is also dependant on various economic factors. However, it is a popular misconception that the existence of society and the environment have the sole purpose of serving the economy while it is actually the reverse. For making human progress sustainable, it is essential to understand the present position of mankind, knowing the direction in which it should be steered and determining whether the destination has been reached (Chambers et al., 2014). It is also essential to determine the point beyond which humanity would be surviving on nature's interest rather than nature's capital. A significant way of determining nature's mean is by carrying out a comparative analysis of human consumption and carrying capacity of the earth by the virtue of ecological footprint analysis (Chambers et al., 2014).

1.1 Humanity's Environmental Footprint

With reference to the limited natural resource capital and assimilation capacity of our planet, it may be concluded that the present environmental footprint of humanity is unsustainable. Assessment of environmental footprints in terms of land, water, energy, material, etc. is significant for developing an understanding of resource sustainability, efficiency and equity amidst producers, consumers and government alike. Reduction of this unsustainable footprint to sustainable levels requires major transformative changes in economic policies across the world (Hoekstra and Wiedmann, 2014).

1.2 Ensuring a Sustainable Environment

All environmental footprints quantify human assumption of natural resources as a source or sink (Galli et al., 2012; Fang et al., 2014). The footprint of a single individual is the fundamental unit of footprint analysis (as shown in Fig. 3.1). Every environmental concern (like limited land resources, fresh water scarcity, etc.) has a specific footprint indicator for determining resource assumption or waste production or both (Hoekstra and Wiedmann, 2014). Both appropriation of land resources and land required for waste uptake (CO_2 sequestration) are determined using ecological footprint (EF) (Hoekstra and Wiedmann, 2014). For the former, it is referred to as land footprint (LF) and for the latter it is known as energy footprint (EnF) (Wiedmann, 2009). Appropriation of fresh water resources consumption of the same for waste assimilation is measured using the water footprint (WF) (Hoekstra and Mekonnen, 2012). Resource appropriation alone is measured using material footprint (MF) and phosphorous footprint (PF) (Wang et al., 2011; Wiedmann et al., 2015). Estimation of greenhouse gas emissions and loss of reactive nitrogen is

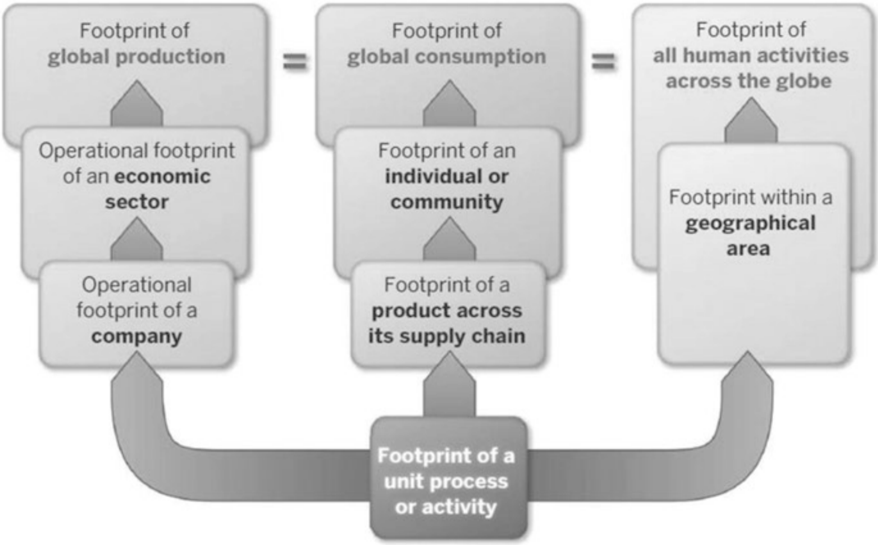

Fig. 3.1 The relation between footprints of different entities. Reproduced with permission from Hoekstra and Wiedmann (2014). At the basis of any footprint account are mutually exclusive unit footprints. A 'unit footprint' is the footprint of a single process or activity and forms the basic building block for the footprint of a product, consumer or producer or for the footprint within a certain geographical area. The footprint of global production is equal to the footprint of global consumption. Both equal the sum of the footprints of all human activities across the globe

carried out using the carbon or climate footprint (CF) and the nitrogen footprint (NF) respectively (Wiedmann and Minx, 2008; Leach et al., 2012). Anthropogenic threats to biodiversity are determined using the biodiversity footprint (BF) (Lenzen et al., 2012). These footprints form the basis for estimating human pressure on environmental resources and environmental changes (like climate change, environmental degradation and pollution, changes in land use, etc.) occurring due to the same as well as its subsequent effects (like loss of biodiversity, human health, economy, etc.) (Hoekstra and Wiedmann, 2014).

For ensuring a sustainable environment, these footprints should not exceed their maximum sustainable levels both globally as well as at smaller geographical levels in certain cases. Environmental sustainability is dependent upon the size and spatio-temporal features of human footprint with respect to the carrying capacity of the earth (Hoekstra and Wiedmann, 2014). Environmental footprints are strongly guided by the planetary boundaries (shown in Fig. 3.2) that determine the thresholds of the earth-system variables, those if exceeded may change the biophysical processes taking place in the planet's natural environments to an unacceptable extent (Rockström et al., 2009).

Analysis of environmental footprints determine the extent of the planetary boundaries that has already been consumed. However, estimation of the maximum sustainable level for each type of footprint is still in its infancy (Fig. 3.3). Proposed

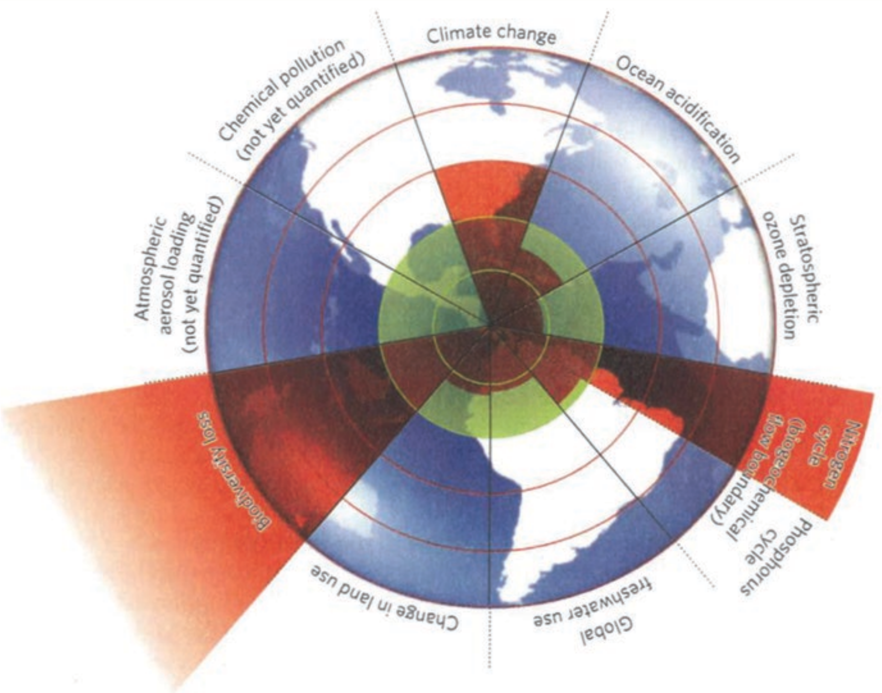

Fig. 3.2 Beyond the boundary. Reproduced with permission from Rockström et al. (2009). The inner light green shading represents the proposed safe operating space for nine planetary systems. The dark red wedges estimate the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded

maximum levels are shrouded by uncertainties, ambiguity as well as subjectivity. Over the previous century, an uninterrupted increase has been observed in case of humanity's environmental footprint. This may have had resulted from a parallel rise in population, mobility and affluence, as well as changes in patterns of consumption. If this continues, all footprints are anticipated to exceed further beyond sustainable levels (Moore et al., 2012; Ercin and Hoekstra, 2014). All producers compete for availing natural resources like land and water as well as for a part of the earth's limited capacity of self-remediation. For ensuring maximum benefit per unit of natural resource appropriation as well as unit of pollution, footprint of the concerned activities and products should be maintained at their minimum levels (Hoekstra and Wiedmann, 2014).

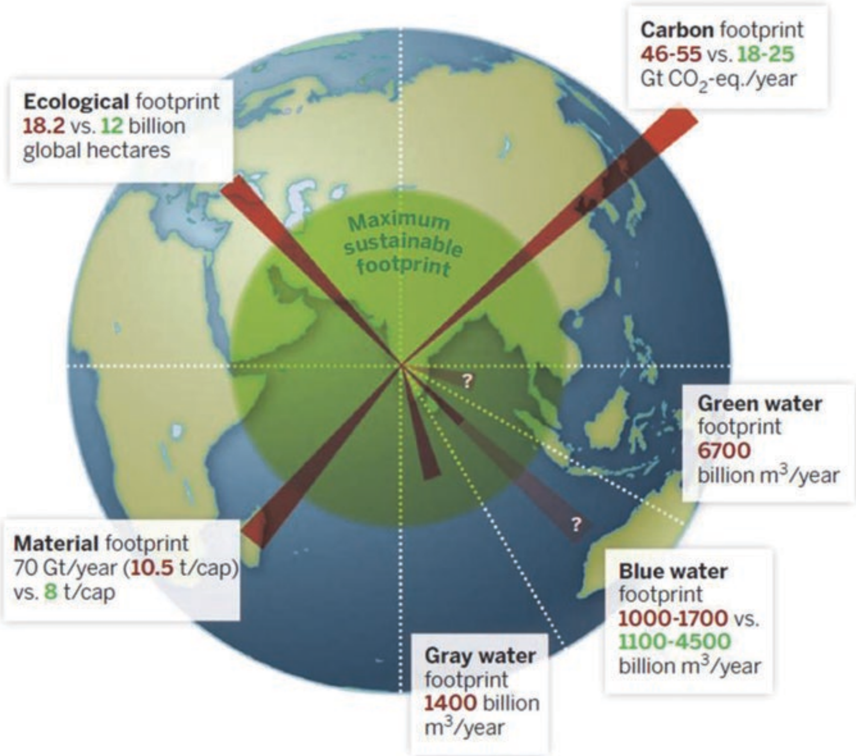

Fig. 3.3 Estimated global footprints versus their suggested maximum sustainable level. Reproduced with permission from Hoekstra and Wiedmann (2014). The inner light green circle represents the maximum sustainable footprint. Dark red bars represent estimates of the current level of each global footprint

2 Significance of Footprints in Environmental Management

Environmental footprints are considered as key indicators of performance in sectors of environmental management. They are also thought of as a method for demonstrating corporate social responsibility (Herva et al., 2011; Čuček et al., 2012). Resource efficiency implies recording a highly reduced footprint for every unit of product. Footprint of any enterprise consists of components of both operational (direct) and supply-chain (indirect) types. The footprints of processes involved in supply chains of a product guide the footprint of the final product. However, in the real scenario, companies tend to design reduction of their direct footprints. In doing so, the indirect footprints, which are often larger than direct ones, are ignored by these companies (Matthews et al., 2008).

Environmental footprint encompasses the consumption behaviour exhibited at both individual and community level. The large variation in consumption behaviour, associated environmental burdens, limited availability of natural resources and the earth's restricted assimilation capacity raises pressing questions like 'who has the largest footprint?' and 'what may actually be considered as a *fair share*?'. Footprints per capita vary widely both within and across nations (Minx et al., 2013). Achieving social equity would necessitate fair sharing of the limited natural resources between countries as well as by people within those countries (Hoekstra and Wiedmann, 2014). Equitable consumption in a world limited by boundaries necessitates reduction of humanity's environmental footprint to sustainable levels and convergence of footprints per capita towards a more equitable distribution (Hoekstra, 2013; Jackson, 2016). Footprints per capita may be estimated from consumption behaviour and extent of natural resource usage or waste generated for every unit of product used (Hoekstra, 2013). Consumers can influence the rate of utilization of natural resources or generation of wastes by purchasing eco-efficient products having low footprints. However, this is often hampered due to unavailability of product information (Hoekstra and Wiedmann, 2014).

3 Role of Ecological Footprint in Ensuring Environmental Sustainability

Of all other types of environmental footprint, the ecological footprint is a tool implemented for tracking the pressure of anthropogenic activities in terms of resource consumption and emission on the regenerative capacity of the biosphere (Galli et al., 2012). The ecological footprint accounts for both direct and indirect anthropological requirement of natural resources and CO_2 assimilation along with a comparative analysis of the same with the available ecological assets (biocapacity) of the planet (Monfreda et al., 2004). The significance of the ecological footprint lies in the fact that it simultaneously monitors different types of human activities (like changes in land-use, consumption of fish, CO_2 emissions, etc.) that are usually determined independently (Galli et al., 2012). Therefore, the ecological footprint efficiently helps in elucidating the environmental impact of anthropological pressure on the biosphere and the ecosystems constituting the same. Moreover, this tool is applicable over a wide range extending from a solitary product to cities, regions, countries as well as global scales (Galli et al., 2012).

Products like food and fibre that are derived from plants (requiring cropland), food and other products obtained from animal sources (requiring cropland and grazing land), food products prepared from fish sources (requiring fishing grounds), timber and non-timber forest products (requiring forest grounds), sequestration of fossil fuel derived CO_2 emissions (land required for carbon uptake) and the physical space utilized for construction of shelter and other infrastructure (developed area) are six primary ecosystem services that are widely demanded of a bio-productive land by the human economy (Galli et al., 2012). The ecological footprint is also used to determine the share of the regenerative capacity of the earth encroached upon by humans. Implementation of this tool is based upon the assumption that the regenerative capacity of the earth may act as a probable limiting factor of human economy if human consumption of the same exceeds the replenishment capacity of the biosphere (Galli et al., 2012).

The ecological footprint is also applied for measuring resource flow which in turn is expressed as units of area required every year for providing or regenerating flow of the concerned resource. This implicates that various fundamental ecosystem services as well as ecological resources are offered by surfaces also serving as sites of photosynthesis. These surfaces are constrained by physical and planetary boundaries and studies on over-utilization of such an area provides a better portrayal of the physical restraints hindering the progress of human economies (GFN, 2010).

Since bioproductivity varies with types of land use and countries, ecological footprints are expressed as units of average global bioproductive area, i.e. global hectares (gha) (Galli et al., 2012). Though the ecological footprint was initially developed to serve as an indicator of environmental impacts created by individuals, human populations or nations, it is also being investigated as an indicator of the environmental performance demonstrated by organizations or corporates as well as product sustainability (Wiedmann and Barrett, 2010).

4 Critical Objectives Addressed by the Ecological Footprint

Ten critical questions identified by Galli et al. (2016) help elucidate the strengths and weaknesses of the ecological footprint as an indicator of sustainability. The questions are addressed as follows.

Q. 1. *What underlying research question does the ecological footprint address*?
Ans: According to Giampietro and Saltelli (2014a,b), the ecological footprint was developed to evaluate anthropogenic impact on the planet by making an aggregated estimation over scales and compartments along with a simultaneous focus on a sub group of relevant dimensions of anthropogenic impact. In a separate study, Lin et al. (2015) stated that the question addressed by the application of ecological footprint was the estimation of the regenerative capacity of the biosphere that is required to meet the demand of anthropogenic activities. The value obtained may then be compared to the available regenerative capacity of the biosphere. Hence, it provides necessary, but insufficient criteria for indicating sustainability.
Q. 2. *How is the research question underlying the ecological footprint relevant or irrelevant to policy concerns*?
Ans: The questions addressed by the concept of ecological footprint are reportedly relevant to policy concerns but the answers provided by the same have been found to be misleading at times (Giampietro and Saltelli, 2014a, b). However, the concept of ecological footprint has been officially incorporated by several governmental and intergovernmental organizations (Lin et al., 2015). The concept of ecological footprint has been applied for guiding major alterations in allocation of finances, sustainable investments and drafting of policies by institutions like the World Business

Council. Besides, civil organization like the World Wide Fund for Nature (WWF) have utilised the concept of ecological footprint for estimating the anthropogenic impact on natural systems (Lin et al., 2015).

Q. 3. *If the research question underlying the ecological footprint has some relevance, are there more accurate methods available for answering this particular question*?

Ans: Besides ecological footprint, there are other indicators like the Planetary Boundaries, Nature Index, theoretical ecological indicators like EMergy analysis, ascendency for aquatic ecosystems, Ecosystem Integrity, etc. and the MuSIASEM (that elucidates the interconnection between energy, food, water and land uses within socio-ecological systems and with respect to environmental impact) (Giampietro and Saltelli, 2014a, b). Though these indicators may not serve as perfect alternatives of the ecological footprint, it still does not establish the ecological footprint to possess legitimacy and quality of comparable measures. These alternative approaches quantify demand but are unable to determine limits (Lin et al., 2015). Hence, the ecological footprint is considered as the best existing approach for estimation of anthropogenic demand on nature.

Q. 4. *Given the quality and accuracy limitations of current ecological footprint results, is society better off without these results*?

Ans: Giampietro and Saltelli (2014a, b) state that the results yielded by the ecological footprint are often misleading and may lead to development of detrimental policies. On the other hand, according to Lin et al. (2015), rejecting the results provided by ecological footprint that suggest a reduction in human consumption for adopting assumptions that ignore physical limitations by far would prove to be worse for mankind.

Q. 5. *What are the external referents used for quantitative assessments in ecological footprint accounting and what is the accuracy of the measurement schemes used to quantify their relevant characteristics*?

Ans: Before quantification, it is essential to gather information regarding the expected characteristics of the item to be quantified as well as the accuracy of the method of quantification. Few other necessary information include information regarding the 'expected characteristics' of the processes generating biocapacity that are estimated using the ecological footprint, significance of the error bar on the estimated biocapacity that is expressed as global hectare equivalent and whether the concerned process is accurate at regional, national as well as global scales (Giampietro and Saltelli, 2014a, b). However, discrepancies indicate the presence of potential noise within data and it is significantly difficult to perform a qualitative assessment of the input data (Lin et al., 2015).

Q. 6. *When calculating ecological footprint and biocapacity, is the measurement referring to the characteristics of a typology (which typology?) or to the characteristics of an instance? (An instance of what?)*

Ans: Giampietro and Saltelli (2014a, b) state that an appropriate definition of the characteristics of the flow-producing elements is essential prior to the measurement of 'biocapacity' as these characteristics indicate the capacity of the elements for producing a sustainable flow. Nevertheless, Lin et al. (2015) state that 'biocapacity' may vary with changes in parameters of environment and management and reflect existing conditions in contrast to the theoretical productivity recorded in absence of anthropogenic impact.

Q. 7. *Ecological footprint accounting methodology generates a unique set of quantitative assessments obtained combining together measurements referring to processes taking place at different scales. This unique set of quantitative assessments is supposed to be equally useful for agents operating at different scales—e.g. farms, cities, provinces, nations, macro-regions and the planet. What are the main benefits and the main limitations of this approach*?

Ans: The ecological footprint estimates flows without differentiating being the various typologies of elements generating the flows (Giampietro and Saltelli, 2014a, b). Summative results yielded by the ecological footprint are obtained by combining the characteristics of instances having different typologies, without any specification regarding the respective sizes of these instances in the combined results (Giampietro and Saltelli, 2014a, b). On the other hand, Lin et al. (2015) state that in absence of country specific data, average values of data obtained at regional or global scale are used for practical application of the ecological footprint. Results obtained in this method are highly accurate and reliable when measured globally or in countries having robust national statistics. For analysis on provincial scales, either appropriate data recorded at provincial levels are required or national data having lower resolution are scaled down though the latter may result in reduced accuracy (Lin et al., 2015).

Q. 8. *Ecological footprint accounting measures the biocapacity required for energy security as the land requirement required to absorb the CO_2 emissions. But then why does it not adopt the same logic for calculating the biocapacity required for food security—e.g. measuring the land required to absorb human dejections and food waste—rather than the land required to produce food*?

Ans: Matter and energy are metabolized by a society in either an endosomatic (metabolism of food within the human body) or an exosomatic (metabolism of nutrients occur outside the human body but under the control of the same) flow (Giampietro and Saltelli, 2014a, b). Both routes of metabolism require biocapacity for providing nutrients and absorbing wastes like dejections and emissions. However, when addressing the stability of endosomatic or exosomatic metabolism, the ecological footprint focuses only on the biocapacity (land) required for nutrient supply and waste sequestration respectively. This is neither logically consistent nor indicative of whether the concerned land may or may not be accounted for contributing to sustainability (Giampietro and Saltelli, 2014a, b). Moreover, Lin et al. (2015) state that the ecological footprint only considers the waste assimilative attribute of a resource without accounting for the anthropogenic impact on nature imposed by wastes and human dejections. These anthropogenic impacts are determined partially by two components of the ecological footprint: carbon footprint (accounts for CO_2 emissions generated during waste collection and processing) and the built-upland footprint (accounts for land used for development of waste disposal infrastructures).

Q. 9. *Can the assessments generated by ecological footprint accounting methodology define: (i) whether the flows considered in the quantitative assessment are in steady-state or referring to transitional states (i.e., flows obtained by stock depletion and filling of sink); (ii) how much these flows are beneficial to the economy and (iii) how much these flows are damaging ecological funds; why should assessments of exported (or imported) biocapacity be relevant*?

Ans: Analysis of ecological footprint and biocapacity help measure the excess or deficiency of biocapacity in terms of trade (Giampietro and Saltelli, 2014a, b). Under favourable conditions of trade, countries may externalize their need of biocapacity by using resources (like land) belonging to other countries. On a global scale, such trade exerts zero effect. However, on a national scale, the ecological footprint provides no information regarding regional environmental impacts. Explicit multi-scale and spatial analysis are required for addressing this limitation of the ecological footprint. As the definition of ecological footprint does not specify whether the biocapacity of a country has been generated by incurring irreversible depletion of natural resources of another country, the concept of ecological footprint is inappropriate for designing virtuous bilateral policies and may only isolate and blame the countries involved in import of biocapacity (Giampietro and Saltelli, 2014a, b).

In contrast to the opinion of Giampietro and Saltelli (2014a, b), Lin et al. (2015) state that in calculating ecological footprints, requirement and replenishment of resources are expressed as flows representing anthropogenic requirement of natural resources and ecological services provided by nature in terms of consistent units. Lin et al. (2015) also suggest that the human economy is a subsystem included within the environmental system. However, exploitation of ecological assets (like loss of soil, groundwater, forest biomass, fish stock or accumulation of carbon in the atmosphere) is not addressed by the measures of footprint. Hence, it may be concluded that though the ecological footprint is related to ecosystem damage it does not address specific questions related to issues of the same.

Q. 10. *How is the ecological footprint accounting similar or different from other international metrics/indicator systems*?

Ans: The ecological footprint differs from other international indicators because it simultaneously violates the following rules:

(i) Semantic rules: measure of biocapacity. It focuses on existing conditions instead of what is sustainable.
(ii) Common sense rules: biocapacity of an ecological system is found to increase with alterations induced in the same.
(iii) Formal rules for accounting: inconsistency in dimensions of the proposed equations.
(iv) Formal rules for analysis of sensitivity: repeated shifts of quantitative analysis across different scales yield in fragile results due to uncertainty induced by conversion factors and approximation of values.

5 Footprint Family

Management of global ecological assets has become a significant challenge for decision makers across the globe. An integrated strategy is expected to provide best information to these decision makers by enabling simultaneous handling of multiple environmental issues without any additional cost. Such an integrated approach will also overcome the limitation of addressing one sector by ignoring direct and indirect implications of activities occurring in other sectors. Hence, it is essential to comprehend the ways in which human activities are interconnected and also how they affect various sectors of this planet. In a study by Galli et al. (2012), authors for the first time have defined 'footprint family' as a combination of indicators (ecological, carbon and water footprints) for tracking anthropogenic pressure on the planet under various angles. Authors have defined the 'footprint family' as '*a set of indicators—characterized by a consumption—based perspective—able to track human pressure on the surrounding environment, where pressure is defined as appropriation of biological natural resources and* CO_2 *uptake, emission of greenhouse gases (GHGs), and consumption and pollution of global freshwater resources*'. Details of this study has been summarised in Table 3.1.

The 'footprint family' is widely applicable to various research and policies as it can be implemented for a particular product, a process, a sector and even at individual, local, national, and global scales alike. This suite of indicators extensively monitors environmental sustainability. However, this approach is yet to be developed for various other environmental, economic and social issues.

6 Conclusion

Footprints as indicators have proved to be powerful tools for increasing the visibility of significant aspects of both environment and society, thereby, enabling efficient management of the same. For achieving a challenge like global sustainability on an urgent basis, appropriate indicators are essential for guiding the major efforts required for an economy and society to cause the necessary transition. At present, there are few indicator systems for sustainable processes being applied at a national scale. These need to be more developed for consistent application across the world. Therefore, much more is needed to be done in this regard for designing and developing indicators of global sustainability. Also, relevant changes in terms of personal motivation and behaviour are essential at individual level for ensuring a sustainable society while there is still time.

Table 3.1 Indicators' testing phase: outcomes. Reproduced with permission from Galli et al. (2012)

	Ecological footprint	*Carbon footprint*	*Water footprint*
Research Question	The amount of the biosphere's regenerative capacity that is directly and indirectly {i.e. embodied in trade) used by humans (namely Ecological Footprint) compared with how much is available (namely biocapacity), at both local and global scale.	The total amount of GHG emissions (CO_2, CH_4, N_2O, HFC, PFC, and SF_6) that are directly and indirectly caused by human activities or accumulated over the life stages of products.	The human appropriation of the volume of freshwater required to support human consumption.
Main Message	To promote recognition of ecological limits and safeguard the ecosystems' life-supporting services enabling the biosphere to support mankind in the long term.	The consumption-based perspective of the Carbon Footprint complements the production-based accounting approach taken by national GHG inventories (e.g., those considered by the Kyoto Protocol).	The Water Footprint concept is primarily intended to illustrate the hidden links between human consumption and water use and between global trade and water resources management.
Data and Sources	• Data on local production, import and export for agricultural, forestry and fisheries products (FAOSTAT, UN Comtrade); • Land use data (FAOSTAT, etc); • Local and trade- embedded CO_2 emissions (IEA and others); and	• National economic accounts (supply, use, input-output tables); • International trade statistics (UN, OECD, GTAP and others); and • Environmental accounts data on GHG emissions (IEA, GTAP, and others).	• Data on population (World Bank); • Data on arable lands (FAO) and total renewable water resources and water withdrawals (FAO); • Data on international trade in agricultural (PC- TAS) and industrial products (WTO); and
	• Land yield (FAOSTAT) and potential crop productivity (provided by the FAO GAEZ model) - this data is needed to express results in units of global hectares.		• Local data on various parameters such as climate, cropping patterns, soil, irrigation, leaching, water quality, pesticides and fertilizers rates, etc.

(continued)

Table 3.1 (continued)

	Ecological footprint	*Carbon footprint*	*Water footprint*
Unit of Measurement	• Global hectares (gha) of bioproductive land. Gha is not a measure of area but rather of the ecological production associated with an area; and • Results can also be expressed in actual physical hectares.	• Kg CO_2 when only CO_2 is included or kg CO_2- equivalent when other GHGs are included as well; and • No conversion to an area unit takes place to avoid assumptions and uncertainties.	• Water volume per unit of time (usually $m^3\ yr^{-1}$) for the Water Footprint of processes; • $m^3\ ton^{-1}$ or litre kg^{-1} for the Water Footprint of products; and • Water volume per unit of time for the Water Footprint of a geographical area.
Indicator Coverage	• Temporally explicit and multi-dimensional indicator that can be applied to single products, cities, regions, nations and the whole biosphere; • Data are available for approximately 240 nations for the period 1961-2007; however, data for only about 150 nations are consistently published (Ewing et al., 2010); • Documents both direct and indirect human demands for both the **source** (resource production) and the **sink** (carbon uptake) capacity of the biosphere;	• Multi-dimensional indicator that can be applied to products, processes, companies, industry sectors, individuals, governments, populations, etc.; • 113 nations and world regions for the year 2004 when using the GTAP7 database (Wiedmann, 2009); • Documents all direct and indirect GHGs emissions due to use of resources and products **(source);**	• Geographically explicit and multi-dimensional indicator: it can be calculated for products, public organizations, economic sectors, individuals, cities and up to nations; • 140 nations for the period 1996-2005 are tracked (Mekonnen and Hoekstra, 2010); • Documents both the direct and indirect use of natural capital as a **source** (demand on blue and green waters) and as a sink (grey water to dilute pollution);

(continued)

Table 3.1 (continued)

	Ecological footprint	*Carbon footprint*	*Water footprint*
	• Provides a measure of both human demand and nature supply; • Provides a clear benchmark; and • It has a consumption- based point of view and thus considers trade.	• Measures the 'demand' side only, in terms of the amount of GHGs emitted; and • It has a consumption-based point of view and thus considers trade.	• Measures the 'demand' side only, in terms of freshwater consumed (by sources) and polluted (by type of pollution) by human activities; • No benchmark is provided; and • It has a consumption-based approach and considers trade.
Policy Usefulness	• Measures 'overshoot' and identify the pressures that humanity is exerting on various ecosystem services; • Monitors societies' progresses towards minimum sustainability criteria (demand ≤ supply); • Monitors the effectiveness of established resource use and resource efficiency policies; • Allows analysis of the consequences of using alternative energies; • Communicates environmental impacts of different life-styles to the overall public; • Tracks pressure on biodiversity; and • Illustrates the unequal distribution of resource use and availability.	• Offers an alternative angle for international policy on climate change as it complements the territorial-based approach used by the UNFCCC; • Offers a better understanding of countries' responsibility and could facilitate international cooperation and partnerships between developing and developed countries; • Can help design an international harmonized price for greenhouse gas emissions; and • Illustrates the unequal distribution of resource use.	• Gives a new and global dimension to the concept of water management and governance; • Offers nations a better understanding of their dependency on foreign water resources; • Offers river basin authorities info on the extent to which scarce water resources are allocated to low-value export crops; • Offers companies a way to monitor their dependence on scarce water resources alongside their supply- chain; and • Illustrates the unequal distribution of resource use.

(continued)

Table 3.1 (continued)

	Ecological footprint	*Carbon footprint*	*Water footprint*
Strengths	• Allows benchmarking human demand for renewable resources and carbon uptake capacity with nature supply and determining clear targets. • Provides an aggregated assessment of multiple anthropogenic pressures; and • Easy to communicate and understand with a strong conservation message.	• Allows for a comprehensive assessment of human contribution to GHG emissions; and • Consistent with standards of economic and environmental accounting. • Consistent emissions data available for the majority of countries.	• Represents the spatial distribution of a nation's water "demand"; • Expands traditional measures of water withdrawal (green and grey waters also included); and • Visualizes the link between (local) consumption and (global) appropriation of freshwater. Integrates water use and pollution over the production chain.
Weaknesses	• Cannot cover all aspects of sustainability, neither all environmental concerns, especially those for which no regenerative capacity exists (including abiotic resources); • Shows pressures that could lead to degradation of natural capital (e.g. reduced quality of land or reduced biodiversity), but does not predict this degradation; and • Not geographically explicit. • Some underlying assumptions are controversial, though documented	• Cannot track the full palette of human demands on the environment: • Additional impact assessment models are needed to analyze the impact of climate change at both national and sub-national levels; • Efforts needed to set up and update a system of MRIO tables and related environmental extensions; and	• Only tracks human demand on freshwater; • It relies on local data frequently unavailable and/or hard to collect. It suffers from possible truncation errors; • No uncertainty studies are available, though uncertainty can be significant; and • Grey water calculation heavily relies on assumptions and estimations.
Complementary Properties of the Footprint Family	• Uses a consumer-based approach to track human pressures on the planet in terms of the aggregate demand that resource-consumption and CO_2 emissions places on the ecological assets (impact on *biosphere*).	• Uses a consumer-based approach to track human pressures on the planet in terms of total GHG emissions and human contribution to climate change (impact on *atmosphere*).	• Uses a consumer-based approach to track human pressures on the planet in terms of the water volumes required for human consumption (impact on *hydrosphere*).

References

Chambers, N., Simmons, C. and Wackernagel, M. (2014). Sharing Nature's Interest: Ecological Footprints as an Indicator of Sustainability. Routledge.

Čuček, L., Klemeš, J.J. and Kravanja, Z. (2012). A review of footprint analysis tools for monitoring impacts on sustainability. *J Cleaner Prod*, **34:** 9–20.

Ercin, A.E. and Hoekstra, A.Y. (2014). Water footprint scenarios for 2050: A global analysis. *Environ Int*, **64:** 71–82.

Ewing, B., Moore, D., Goldfinger, S., Oursler, A., Reed, A. and Wackernagel, M. (2010). Ecological Footprint Atlas 2010. Global Footprint Network, Oakland. Accessed from http://www.footprintnetwork.org/images/uploads/Ecological%20Footprint%20Atlas%202010.pdf on 12.10.10.

Fang, K., Heijungs, R. and de Snoo, G.R. (2014). Theoretical exploration for the combination of the ecological, energy, carbon, and water footprints: Overview of a footprint family. *Ecol Indicators*, **36:** 508–518.

Galli, A., Giampietro, M., Goldfinger, S., Lazarus, E., Lin, D., Saltelli, A., Wackernagel, M. and Müller, F. (2016). Questioning the ecological footprint. *Ecol Indicators*, **69:** 224–232.

Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B. and Giljum, S. (2012). Integrating ecological, carbon and water footprint into a "footprint family" of indicators: Definition and role in tracking human pressure on the planet. *Ecol Indicators*, **16:** 100–112.

Giampietro, M. and Saltelli, A. (2014a). Footprints to nowhere. *Ecol Indicators*, **46:** 610–621.

Giampietro, M. and Saltelli, A. (2014b). Footprint facts and fallacies: A response to Giampietro and Saltelli (2014) footprints to nowhere. *Ecol Indicators*, **46:** 260–263.

Global Footprint Network (GFN) (2010). Harmonizing the National Footprint Accounts with the System of Integrated Environmental and Economic Accounting. Paper number UNCEEA/5/11 prepared for discussion at the 5th Meeting of the UN Committee of Experts on Environmental-Economic Accounting, 23–25 June 2010, New York. http://unstats.un.org/unsd/envaccounting/ceea/meetings/UNCEEA-5-11.pdf (accessed 10.10.10).

Herva, M., Franco, A., Carrasco, E.F. and Roca, E. (2011). Review of corporate environmental indicators. *J Cleaner Prod*, **19(15):** 1687–1699.

Hoekstra, A.Y. (2013). The Water Footprint of Modern Consumer Society. Routledge.

Hoekstra, A.Y. and Mekonnen, M.M. (2012). Reply to Ridoutt and Huang: From water footprint assessment to policy. *Proc Natl Acad Sci USA*, **109(22):** E1425–E1425.

Hoekstra, A.Y. and Wiedmann, T.O. (2014). Humanity's unsustainable environmental footprint. *Science*, **344(6188):** 1114–1117.

IUCN (2009). Caring for the earth: A strategy for sustainable living. Earthscan.

Jackson, T. (2016). Prosperity without Growth: Foundations for the Economy of Tomorrow. Routledge.

Leach, A.M., Galloway, J.N., Bleeker, A., Erisman, J.W., Kohn, R. and Kitzes, J. (2012). A nitrogen footprint model to help consumers understand their role in nitrogen losses to the environment. *Environ Dev*, **1(1):** 40–66.

Lenzen, M., Moran, D., Kanemoto, K., Foran, B., Lobefaro, L. and Geschke, A. (2012). International trade drives biodiversity threats in developing nations. *Nature*, **486(7401):** 109.

Lin, D., Wackernagel, M., Galli, A. and Kelly, R. (2015). Ecological footprint: Informative and evolving—A response to van den Bergh and Grazi (2014). *Ecol Indicators*, **58:** 464–468.

Matthews, H.S., Hendrickson, C.T. and Weber, C.L. (2008). The importance of carbon footprint estimation boundaries. *Environ Sci Technol*, **42(16)**: 5839–5842.

Mekonnen, M.M. and Hoekstra, A.Y. (2010). A global assessment of the green, blue and grey water footprint of crops and crop products. Value of Water Research Report Series. UNESCO-IHE, Delft, The Netherlands.

Minx, J., Baiocchi, G., Wiedmann, T., Barrett, J., Creutzig, F., Feng, K., …, and Hubacek, K. (2013). Carbon footprints of cities and other human settlements in the UK. *Environ Res Lett*, **8(3):** 035039.

Monfreda, C., Wackernagel, M. and Deumling, D. (2004). Establishing national natural capital accounts based on detailed ecological footprint and biological capacity assessments. *Land Use Policy*, **21(3):** 231–246.

Moore, D., Cranston, G., Reed, A. and Galli, A. (2012). Projecting future human demand on the Earth's regenerative capacity. *Ecol Indicators*, **16:** 3–10.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F.S., Lambin, E.F., …, and Nykvist, B. (2009). A safe operating space for humanity. *Nature*, **461(7263):** 472.

Wang, F., Sims, J.T., Ma, L., Ma, W., Dou, Z. and Zhang, F. (2011). The phosphorus footprint of China's food chain: Implications for food security, natural resource management, and environmental quality. *J Environ Quality*, **40(4):** 1081–1089.

Wiedmann, T. and Barrett, J. (2010). A review of the ecological footprint indicator—Perceptions and methods. *Sustainability*, **2(6):** 1645–1693.

Wiedmann, T. (2009). A review of recent multi-region input–output models used for consumption-based emission and resource accounting. *Ecol Economics*, **69(2):** 211–222.

Wiedmann, T. and Minx, J. (2008). A definition of 'carbon footprint'. *Ecol Econ Res Trends*, **1:** 1–11.

Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J. and Kanemoto, K. (2015). The material footprint of nations. *Proc Natl Acad Sci USA*, **112(20):** 6271–6276.

Chapter 4
Air, Noise and Odour Pollution and Control Technologies

Dipanjali Majumdar

1 Introduction

One of the major and pressing challenges in today's world faced by developed and developing nations alike is atmospheric pollution in the form of air, noise and odour pollution. Nations' quests towards perpetual economic growth coupled with increasing population load requires vast and extensive exploitation of natural resources. In this process of walking the path of 'progress' and to achieve 'development', an enormous amount of unwanted and potentially harmful waste products are released into atmosphere on a regular basis. Societies for long have failed to understand the carrying capacity of atmosphere till the point where the atmospheric pollution has not only started to affect the wellbeing and health of people, vegetation, caused damages to crops and wildlife but also affected the climate and resulted in depletion of natural resources. For developing nations, the challenges are particularly critical as in one hand the polluting sources include onus from industrial development where as in other hand poverty, lack of management and related sources such as solid fuel burning and poor management of waste becomes equally important factor (World Bank, 2005). Although air pollution can be caused by both natural and anthropogenic activity, but here we restrict our discussion to man-made pollution only.

2 Air Pollution

Until a few decades ago well into twentieth century, air pollution was synonymous with suspended particulate matter, i.e., soot, smoke and sulphur dioxide to most people. As twentieth century progressed, sharp increase in petroleum product use,

D. Majumdar (✉)
CSIR-National Environmental Engineering Research Institute, Kolkata Zonal Centre, Kolkata, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_4

development of new chemicals and industrial processes occurred (Dara, 1995). As a result, the type of air pollutants as well as concern for pollution of the atmosphere has ranged across a large number of pollutants.

2.1 Particulate Matter

The range of finely divided solids and liquids dispersed into atmosphere having aerodynamic diameter from 100 μm to <0.1 μm are termed as suspended particulate matter (SPM).

Respirable particulates matter (RPM) also known as PM_{10} is referred to those particulate matter, which have aerodynamic diameter less than 10 μm. They are significant with respect to their effect on human health as these can penetrate to the respiratory system. Typical urban RPM usually exhibits bimodal size distributions comprising a coarse mode (associated with suspension, resuspension and abrasion processes) and a fine mode (associated with accumulation and secondary formation process). Traffic emissions increase the particulate matter concentration significantly especially in the size range of 0.5–5 μm as a consequence of both primary particulate traffic emission and re-suspension of soil dust. This type of emission has little influence on the finest size fraction (<0.5 μm), which are derived from secondary formation processes in the atmosphere. Particulate size distribution varies with season and meteorological parameter such as wind speed and direction, temperature, atmospheric pressure, relative humidity, mixing height etc. Variability in size distribution of urban RPM depends upon both local emission and removal processes such as deposition on canopy cover (Rao and Rao, 1997; Dara, 1995; Freiman et al., 2006).

The subgroup of respirable particulate matter having diameter less than 2.5 μm is termed as fine particulate matter or $PM_{2.5}$. Major sources of anthropogenic $PM_{2.5}$ are fossil fuel combustion such as coal or petroleum product. Any kind of combustion such as biomass, waste, plastic etc. also leads to formation of $PM_{2.5}$. Apart from primary emission of fine particulates, secondary formation from precursors such as oxides of nitrogen and reactive organic gases are also prominent contributors to atmospheric level of $PM_{2.5}$.

A major constituent of particulate matter especially in urban atmosphere is black carbon (BC); mostly originates from fossil fuel combustion such as from coal fired power plants, gas and diesel engines etc. Black carbon is pure carbon in several linked form that affects reflectivity of the atmosphere, also affects stability as well as alters duration of clouds and precipitation (USEPA, 2004a; Miranda and Tomaz, 2008).

The health effects arising from airborne particulate matter (PM) depend upon the particle characteristics in terms of its size, composition and concentration. The guideline values recommended by World Health Organization (WHO) is 20 μg/m^3 for PM_{10} and 10 μg/m^3 for $PM_{2.5}$ considering yearly average. Adverse health effects are more strongly associated with the organic and inorganic carbon fraction (OC/EC) of particulate matter than with the inorganic components such as sulphate and nitrate. Particles having size below 10 μg pose most health risk since they are likely to be inhaled and deposited in the lungs and are highly bioreactive. Epidemiological studies across the world confirmed association between chronic exposure to ambient fine particulates with acute and chronic respiratory disorders, lung cancer leading to morbidity and mortality. Fine particulate fraction is the most harmful to human health as they can penetrate into the alveoli of lungs where gases are exchanged with the blood stream. Thus, toxic chemicals including carcinogens associated with fine particulate matter enters blood stream and may cause inflammation or may trigger heart and lung diseases (USEPA, 2004a; USEPA RAIS; Gadkari and Pervez, 2007; Wichmann, 2000) (Fig. 4.1).

2.2 Gaseous Pollutants

Gaseous air pollutants include both inorganic and organic gases from various sources.

2.2.1 Sulphur Dioxide

The main source of sulphur dioxide (SO_2) is combustion of fossil fuel mainly coal. The major fraction of sulphur in the coal (about 80%) reacts with atmospheric oxygen to form SO_2 during combustion. The rest of the sulphur remains in the ash as inorganic sulphur. The sulphur content in coal may vary from less than 1% to over 4% in bituminous coal. Sulphur is also a constituent of crude petroleum oil. Refining process of petroleum through fractional distillation tend to concentrate the sulphur compounds in heavier fraction. Hence, diesel contains more sulphur than petrol. SO_2 is also produced during metallurgical operations. Extraction of metals such as zinc, copper or lead from their sulphide ores by smelting process inevitably releases

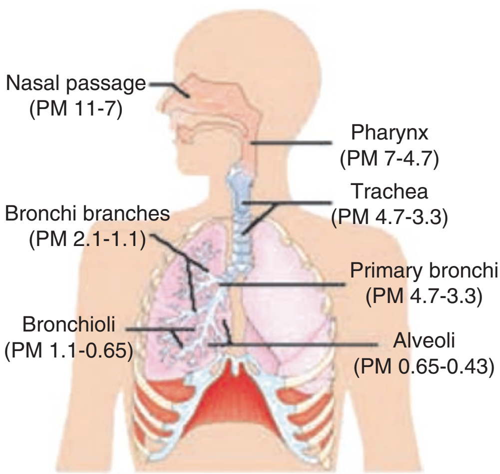

Fig. 4.1 Deposition of particulate matter in different part of lungs depending upon the particulate aerodynamic diameter in micrometres

the sulphur in the environment in the form of oxide. However, these may be recovered as sulphuric acid with proper technology. Sulphur dioxide may also be released in atmosphere from sulphuric acid or paper manufacturing plants. Other sources include open burning on municipal waste and biomass burning such as wood, twigs, dung cake etc.

Sulphur dioxide gets absorbed in the mucous membranes of the nose and human upper respiratory tract. Chronic exposure to elevated level of SO_2 have been associated with decreased lung function, wheezing etc. The health effect may be aggravated with simultaneous exposure of fine particulate matter. The present WHO guideline for SO_2 is 20 μg/m^3 (24 hourly mean).

2.2.2 Oxides of Nitrogen

Oxides of nitrogen (NOx) are one of the most critical inorganic gaseous pollutants especially in urban environment. The oxides of nitrogen may include nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), dinitrogen trioxide (N_2O_3), dinitrogen tetroxide (N_2O_4), dinitrogen pentoxide (N_2O_5) and nitric acid (HNO_3). The major contribution of NOx in atmosphere comes from automobile exhaust where the high temperature generated in the combustion engine results in reaction between atmospheric oxygen and nitrogen towards formation of nitrogen oxides. NOx are also generated during power generation process. Atmospheric NO_2 is mostly emitted as NO, then it is rapidly oxidised to NO_2 in atmosphere in presence of ozone. Nitrous oxide is a potent greenhouse gas. Nitrogen dioxides reduce visibility by forming aerosol and they have potential to cause increase in global surface temperature. Nitrogen dioxide, in the presence of non-methane volatile organic compounds and UV radiation, produces tropospheric ozone and secondary aerosols (nitrate). These secondary aerosols are major constituent of fine particulate matter of the ambient air ($PM_{2.5}$). NO_2 are often used as a marker for the blend of pollutants originated during combustion process, such as vehicular sources or indoor combustion sources (IPCC, 2001, 2006).

The current WHO guideline value for NOx in ambient air is 40 μg/m^3 (annual mean). Long-term exposure to level higher than this level may cause decreased lung function or have effect of respiratory system especially for children. Short-term exposure to high level of NOx (above 200 μg/m^3) may cause adverse health effect. Epidemiological studies have proved association of increased bronchitis symptoms of asthmatic children with annual ambient level of NO_2.

2.2.3 Non-methane Volatile Organic Compounds

Non-methane volatile organic compounds (NMVOCs) are organic chemical compounds that have high enough vapour pressures under normal conditions to significantly vapourise and enter the atmosphere. The major anthropogenic sources of a vast range of VOCs in the urban environment are vehicle exhaust due to incomplete combustion of the fuel, gasoline evaporation at normal surface temperatures, emissions from the use of solvents, and gas leakage from natural gas and liquefied petroleum gas (LPG). Large scale industries like petroleum refineries are responsible for extensive emission of VOCs like butadiene, benzene and other aromatics, methyl tertiary butyl ether (MTBE), tetrachloroethylene and formaldehyde. Also, household products including paints, paint strippers and other solvents, wood preservatives, cleansers and disinfectants, moth repellents and air fresheners, stored fuels and automotive products, dry-cleaned clothing and cosmetics are good sources of VOCs in the atmosphere (Derwent, 1995; Varshney and Padhy, 2008).

VOCs have 2-fold impact in tropospheric chemistry. VOCs in the atmosphere rapidly react with anthropogenic compounds (mainly NOx) to form ground level ozone, photochemical oxidants and smog episodes, which are especially favoured by high radiation and temperature with low wind speed and they are harmful to the ecosystem (Atkinson, 2000). Also, photochemical reactions of VOCs in the presence of oxides of nitrogen (NOx) and ozone give rise to secondary organic aerosol (SOA) (Kroll and Seinfeld, 2008). The formation and removal of particle in the atmosphere is a dynamic process. The combination of chemical, physical and meteorological processes defines the production rate of non-volatile substances that can then either nucleate or condense onto the surfaces of foreign particles. The organic free radicals produced in the oxidation reactions of certain gas-phase organic species result in secondary products of volatility that is sufficiently low that they partition between the gas and aerosol phases. The fraction that partitions to the aerosol phase is known as secondary organic aerosol (SOA). Because of its nature of formation, SOA is mostly concentrated in the sub-micrometer fraction of the fine particulate and became an integral part of the urban aerosol. In most urban areas, carbonaceous species constitute 20–50% of fine particle mass. Interest in SOA formation in the atmosphere has been increased because of its possible serious impact on visibility in atmosphere through absorption and scattering of the incoming radiation, formation of clouds, change of climate and human health (NIOSH, 2007).

A number of adverse health effects such as asthma, dizziness, fatigue, eye, nose and throat irritation, nausea and similar nonspecific symptoms have been associated with different types of anthropogenic VOCs. These were found to have positive correlation with severe symptoms of asthma among children. Many of the VOCs are proven or probable human carcinogen. There are more than 100 different Polycyclic aromatic hydrocarbons (PAHs) that draw health concerns and several of them are human carcinogens and/or mutagens, the most notorious being benzo[*a*]pyrene. Some PAHs, phthalates and phenols are probable human carcinogens and endocrine disruptors (NIOSH, 2007).

2.2.4 Ozone

Ozone is known to be ‘good up high, bad nearby’. While the stratospheric ozone is considered to be one of the most effective protections for all life forms on the earth from harmful cosmic UV rays, ozone in lower troposphere is considered to be an air pollutant. Ozone is generally not emitted from primary sources but is photochemically formed at ground level from its precursors such as NO_x and VOCs in the presence of sunlight. Hence, ozone is known as secondary pollutant. Ozone pollution mainly occurs in urban and suburban areas due to the presence of precursors and the produced ozone can travel to nearby rural areas and pollute thereby. Ozone is highly reactive species and it readily undergoes other photochemical reaction with NOx and VOCs to form other secondary pollutants such as peroxyacetyl nitrate (PAN), which together may cause photochemical smog in favourable meteorological condition. Ozone also causes formation of secondary particulate matter especially fine particulates and hence elevates the level of $PM_{2.5}$ in ambient air (Finlayson and Pitts, 1997).

Ozone is a known irritant and poses detrimental effect on vegetation and crop yield. WHO guideline value for ground level ozone is 100 μg/m^3 (8 h average). Exposure to ozone above the recommended value may cause various health effects such as decrease in lung function and even increased mortality. Ozone poses severe health risk especially for children, the elderly and people with chronic lung and heart disease. Healthy people who exercise outdoors may get affected by ozone due to increased breathing rate.

Table 4.1 gives the guideline values of major air pollutants recommended by World Health Organization as safe level.

2.3 Air-Pollution Control

Air pollution control is a complex subject impacting one and all. There are two aspects of air pollution control: policy intervention and technological solutions (Dara, 1995; Elsom, 1987).

Table 4.1 WHO Guideline levels for each pollutant (μg/m^3)

Air pollutant	*Exposure period*	*Recommended level*
$PM_{2.5}$	1 year	10
	24 h (99th percentile)	25
PM_{10}	1 year	20
	24 h (99th percentile)	50
Ozone, O_3	8 h, daily maximum	100
Nitrogen dioxide, NO_2	1 year	40
	1 h	200
Sulphur dioxide, SO_2	24 h	20
	10 min	500

Source: url: https://www.who.int/airpollution/publications/aqg2005/en.

2.3.1 Policy Intervention

Policies related to air pollution control may be broadly categorised into three categories: air quality management, emission standards for source and economic policy intervention.

(a) Air Quality Management

Air quality management strategy of any given region is a complex task involving multi-tier scientific studies considering air pollutants, their effect on community health as well as economy. This includes designating the acceptable level of air pollutant in a particular environment such as ambient or other micro-environment like residential indoor, workplace etc. It can be described as setting a clearly defined set of air quality standard goal. As evident, such goal is closely related to emissions from numerous sources as well as meteorological condition of the nation or state under consideration. However, it is the first step for any nation to assess the air quality in general and to understand the non-attainment areas and the extent of it. Such air quality standard is also pivotal in public understanding as well as mass awareness. One of the basic tools of air quality management of any given nation, state or region is the 'emission inventory'. This is an in-depth exercise that considers all air pollution generating activity within the given area in a particular time frame. With the help of source as well as activity specific emission factors, the total emission of air pollutant may be estimated. Emission inventory gives a broad estimation regarding the major air polluting sources (Fujita et al., 1995). A receptor source apportionment study is also important to understand the actual source contribution to ambient air pollution. In this exercise, air sampling is performed in selected representative location referred to as receptor sites and they are chemically characterised further. Utilising complex model such as CMB 8.2 (chemical mass balance) or PMF (positive matrix factorisation) and reference source signature, such a study will give an estimate of the contribution fraction of major sources at those receptor sites (USEPA, 2004b; Willis, 2000). It is important to understand that the source contribution from emission inventory will widely vary from the source contribution estimated at receptor points, which even vary considerably from site to site. The emission from various sources, e.g., point, area as well as line sources are emitting pollutant at different height and different meteorological condition. A stack will emit pollutant at a height whereas emission from domestic fuel consumption will be at ground level. Emission from industry may receive a high wind speed to disperse quickly whereas vehicular emission may be accumulated over time in a narrow street canyon. Hence, the observed pollutant concentration as well as source contribution at any given receptor point will be subject to source intensity (as indicated by emission inventory) of various contributing sources along with meteorology driven dispersion and even secondary reactions of those primarily emitted air pollutants. Thus, a mathematical model (known as dispersion model) is required to calculate and predict the air pollution level of a given region from an emission inventory under varying meteorological condition and to predict air-pollution levels arising from proposed changes to emission in that region. It is important to note that apart from the primary emission in the given region the observed level of air pollution will also correspond to (i) secondary pollutant formed in-situ, (ii) pollutant received from immediate neighbouring region and (iii) pollutant in aged air mass that are transported from long range. Subsequent to these exercises, a set of pollution reducing tactics is needed in view of the requirement to achieve compliance to air quality standards. Such option may involve comprehensive integral planning of energy supply, transportation, land use, industrial development, waste management and even sustainable development. Specifically, pollution control option may include emission control norms, restriction of certain fuel usage (e.g., solid fuel). Ban on certain activity (such as open burning). However, all such actions need to be examined for their effectiveness in reducing air pollutant level at receptor points utilising predictive dispersion modelling vis-a-vis their economical feasibility, rate of possible implementation as well as enforceability.

(b) Emission Standard Strategies

These strategies specify the maximum amount or concentration of a pollutant which is permissible to be emitted from a given source. Emission standards are designated for a group of pollutants and may be applied to individual source or a group of emitters. The emission standard may be derived considering air quality standard as a part of air quality management strategy. The emission standard may also be derived considering best available technology, and economic consideration as part of good practice.

To achieve an emission standard, it is often required for the pollution generating sources to make change in the fuel or in process, retrofitting of pollution control device or shifting to new technology based on practical and economical feasibility.

(c) Economic Strategies

Financial leverages or incentives to control air pollution may be considered under this category. An example of such strategies is to provide financial incentive or tax relaxation to industries for reducing pollution emission. Regulation in fuel prices or higher transportation fee during rush hour may also be considered as economic strategies. Imposing fine for polluters to pay may also prove useful for controlling air pollution.

2.3.2 Technological Solutions

Technological solutions of air pollution control are mostly applicable at pollution emitting sources and can be grouped under four broad categories.

(a) Reduction of pollution emission from sources by using pollution control equipment.
(b) Reduction of source emission by change in one or combination of raw material, process, operation etc.

(c) Dilution of source emission by use of tall stack.
(d) Dispersion of source emission by isolation and allowing designated land usage, such as industrial cluster etc.

2.4 Methods and Equipment Used for Controlling Particulate Emissions

The pollution control devices for removing particulates from an emission stream are based on the size, shape, electrical and hygroscopic properties of the particulates to be arrested. The various devices used may be categorised as follows:

***Mechanical separation*:** These devices mostly operate on the basis of gravity settling or change in momentum. In gravity settling in which the velocity of the emission stream is reduced sufficiently to allow the particles to settle by gravitational force. Alternatively, particles due to their greater momentum get separated on rapid change of direction of the gas flow. A few commonly used mechanical pollution control devices are settling chambers, buffer chambers, cyclone separators etc.

***Separation by filtration*:** Particulate rich emission stream is forced through filter device with porous medium. Particles get trapped in the filter whereas gases pass through the system. Dust-laden gases are forced through a porous medium such as woven or filled fabric. Commonly used filters include fibrous or deep-bed filters and cloth bag fabric filters made from material like cotton, wool, nylon for lower temperature or more complex material such as asbestos, silicone coated glass cloth etc. for high temperature (up to 350 °C) usage. Different media may be used for acidic gas stream (wool, orlon and vinyon) or alkaline one (cloth, nylon and asbestos).

***Electrostatic precipitators*:** Gas stream with heavy particulate load is passed through a heavily charged electric field created by two electrodes having sufficient potential difference, and then the particulates get precipitated on the electrodes. An electrostatic precipitator (ESP) consists of a high voltage source, two electrodes; one is a high voltage discharge electrode (usually negative) with small cross-sectional area, such as a wire, and another one, a collecting electrode (usually positive and at ground potential) of large surface area, such as a series of plate. An electrostatic precipitator will also contain a device for disposing the collected particulates. The control device will at first electrically charge the particles by ionisation and then will transport the charged particles to the collecting surface by electrical field. After collection, the precipitated particles are neutralised and removed from the collecting surface. In earlier one-stage devices (ESP-I) ionisation and collection are performed in a single step. In improved devices, two-stage precipitators are employed (ESP-II), where a pre-ionising step is followed by collection. Efficiency of ESP-II is more than ESP-I. ESPs are widely used for controlling air pollution from very large volumes of emission stream or for recovery of material and also for high removal efficiency for fine particulates at high temperature. ESPs are effectively used in power plants, iron and steel plants, mining and metallurgical industries, paper and pulp industries, refineries, chemical industries such as sulphuric acid plants, carbon black manufacturing industries etc.

***Wet scrubbers*:** Wet scrubbers are often used to remove both fine particulate and gaseous pollutants simultaneously. This control device is effective for low volume of emission stream with high temperature that requires cooling. Wet scrubbers may be liquid carriage type where the gas stream containing the particles is allowed to strike a liquid surface within the collector and the liquid traps the gas particles within the liquid droplets and then the liquid is collected for disposal. In particle conditioning technology, the particulates in the emission stream are brought into immediate contact with water so that heavier water-particulate agglomerates could be formed with bigger effective size that can be more easily separated from the gas stream by any other collection mechanisms. Different wet scrubbers used widely in the industries include ventury scrubber, gravity spray scrubber, wet impinge scrubber, cyclone spray chambers, wet centrifugal scrubber, etc. Wet scrubbers are useful for in chemical, mining and metallurgical industries to trap inorganic gases and metal fumes along with particulates.

2.5 Methods and Equipment Used to Control Gaseous Pollutants

Gaseous pollutant both inorganic and organic may be controlled using variety of technology as follows:

***Combustion*:** Organic gases or vapours can be controlled using this technique. Flame combustion or catalytic combustion of such pollutants can easily convert them into less harmful carbon dioxide and water. Such catalytic converters are used for controlling vehicular emission. Vehicular emission contains hydrocarbons and other organic gases generated due to incomplete combustion of gasoline. Vehicular exhaust thus passed through a chamber where the organic pollutants are catalytically converted to control those organic pollutants. Other equipment used for combustion include fume incinerators, steam injection, venture flares and after-burners.

***Absorption*:** Gaseous emissions are often passed through scrubbers or absorbers containing a suitable liquid absorbent to remove or modify one or more of the pollutants present in the emission stream requiring pollution control. The effectivity of the absorption process depends on multiple parameters such as chemical reactivity of the gaseous pollutant in the liquid phase, surface contact between the liquid and the gas, contact period and also the concentration of the absorbing medium. Commonly used equipment for removing gaseous pollutants like NOx, H_2S, SO_2,

SO_3 and fluorides from emission stream utilising absorption technology are packed towers, plate towers, bubble-cap plate towers, spray towers, liquid jet scrubber towers etc.

***Adsorption*:** Certain gaseous pollutants may effectively be removed from emission stream by the process of adsorption or chemisorption on the surface of a suitable adsorbent. Being a surface phenomenon, the efficiency of adsorption depends upon the available surface area per unit weight of the adsorbent as well as physical and chemical characteristics of the adsorbent and nature of the pollutant adsorbed. The common adsorbents used for various gaseous pollutants are silica gel, zeolite, iron oxide, alumina, molecular sieve and activated charcoal. The adsorbent can often be regenerated by desorption of the previously adsorbed gases.

3 Noise Pollution

Sound is transmitted through air, which vibrates the eardrum and creates the sensation of hearing. Noise is referred to as unwanted sound although like odour it is also dependent on personal perception. A sound that is music to one may be noise to another. Noise can adversely affect human activity or communication (Dara, 1995; Elsom, 1987).

Sound as well as noise can be described by 'frequency' and 'intensity'. Human ear's response to a sound is proportional to its intensity. The loudness of noise is expressed in terms of 'decibel'.

$$\text{Decibel}(\text{dB}) = 10\log(\text{sound intensity measured} / \text{reference sound intensity})$$

The reference sound intensity is 10^{-12} W/m^2. This is known as 0 dB which is barely audible to human ear. Normal conversation is done at 60 dB whereas 140 dB is the human threshold of pain. There are three internationally accepted weighting networks, namely A, B and C. Most noise including industrial noise are measured over Network A and denoted as dBA (i.e., decibel measure on network A). In A network, higher weightage are given to the frequencies that affect human most.

As per equal energy principle, the combined effect of all noise events is related to the aggregated sound energy of those events. Thus, the total energy over a given time period (T) measured as equivalent continuous sound pressure level (LA_{eq}, T) gives the level equivalent to the average sound energy over that period. Such average sounds levels are typically based on integration of A-weighted levels. Thus, LAeq, T is the average energy equivalent level of the A-weighted sound over a period T.

Exposure to noise for prolong period may damage hearing ability or cause physiological even psychological effect on human. The acute effect of noise depends upon both frequency and intensity. At 150 dB, immediate hearing loss may occur. Noise with 120–140 dB may cause severe effect on respiratory system, disorientation and other physiological effects including nausea, vomiting etc. Loud noise may alter secretion of certain hormones from pituitary gland such as ACTH that stimulate adrenaline gland, which in turn affect secretion of other hormone causing various effects such as elevated blood sugar level, immune system suppression, lever dysfunctions etc. Chronic exposure to elevated noise level may cause noise induced hearing loss. Loud continuous noise may result in reduction in work efficiency even mental capability. It hampers ability to think, interferes with communication and increases possibility of accidents. Noise may disturb sleep and consequently may affect emotional stability and cause distress. The noise exposure level or NEI is often used to assess the total exposure to noise. NEI is calculated as follows:

$$\mathrm{NEI} = t_1 / T_1 + t_2 / T_2 + \ldots + t_n / T_n$$

where t_1 to t_n are the actual limits of exposure at the corresponding noise level and T_1 to T_n are the permissible time span at the corresponding noise level. A NEI value greater than 1 indicates the total noise exposure is harmful to human being. Table 4.2 lists the guideline noise values in various situations as advised by the World Health Organization.

Noise level may be measured by various instruments depending upon the requirement of accuracy level. A simple sound level metre will give a broad idea about the level of sound around the sampling site whereas sophisticated noise level metres may be used for more accurate equivalent continuous noise level measurement. If the noise level of a site, indoor or outdoor, is above the desirable level as indicated by appropriate instrument for prolong period then it can be attributed as noise pollution.

Noise Pollution Control

Noise management and control may be done as follows:

(a) Modification in existing procedures and practises, such as discouraging horn or sirens, reducing traffic etc.
(b) Protecting the source that generate noise so that the noise may not generate or propagate further, e.g., use of damping material to arrest the vibration in automobile or industrial equipment.
(c) Protecting the noise receiver typically with personal protective equipment (PPE), such as earplug, control boot etc.
(d) Isolating noise generating sources such as airport or industrial clusters away from general population or residential areas.

Noise control may be imposed both by administrative mode or engineering mode. In administrative noise control method, a permissible level is imposed by authority, which is to be adhered to. There are several engineering solutions available for noise control especially in industrial set up. However, the application of different technology is to be selected as per noise emitting source available resources and prevailing administrative requirement. Engineering solutions of noise control may be divided in three major categories: suppression of noise source, path control and protection of individuals.

Table 4.2 WHO for community noise in specific environment

Specific environment	*Critical health effect (s)*	L_{Aeq} *[dB(A)]*	*Time base [hours]*	L_{Amax} *fast [dB]*
Outdoor living area	Serious annoyance, daytime and evening Moderate annoyance, daytime and evening	55 50	16 16	– –
Dwelling, indoors Inside bedrooms	Speech intelligibility and Moderate annoyance, daytime and evening Sleep disturbance, night time	35 30	16 8	45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
School class rooms & pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	During class	–
Pre-school, bedrooms indoor	Sleep disturbance	30	Sleeping time	45
School, playground outdoor	Annoyance (external source)	55	During play	–
Hospital, ward rooms, indoors	Sleep disturbance, night-time Sleep disturbance, daytime and evening	30 30	8 16	40 –
Hospitals, treatment rooms, indoors	Interference with rest and recovery	#1		
Industrial, commercial shopping and traffic areas, indoors and outdoors	Hearing impairment	70	24	110
Ceremonies, festivals and entertainment events	Hearing impairment (patrons: <5 times/year)	100	4	110
Public addresses, indoors and outdoors	Hearing impairment	85	1	110
Music and other sounds through headphones/ earphones	Hearing impairment (free-field value)	85#4	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults) Hearing impairment (children)	—	—	140 #2 120 #2
Outdoors in parkland and conservations areas	Disruption of tranquility	#3		

#1: As low as possible. #2: Peak sound pressure (not LAF, max) measured 100 mm from the ear. #3: Existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low. #4: Under headphones, adapted to free-field values.
Source: (Berglund et al., 1999)

***Suppression of noise source*:** High noise generating equipment such as compressors, pneumatic instruments flares are often used in various processes. In many instances, the inherent noise can be minimised by proper design, location, installation operation as well as regular maintenance. These approaches are economically effective especially when the noise level is too high. Suppression may often be the first set of noise control when the noise generation is inherent to the operation.

***Path control*:** The path of noise propagation from source includes the structure that hosts the noise source, surface and panels attached to the source, cables, belts, wires etc. connected to source, also any fluid that is flowing surrounding the source such as in chemical industry. Three major parameters of path control are: sound absorption, sound insulation and vibration control. Sound absorption is done to reduce the loudness of reflected sound and to decrease re-vibration in immediate environment of sound source. Such absorption can be achieved by sound absorbent surface that can absorb the sound energy and does not allow it to propagate further. Sound insulation is achieved by reducing sound transmission using blockade of heavy and dense sound insulating material. Vibration control may be done to reduce noise pollution by isolating the noise source from its immediate structure to the extent possible. Such control may be achieved by an isolation booth or use of a specially designed pipe called muffler or silencer, or by decoupling two neighbouring noise sources.

***Protection of individual*:** Whenever the noise level cannot be reduced to safe level in an environment and individuals need to dwell in that environment then personal protective equipment (PPE) usage is must. The choice of suitable protector is dependent on the residual noise level as well as surrounding situation. Example of PPE can be ear plug, ear muff, helmet or personal isolation booth.

4 Odour Pollution

Odours are one of the most complex air pollution problems. Odours are a mixture of complex gases that stimulate the olfactory or smelling sense. Odours are considered nuisance and unhealthy annoyance that may affect the well-being of human population by causing unpleasant sensation. Odour pollution may trigger harmful reflexes and other physiological reactions by modifying olfactory functions. Odour may cause nausea, insomnia and discomfort. From economic perspective, odour pollution may cause loss of property value such as near poorly operated dumping yard or tanneries etc.

Odours are emitted from several sources. Among industrial sources food processing, tanneries, oil refining, paint factories, pulp and paper and rubber industries are major known contributors. Other sources of odour include municipal solid waste storage and processing, sewage and agricultural activities. An odour compound may originate from solid liquid or concentrated gas. The source of odour may be confined (such as from ducts) or unconfined (such as open drainage or settling lagoons). Some very commonly known odorous compounds are sulphur containing compounds such as hydrogen sulphide, mercaptans, carbon disulphides or nitrogen containing compounds such as protein decomposition product, phenol, aromatic hydrocarbons etc.

Odours are often indicated as the ‘perception of smell’; the sense and intensity of odour is subjective and differ from person to person. The odour is registered in human brain as a result of the sensation received through the receptors of olfactory epithelium, situated in the upper nasal cavity. Till date, there is no instrumental or chemical analytical procedure that can detect or decide the intensity range of odour and replace the functionality of human nose. Molecules with similar or different structure may have similar odour and the nature as well as strength may change with dilution.

4.1 Threshold Concentration

A panel of 6–12 persons of normal health is selected as sniffers for determination of odour of a particular study site. Odour intensity is generally reported in predetermined scale. The scales are subjective such as 0 for no odour 1 for barely perceivable, 2 for definite odour, 3 for strong odour and 4 for very strong. The average score for all panellists may decide the level of the odour of a particular study site.

Each odourous compound has a certain level in air below which the perception of odour is not possible for most individuals. This level is called the threshold concentration or the minimum identification level of the particular compounds. The threshold level of different compounds can vary widely. The reported threshold for acetone is 100 ppm, for acetic acid is 1 ppm and for pyridine it is only 0.02 ppm.

Odour measuring devices are known as osmometers and they involve multiple ‘observers’ or ‘sniffer’. For determining the threshold level of an odorous substance, a known amount of odour producing substance is added in the osmometer and diluted with pure air following vapour dilution method till the observer can barely detect the smell of the target substance.

The intensity of odour increases with the concentration of the odorant and the relationship can be expressed as follows:

$$P = K \log S,$$

where P is odour intensity, K is the constant and S is odour concentration.

4.2 Odour Pollution Control

The odour pollution is best controlled at site. Controlling odour from point source is easier than odour from area source. When the pollution is from a vast area source such as waste dump then the control becomes difficult and management options need to consider a no-development zone close to the area-odour sources. A buffer zone should be determined considering the intensity of odour, topography, meteorology and geography of the region. Best management practices should also help to manage the nuisance. A green belt around the area source may restrict the odour to some extent to reach the neighbouring area. Technological solutions such as use of nozzle spray or atomiser that spray ultrafine particulate along the periphery of the area source may be utilised to suppress the odour. However, such method can be costly in case of vast area source.

Odours from point sources can be controlled by different ways such as:

***Modification of process*:** Odours generated from an industrial process may be controlled by modification in the process in terms of material use or other parameters. In a process shifting of high odour solvent to low-odour one, adjustments in process variables such as temperature, humidity or residence period may be considered for control of odour pollution if such modification is technically and economically feasible.

***Dilution*:** Odourous gas stream from stack or in enclosed space may be diluted with fresh air or may be allowed to disperse naturally to get diluted below threshold level.

***Absorption*:** If the odourous substance are soluble in a liquid or can react chemically in solution then they can be removed by absorption in a wet scrubbing process in a suitable unit. This method is widely used in industrial odour control.

***Adsorption*:** Certain adsorbing material such as activated charcoal or other commercially available material may be used to adsorb the odourous substances in a gas stream. Adsorbents have highly porous structure that can trap the odour producing substances. The adsorbent can be easily regenerated by thermally desorbing the adsorbed molecule.

***Combustion or oxidation*:** In this process, the odourous gas stream is passed through a combustion chamber at a high temperature directly or in presence of a catalyst and excess oxygen to oxidise the compounds. This process is energy intensive and requires high amount of fuel. The recovered heat may be used at other processes such as steam generation etc.

***Odour masking*:** When two odours are mixed, the strong one will mask the weaker one. So, a strong pleasant odour may be used to mask a weak unpleasant odour.

Odour masking can be used in outdoor places as well as in indoor micro-environment.

***Odour counteraction*:** Certain pair of odour counteracts each other. These odour pairs are antagonistic hence when mixed with each other they neutralise each other's intensity. Musk and bitter almond, cedar wood and rubber are examples of such odour pairs.

***Injection of reactive substance*:** Certain reactive gases such as chlorine or ozone may help in controlling the odourous compounds in the process stream. Chlorine in the form of hypochlorite or chlorine dioxide may be used in gaseous or liquid form to remove odourous compounds through bactericidal or chemical activity. Compounds with intense odour such as mercaptans may be partially oxidised to less odorous disulphide by use of hypochlorite. Ozone reduces odour by oxidising odourous compounds to corresponding carbonyl or acids. Ozone is also useful to destroy odour forming microbes.

***Bio-filtration*:** The biological treatment of odour using bacteria has become popular as sustainable management of odour control. In this process, the waste gas stream from industrial processes are forced through filters that contain bacteria that are able to degrade odourous compounds. The bacteria population sustain by using the odourous compounds as feed material.

References

Atkinson, R. (2000). Atmospheric chemistry of VOCs and NOx. *Atmos Environ*, **34:** 2063–2101.

Berglund, B., Lindvall, T., & Schwela, D. H. (1999). Guidelines for community noise: World Health Organization. https://www.who.int/docstore/peh/noise/Comnoise-1.pdf

Dara, S.S. (1995). A Text Book of Environmental Chemistry and Pollution Control. S. Chand & Company Ltd.

Derwent, R.G. (1995). Volatile organic compounds in atmosphere. *Issues Environ Sci Technol*, **4:** 1–15.

Elsom, D. (1987). Atmospheric Pollution – Cause, Effect and Control Policies. Basil, Blackwell Ltd.

Finlayson-Pitts, B.J. and Pitts Jr., J.N. (1997). Tropospheric air pollution: ozone, airborne toxics, polycyclic aromatic hydrocarbons, and particles. *Science*, **276:** 1045–1052.

Freiman M.T., Hirshel N. and Broday D.M. (2006). Urban-scale variability of ambient particulate matter attributes. *Atmos Environ*, **40(29)**: 5670–5684.

Fujita, E.M., Watson, J.G., Chow, J.C. and Magliano, Z.K. (1995). Receptor model and emissions inventory source apportionments of nonmethane organic gases in California's San Joaquin Valley and San Francisco Bay area. *Atmos Environ*, **29:** 3019–3035.

Gadkari, N.M. and Pervez, S. (2007). Source investigation of personal particulates in relation to identify major routes of exposure among urban residential. *Atmos Environ*, **36(41)**: 7951–7963.

IPCC (2001). Climate Change 2001: The Scientific Basis. Third Assessment Report of the Intergovernmental Panel on Climate Change Published for the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC (2006). IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. *In:* Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (eds). IGES, Japan.

Kroll, J.H. and Seinfeld, J.H. (2008). Chemistry of secondary organic aerosol: Formation and evolution of low-volatility organics in the atmosphere. *Atmospheric Environment*, **42(16)**: 3593–3624

Miranda, R. and Tomaz, E. (2008). Characterization of urban aerosol in Campinas, São Paulo, Brazil. *Atmos Re*, **87:** 147–157.

NIOSH (2007). NIOSH Pocket Guide to Chemical Hazards. DHHS National Institute for Occupational Safety and Health, Publication No. 2005–149.

Rao, M.N. and Rao, H.V.N. (1997). Air Pollution. Tata McGraw-Hill Publishing Company Limited

USEPA, RAIS. Online Database of The Risk Assessment Information System (RAIS). url: http://rais.ornl.gov.

USEPA (2004a). Air Quality Criteria for Particulate Matter. Volume I of II. EPA/600/P-99/002aF. National Center for Environmental Assessment-RTP Office. Office of Research and Development U.S. Environmental Protection Agency. Research Triangle Park, NC.

USEPA (2004b). CMB 8.2 Users Manual. EPA-452/R-04-011. US. Environmental Protection Agency Office of Air Quality Planning & Standards Emissions, Monitoring & Analysis Division Air Quality Modeling Group.

Varshney, C.K. and Padhy, P.K. (2008). Emissions of total volatile organic compounds from anthropogenic sources in India. *J Ind Ecol*, **2:** 93–105.

Wichmann, H.E. (2000). Daily mortality and fine and ultrafine particles in Erfurt, Germany. Part I. Role of particle number and particle mass. Health Effects Institute Report No. 98, pp. 5–93.

Willis, R.D. (2000). Workshop on UNMIX and PMF as applied to PM2.5. US Environmental Protection Agency, Report No. EPA/600/A-00/048, Research Triangle Park, NC.

World Bank (2005). For a Breath of Fresh Air: Ten Years of Progress and Challenges in Urban Air Quality Management in India 1993–2002.

Chapter 5
Water Pollution and Treatment Technologies

Abhisek Roy, Biswajit Thakur, and Anupam Debsarkar

1 Introduction

The very notion that water is plentiful, covering 70% of the planet is a bit misleading, as only 2.8% of all water is freshwater. As an irony of fate, this limited resource will need to support a projected population of 9.7 billion in 2050; and by that date, an estimated 3.9 billion, i.e. over 40% of the world's population will be forced to live in severely water-stressed river basins (OECD, 2012). However, it is not just population that is pressuring water resources. Excessive use of water is also evident as the global population tripled in the twentieth century, while the use of water increased 6-fold (FAO, 2009). Between now and 2050, water demands are expected to increase by 400% from manufacturing, and by 130% from household uses (OECD, 2012). As water availability decreases, competition for access to this limited resource will gradually increase.

Though the 'global water crisis' tends to be viewed as a water quantity problem, water quality is increasingly being reckoned to be the central factor in the water crisis. Water pollution has become a major concern worldwide, especially in developing countries where around 3.2 million children die each year as a result of intake of unsafe drinking water and poor sanitation (Abbaspour, 2011). It has been estimated that 90% of sewage in developing countries is discharged untreated directly into water bodies and every day 2.0 million tonnes of sewage and other effluents drain into the world's water bodies (UN WAAP, 2003). Industry discharges an estimated 300–400 megatonnes of waste into water bodies every year (UN WAAP, 2003). Access to adequate wastewater treatment facilities in the developing countries is also very limited. For example, only 209 of India's 3119 towns and cities, i.e.

A. Roy · B. Thakur
Department of Civil Engineering, Meghnad Saha Institute of Technology, Kolkata, India

A. Debsarkar (✉)
Department of Civil Engineering, Jadavpur University, Kolkata, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_5

less than 1 in 10, have even partial sewage systems and treatment facilities. As a result, water bodies in developing nations are often used as open sewers for human waste products and garbage, which is evident at the Ganges River in India, which receives over 1.3 billion litres of domestic waste, along with 260 million litres of industrial waste, run off from 6.0 million tonnes of fertilisers and 9000 tonnes of pesticides used in agriculture, and thousands of animal carcasses.

The fact that on global basis, some 8.42 million persons, mainly children and infants die annually from water-borne diseases, has not been enough to mobilise international action about water quality. The water quality situation in developing countries is highly variable reflecting social, economic and physical factors as well as state of development. And while not all countries are facing a crisis of water shortage, all have to have greater or lesser extent serious problems associated with degraded water quality. In some countries, these are mainly associated with rivers, in others it is groundwater resources, and in yet others it is large lakes; in many countries it is all three. As the range of polluting activities varies widely from one country to another, and the nature of environmental and socio-economic impacts is equally variable, there is no 'one-size-fits-all' solution.

In developing countries, the very reason behind the absence of adequate water treatment facilities and regulations is the lack of finances available for funding infrastructure that can regulate water pollution. This in turn reduces the amount of safe water available for human consumption, sanitation, agriculture and industrial purposes, in addition to various other ecosystem services. A decrease in the amount of water available for use holds devastating environmental, health and economic consequences that may disrupt a country's social and economic growth.

1.1 Water and Sustainable Development Goals

Water, under present circumstances, is rightly termed as foundation of life and livelihoods, and is essential for achieving sustainable development. Successful water management practices serve as a foundation for the achievement of majority of the 17 sustainable development goals (SDGs), particularly for SDG-6—which is to 'ensure availability and sustainable management of water and sanitation for all'. SDG-6 specifically aims to ensure access to water and sanitation for all, setting out the following objectives for joint action:

- Improve the management and quality of water resources, involving communities and including women and girls.
- Ensure that people have access to safe and affordable drinking water and adequate sanitation and hygiene.
- Protect and restore water-related ecosystems.

Water quality is addressed also under other SDGs such as the goals on health, poverty reduction, ecosystems and sustainable consumption and production, recognising the links between water quality and the key environmental, socio-economic and development issues (Goals 1, 3, 12, 15 and Targets 1.4, 3.3, 3.9, 12.4, 15.1). The clear focus on water quality in the SDGs demonstrates growing attention on the urgent need to improve water quality worldwide.

1.2 Water Pollution

Water quality is affected by both point and non-point sources of pollution. These include sewage discharge, discharge from industries, run-off from agricultural fields and urban run-off. Water quality is also affected by floods and droughts and can also arise from lack of awareness and education among users. Water pollution, resulting from anthropogenic activities, disturbs aquatic ecosystems not only in structure but also in function, affecting and modifying the integrity of these systems. Clear evidences are eutrophication (high loads of nutrients, such as phosphorus and nitrogen) and acidification, putting more pressure on water resources systems. Water pollution thus constitutes a serious threat not only to securing enough water of good quality for human needs and activities, but also to meeting the ecosystem requirements and maintaining environmental flows.

In developing countries, the most common form of contamination comes from water that has been stored in poor conditions, urging the need for better water treatment technologies. It is imperative to treat water for bacteria and other chemical/microbial components that may compromise public health safety. Advanced and affordable water treatment technologies are continued to be developed to provide assistance to those who cannot afford clean water. Prevention strategies such as treating water, educating guidelines for safe storage of drinking water and practicing improved sanitation techniques can significantly reduce the risk of deadly waterborne diseases.

1.3 Water Treatment Technologies

The water treatment process may vary slightly at different locations, depending on the technology of the plant and the water it needs to process, but the basic principles are largely the same. In the case of surface water, the major forms of contamination are pathogens and solids. However, groundwater contamination has got some unique characteristics, viz. arsenic, fluoride, iron, nitrate or even in some areas, uranium too. Based on the type of contaminants present, the technology of water treatment may vary substantially.

2 Surface Water Treatment Technologies

Aesthetic qualities (such as visual appearance, taste and smell) of drinking water were the main concerns for ancient civilisations and methods to improve them could be found in records from 4000 BC. Methods like charcoal filtration, sunlight exposure, boiling and straining are reported in ancient Greek and Sanskrit documents. Clarification of the turbidity (then identified as visible cloudiness) using alum was made by Egyptians around 1500 BC, and it took another 3000 years when sand filtration found its application in removal of particle contaminants from water. At large community scale, surface waters from sources like rivers, streams, lakes and ponds have always been the primary choice because of their easy availability; but beside solid impurities, these waters are also susceptible to pathogenic contamination in most cases. However, the fact of pathogenic contamination of surface water and its relation to water-borne diseases started to unfold by a series of discoveries since mid-nineteenth century. The identification of Cholera as a water-borne disease in 1855 by John Snow or the demonstration of 'germ theory' by Louis Pasteur in 1880 has been the path breakers (USEPA, 2000). Since the late nineteenth and early twentieth century, disinfection of surface water supplies was considered to be an absolute necessity and technologies like chlorination gradually started to evolve alongside solid removal technologies. In the subsequent sections, a comprehensive discussion about various surface water treatment options, as practiced now is elaborated.

2.1 Removal of Solid Impurities

Removal of solid impurities present in the surface water in suspended, settling or dissolved form constitutes the major part of water treatment process. Floatation is the commonly applied technique of separating solids lighter than the water and conventional treatment options of sedimentation or clarification followed by filtration is adopted to separate heavier suspended or precipitating solids, both involving gravity as the main driving force for the separation to occur. Removal of dissolved solids, inorganic or organic, however requires some special techniques such as chemical treatments, ion exchange process, membrane separation techniques like reverse osmosis, electrodialysis, adsorption etc.

2.1.1 Floatation

Substances that are naturally lighter than water or made lighter than water by floatation agents could be separated from water using dissolved air flotation (DAF) technique. Fine air bubbles (released either by diffusion of compressed air or by desorbing dissolved air) or chemical compounds (hydrophobic, wetting and

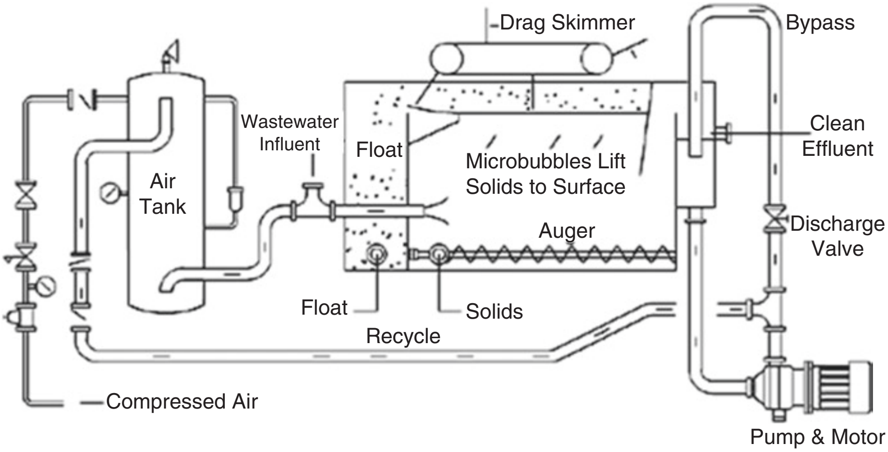

Fig. 5.1 A conventional DAF system. (*Source*: PAN America Environmental)

foaming agents) act as the floatation agents, impart buoyancy to the suspended particles and lift them up to the water surface. Once the impurities float to the surface, they are skimmed off. Figure 5.1 shows a schematic diagram for a conventional DAF system.

Typical examples of chemical floatation agents are the metallic salts of aluminium and iron and the anionic, neutral or cationic polyelectrolytes. DAF is used in potable water treatment facilities for water clarification as well as for sludge thickening in wastewater treatment plants (Shammas and Wang, 2016).

2.1.2 Sedimentation

Depending on the nature of the solid impurities (discrete or flocculating) and the suspension density (dilute or concentrated), the sedimentation process could be categorised. During treatment of water, the raw suspension to be treated could be considered as a dilute one (where particle concentration cannot displace the water significantly during settling). The sedimentation of discrete particles (particles maintaining their size, shape and specific gravity over time during sedimentation) in such a suspension is termed as Type-1 settling and that of flocculating particles (particles aggregating or coalescing with other particles on contact and thereby changing the size, shape and specific gravity over time) in the same is called Type-2 settling (Peavy et al., 1985).

Sedimentation removes discrete or flocculating suspended solids either originally present in the raw water or generated as precipitates during removal of dissolved solids through other treat processes (e.g., softening). Type-1 settling or plain sedimentation is employed to treat surface waters having turbidities less than 50 NTU (CPHEEO, 2009). For more turbid surface waters with large amount of smaller suspended solids (less than 50 μm in diameter having very low settling velocity and

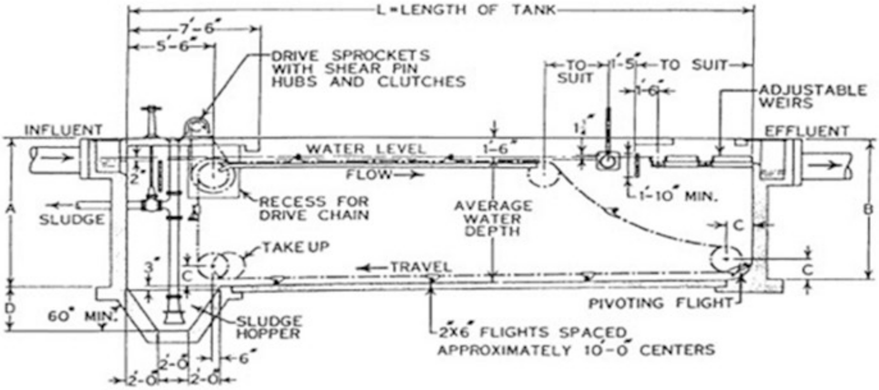

Fig. 5.2 A typical horizontal primary sedimentation tank. (*Source*: CivilDigital.Com)

making plain sedimentation ineffective as a result) flocculation followed by sedimentation, together known as clariflocculation which follows the theory of Type-2 settling is employed. Figure 5.2 shows the schematic of a plain sedimentation tank.

In case of clariflocculation, chemical coagulants such as (aluminium sulphate or common alum), (ferrous sulphate or copperas), combination of (ferric sulphate) and (ferric chloride) known as chlorinated copperas are first mixed thoroughly (rapid mixing) with the turbid water. This process is called coagulation during which the added coagulants in presence of alkalinity in the water form flocs (a gelatinous precipitate of corresponding metal hydroxides) which destabilises charged solid impurities of smaller sizes to be removed. The rapid mixing is followed by a slow mixing which brings these destabilised solid impurities in close contact with one another and with the flocs resulting in the formation of larger agglomerates of flocs and particles with increased settling velocities. This process named as flocculation is followed by the sedimentation or clarification process which separates these larger agglomerates easily under the action of gravity in clarifiers. Figure 5.3 shows a typical schematic of a centrally driven clariflocculator.

Sedimentation tanks used in water treatment plants could be of long-rectangular type, circular type or solid contact clarifiers depending on the need addressing different technical issues.

2.1.3 Filtration

Filtration is mostly a polishing process to remove finer solids, precipitates or remaining smaller flocks which escapes the clarification process during sedimentation. Raw surface water with low turbidity such as 10-15 NTU could be directly applied on rapid sand filters with addition of alum.

The filtration essentially involves passing the water to be treated through a stationary bed of granular medium. There must be a driving force which allows the

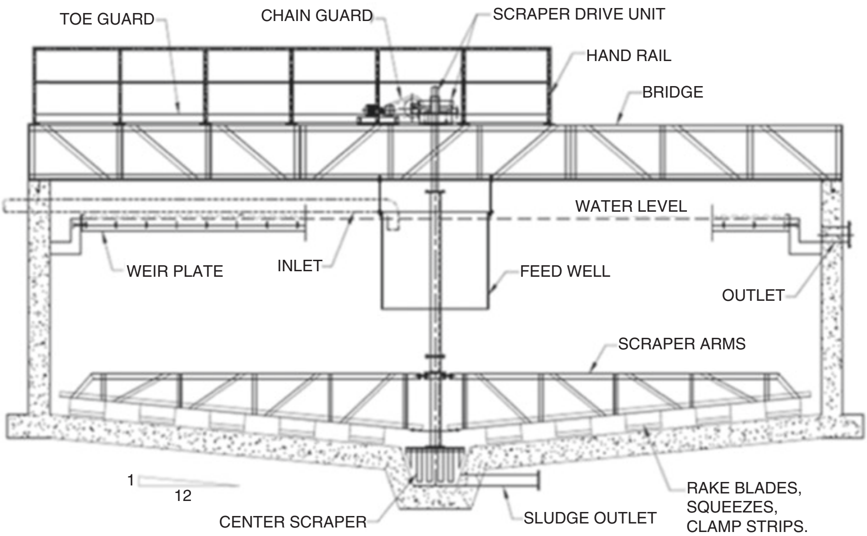

Fig. 5.3 A centrally driven clariflocculator. (*Source*: Shree Virkrupa Engineering)

water to overcome the head loss while passing through the filter media; and depending on the same, the filtration process could be categorised as gravity filters or pressure filters. For large scale water treatment facilities gravity filtration in a downward mode through a specifically designed sand media (either uniform or layered) is widely accepted. Size of the sand grains used controls the speed as well as the quality of filtration. The finer grains (and thus finer pore sizes) lowers the filtration speed (slow sand filtration with filtration rate of 100–200 L/hr/m^2 of filter area) but is capable of arresting much finer particles including pathogenic microorganisms. Slow Sand Filtration was developed way back in England in 1829. However, with the advent of effective disinfection technologies the burden of removing pathogenic microorganisms got released from the filtration unit which allowed the gravity filtration to employ coarser sand media increasing the speed of filtration to about thirty times compared to their slow sand counterparts. This process called Rapid Sand Filtration after being developed at the last decade of nineteenth century gradually took over the industry and at present it is the most adopted technique for large municipal scale water treatment facilities. Figure 5.4 shows typical components of an open rapid sand filtrations system.

Though mechanical straining (arrest of larger impurities while travelling through smaller filter media pores) is the dominant mechanism during filtration process other mechanisms also play vital roles. These include flocculation and sedimentation within sand media pores (making the pores to act like tiny sedimentation tanks allowing removal of even smaller impurities), biological metabolism (stabilisation of the organic solids by the microorganism colonies built up in the media) and electrolytic changes.

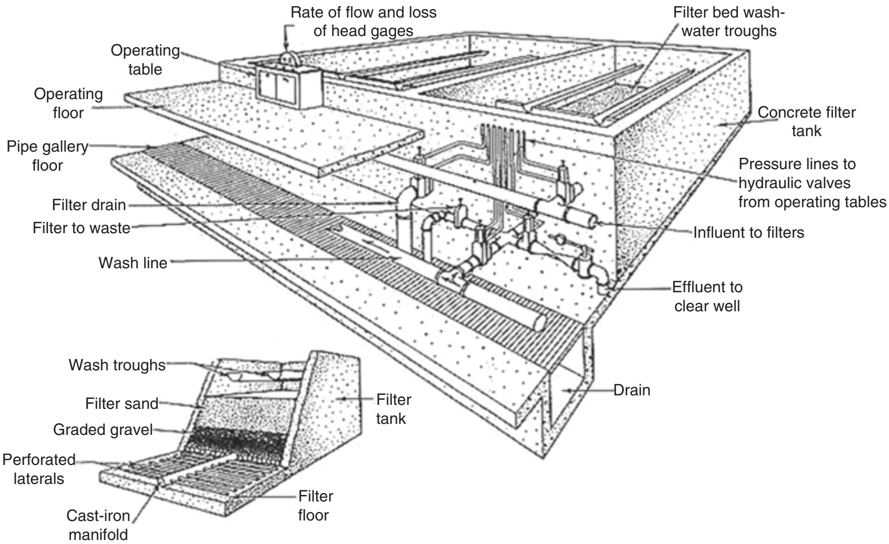

Fig. 5.4 Components of a typical open rapid sand filter. (*Source*: Bruni, M. and Spuhler, D.)

The essential problem of filtration process is the clogging of media pores by the arrested impurities which requires a periodic cleaning of the filtration bed. The same under-drainage system (a set of porous pipes placed underneath the sand media to collect the clean filtered water under the action of gravity) is employed in the cleaning process called backwashing. Clear water is flown upwards through the media with sufficient pressure head which disintegrates the sand particles of the media separating the arrested solid impurities from them and finally forcing those impurities out through surface overflow quickly. After the backwashing water is withdrawn the sand media particles again settle down to their original designed layers making the filter bed ready for further operation.

2.1.3.1 Pressure Driven Membrane Filtration Systems

Pressure driven membrane filtration techniques are capable of removing very small sized pollutants, ions, salts, other dissolved solids, non-volatile organics and microorganisms effectively. The processes are costly and impractical to be used in mass scale municipal water treatment facilities. However, they are finding use in sophisticated small-scale household water treatment systems. A summary of such systems is provided in Table 5.1. Figure 5.5 schematically shows the reverse osmosis process.

Table 5.1 Information regarding membrane filtration systems

Type of system	*Pore size range*	*Transmembrane pressure*	*Pollutants separated*
Microfiltration (MF)	0.1–10 μm	7–208 kPa	Bacteria, large microorganisms, fine solids, large flocs, large colloids
Ultrafiltration (UF)	0.005–0.09μm	208–517 kPa	Colloids, flocs, turbidity, suspended solids, large microorganisms
Nanofiltration (NF)	0.0005–0.005μm	517–1027 kPa	Divalent and trivalent ions, hardness, DBP, NOM, *Giardia* cysts, *Cryptosporidium*, colour, surfactants
Reverse Osmosis (RO)	0.0001–0.001 μm	1034–3448 kPa	Desalination or separation of monovalent ions, such as salts, sodium, nitrate, nitrite, chloride

(*Source*: Shammas and Wang, 2016)

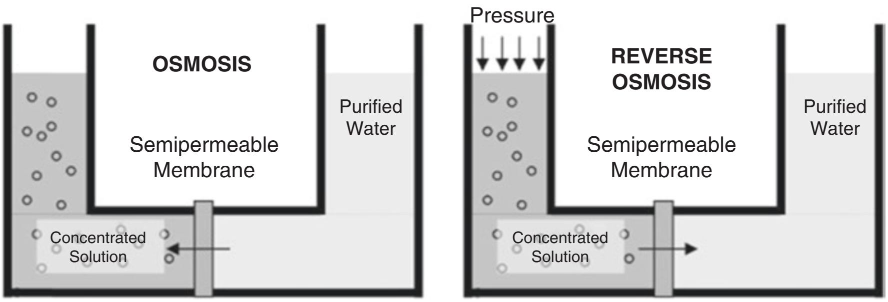

Fig. 5.5 Reverse osmosis process. [*Source:* Compiled by Author]

2.1.3.2 Horizontal-flow Roughing Filtration

Horizontal-flow Roughing Filtration has long been used to remove turbidity from raw surface water even before the advent of water treatment options using chemical processes. In developing countries, it serves as an effective pre-treatment prior to Slow Sand Filtration for the reduction of the raw water turbidity without any chemical requirements. The filter unit essentially consists of multiple interconnected filtration beds filled up with filter media of different sizes. The raw water flows in a horizontal mode from one filter bed to the next progressively passing through the coarser media (like gravels) to finer media (like fine sand grains) which separates the turbidity out.

Though the roughing filters require larger space, however it is very much suitable for rural and small urban water treatment facilities in developing countries and therefore the treatment option is gaining a renewed interest over recent years. The conceptual design theory for evaluating the efficiency of the filter is based on the filtration theory described by Wegelin (1996). The main advantage is its simplicity in design and virtually unlimited filter length if space permits. The silt storage capacity of roughing filters is large and therefore horizontal-flow roughing filters

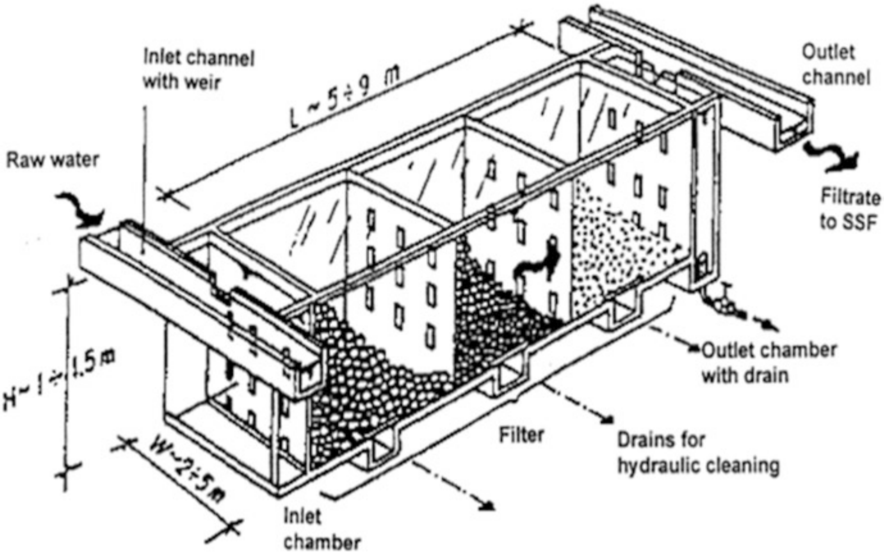

Fig. 5.6 Horizontal flow roughing filter. (*Source*: Burch, J.D. and Thomas, K.E.)

are less sensitive to filtration rate changes, as clusters of filtered solids gradually drift towards the filter bottom or gets separated and retained by the subsequent filter layers. Figure 5.6 shows the construction schematic of a Horizontal Flow Roughing Filter.

Sands and gravels are the most commonly used media for roughing filters; however, they could be easily replaced by any locally available clean, insoluble materials having sufficient mechanical strength (Graham, 1988). For desired performance, the filtering rate has to be kept low in the range of 0.3–1.5 m/h. Turbidity and suspended solid removal in the order of 60–90% has been reported by researchers from different countries under different flow conditions (Nkwonta and Ochieng, 2009).

2.1.4 Adsorption

Surface water sources are less likely to have a high concentration of inorganic dissolved solids; however, presence of dissolved organic compounds particularly refractory ones could be expected and suitable treatment options to remove the same are to be adopted. Adsorption using activated charcoal as the adsorbent media is a widely accepted method of removing dissolved organic solids such as aromatic solvents (benzene, toluene, nitrobenzene, etc.), chlorinated aromatics (chlorobenzenes, chloronaphthalene, PCBs, etc.), phenol and chlorophenols, pesticides and herbicides (aldrin, DDT, chlordane, heptachlor, etc.), polynuclear aromatics (acenaphthene, benzopyrenes, etc.), chlorinated non-aromatics (chloroalkyl ethers, carbon tetrachloride, etc.) and high molecular weight hydrocarbons (gasoline, amines, humics, dyes, etc.) (Shammas and Wang, 2016).

Adsorption is defined as the accumulation of substances at the interface between two phases (Sunderstron and Klei, 1979). In treating waters with dissolved solid content an interface is created between the liquid (i.e., water or solvent) and the solid adsorbent media where the dissolved impurities (solute or adsorbate) accumulates and gets separated from the solution. Activated carbon produced from carbonaceous materials is a highly porous material having extremely high specific surface area providing enough interface surface area for adsorption to occur is the most used adsorbent in water treatment. Figure 5.7 represents the process of adsorption ion activated carbon.

Water containing dissolved solids is brought into contact with fixed or moving beds of activated carbon either in its crushed granular form (GAC or granular activated carbon) or pulverised finely powdered form (PAC or powdered activated carbon) for a pre-designed contact time till the adsorptive capacity of the material gets exhausted (Peavy et al., 1985). The adsorbent bed needs to be regenerated periodically. GAC beds are regenerated by leaching. Spent PAC is generally wasted (Shammas and Wang, 2016).

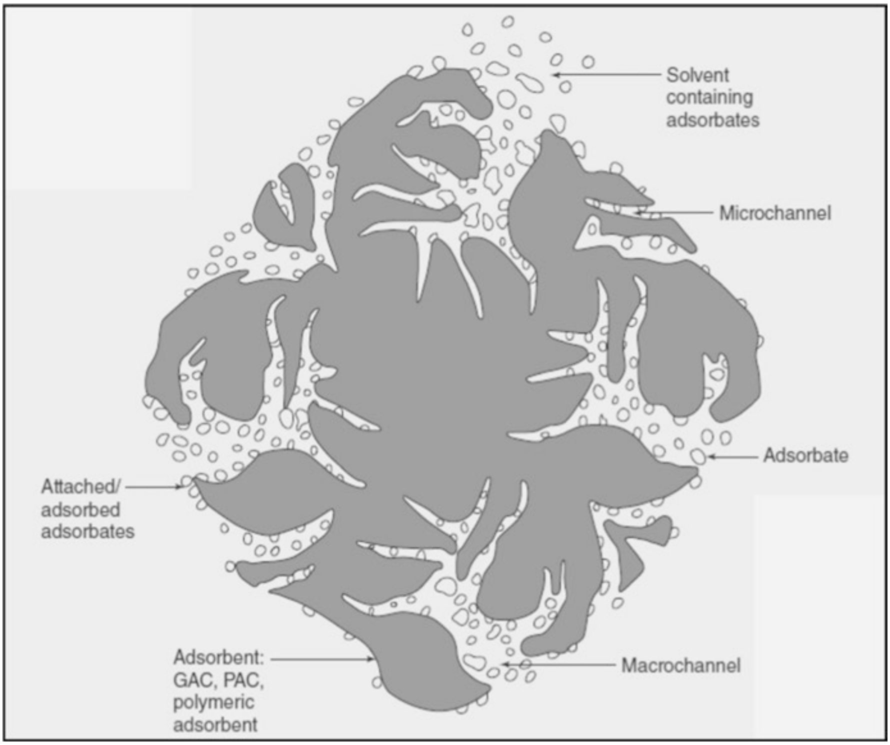

Fig. 5.7 Adsorption on activated carbon. (*Source*: Shammas, N.K. and Wang, L.K.)

2.2 *Removal of Pathogenic Microorganisms: Disinfection*

A major problem with surface waters is the presence of high concentration of pathogenic (disease causing) microorganisms and therefore effective disinfection is absolutely necessary in the treatment of such waters. Though the other preceding treatment options such as coagulation, sedimentation and filtration remove such pathogens significantly, however to meet water quality standards further removal of remaining pathogens becomes necessary. Disinfection could be done employing chemical disinfectants, viz. halogen elements (particularly chlorine), ozone or silver or exposing the pathogens to physical means such as gamma rays, ultraviolet lights, sonification, electrocution or heat. For large municipal scale treatment facilities, chlorination is a widely used technique.

2.2.1 Disinfection Through Chlorination

For disinfection chlorine is added to water either in gaseous form (Cl_2) or as Ca $(OCl)_2$ (calcium hypochlorite) or NaOCl (sodium hypochlorite). When added to water they form two strong disinfectants namely hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). The combination of these two agents, named as free chlorine residuals are the primary disinfectants in case of chlorination. Though chlorine gas is a much stronger disinfectant, hypochlorite is preferred for a mass scale use because the latter is much easier and safer to handle. The dose of the disinfectant is determined based on the time of contact with the contaminated water and the level of pathogen kill (generally expressed as percentage kill) desired. Figure 5.8 shows a typical breakpoint chlorination curve.

Chlorine being a strong oxidant reacts readily with materials present in the water in reduced state such as (ferrous), (manganous), (hydrogen sulphide) and organics. The oxidation products with organics, if present in the water on reaction with chlorine, are highly undesirable causing taste odour and other severe problems. Their formation could be avoided by formation of chloramines on the first hand by adding a trace amount of ammonia to the water before the addition of chlorine. Ammonia reacts with the added chlorine first without letting it to react with the organics, and forms a group of compounds called chloramines (called combined chlorine residuals), which are again very effective disinfectants providing persistent protection against pathogenic contamination and regrowth even in the distribution system.

Special precautions must be taken in the handling, application and mixing of chlorine as disinfectant because of its highly reactive nature maintaining proper safety protocols.

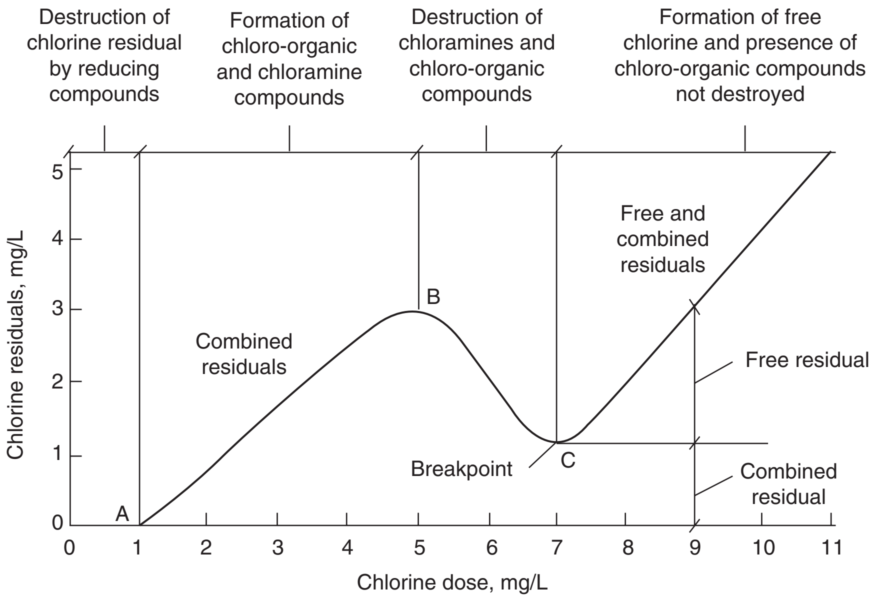

Fig. 5.8 Breakpoint chlorination. (*Source*: Peavy et al., 1985)

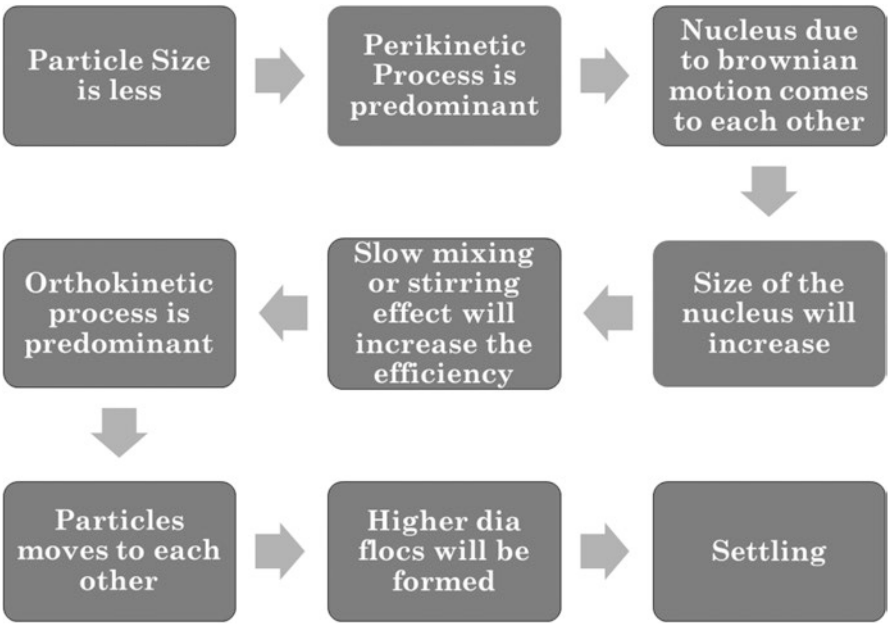

Fig. 5.9 Process flow diagram of coagulation and flocculation

2.2.2 Disinfection Through Ozonation

Ozone is widely used as an effective replacement of chlorine as disinfectant. The major advantages of ozone are, unlike chlorine it forms environmentally acceptable compounds on reaction with organics present in the water, and it is more effective and vigorous in killing of harmful pathogens even the most resistant strains. The treatment process is however more costly than chlorination and due to instability ozone has to be produced insitu. It is also less soluble in water and thorough mixing is necessary to get adequate contact with the pathogens for their effective removal. As ozone is not that persistent, the main problem of using it as disinfectant is its incapability of providing protection against future growth of pathogens in the distribution system while treating large quantity of water at municipal scale.

2.2.3 Disinfection Through Ultraviolet (UV) Radiation

Ultraviolet light generated from low-pressure mercury vapour lamps (spanned between the wavelengths of 2000 and 3900 Å) kills harmful pathogens effectively through irradiation although it does not provide any residuals. The technique is finding wide application in household water treatment machines and small-scale facilities.

3 Groundwater Contamination Treatment Technologies

Groundwater sources are recharged by the rainwater percolating into the ground and reaching permeable layers (aquifers). The rainwater seeps down through the soil and reaches the aquifer. During this downward movement, it comes in contact with several constituents and acquires the chemical properties of the soil strata, which are known as contaminants or pollutants. However, as groundwater percolates through the sub-soil, the bacteria masses get filtered and generally, groundwater are less contaminated with bacteria than the surface water. Groundwater often contains various inorganic contaminants like iron, fluoride, uranium, arsenic and boron. Conventional water treatment system with groundwater as water source mainly comprises of aeration, adsorption, coagulation, flocculation, sedimentation, filtration and chlorination. Sometimes, along with those softening and demineralisation units are also used.

3.1 Aeration

In water treatment, aeration is used to increase the dissolved oxygen level in the water, which provides some freshness and also removes the odour. In aeration process, dissolved lower valence ions (e.g., Fe^{2+}) are oxidised by oxygen to higher valence ion and gets precipitated. That is why aeration is helpful for the removal of iron and manganese.

$$4Fe^{2+} + 3O_2 \rightarrow 2Fe_2O_3$$

$$4Mn^{2+} + 3O_2 \rightarrow 2Mn_2O_3$$

3.2 Coagulation

Coagulation is the process of destabilisation of colloid particles by addition of chemical agents known as coagulants. Effective coagulation can be achieved by the addition of appropriate coagulants of appropriate dose followed by rapid mixing. In water, the primary charges of the colloids are generally found to be '–ve'. It is necessary to add counter-ions to counteract that '–ve' charge so that the van der Waals attraction force will be predominant, which will help in the process of destabilisation of colloid. So, coagulation is basically charged neutralisation of colloid particles by addition of polyvalent metal ions as coagulants. Commonly used coagulants in water treatment are alum [$Al_2(SO_4)_3{\cdot}18H_2O$], ferric chloride [$FeCl_3$], ferric sulfate [$Fe_2(SO_4)_3$], chlorinated [$Cl_2$] copperas [$FeSO_4{\cdot}7H_2O$], ferrous sulphate [$FeSO_4{\cdot}7H_2O$], and lime [$Ca(OH)_2$].

$$\underbrace{Al_2\left(SO_4\right)_3{\cdot}18H_2O}_{\text{common alum}} + \underbrace{3Ca\left(HCO_3\right)_2}_{\text{alkalinity}} \rightarrow 2\,Al\left(OH\right)_3 \downarrow + 3CaSO_4 + 6CO_2 + 18H_2O$$

$$2FeCl_3 + \underbrace{3Ca\left(HCO_3\right)_2}_{\text{alkalinity}} \rightarrow 2Fe\left(OH\right)_3 \downarrow + 3CaCl_2 + 6CO_2$$

$$Fe_2\left(SO_4\right)_3 + \underbrace{3Ca\left(HCO_3\right)_2}_{\text{alkalinity}} \rightarrow 2\,Fe\left(OH\right)_3 \downarrow + 3CaSO_4 + 6CO_2$$

Each of the above reactions has an optimum pH range.

3.3 Flocculation

Flocculation and coagulation are often used together indiscriminately. However, flocculation is the mechanical slow stirring or slow mixing process adopted to enhance the floc formation process of destabilised colloid particles. It is a common practice to provide an initial rapid (or) flash mix for the homogeneous dispersion and mixing of coagulants into the water. Slow mixing is then performed, during which the growth of the floc takes place. In modern day, flash mixing and slow mixing are together called flocculation process. The flocculation process can be broadly classified into two types, perikinetic and orthokinetic. Perikinetic flocculation refers to flocculation (contact or collisions of colloidal particles) due to Brownian motion of colloidal particles. Orthokinetic flocculation refers to contacts or collisions of colloidal particles resulting from bulk fluid motion, such as stirring. Generally, rapid mixing was done for 30–60 s with 100 rpm and slow mixing was done for 15–30 min with 20–30 rpm.

3.4 Sedimentation

Sedimentation or clarification is defined as the method of removal of particulate matter, chemical floc and precipitates from suspension through gravity settling. Sedimentation is the separation of water by gravitational settling of suspended particles that are heavier than water ($S_p > S_w$). Sedimentation/clarification can be provided prior to chemical treatment or after coagulation and flocculation. The efficiency of the sedimentation basin can be enhanced by increasing the surface area either by tube settler modification or plate settler modification.

3.5 Filtration

Filtration process is used to remove or separate out the suspended and colloidal impurities and water through porous media/filter. In conventional municipal water treatment system, generally, two types of filtration systems are in use: (i) slow sand filter and (ii) rapid sand filter.

3.6 Disinfection

Disinfection is a unit process involving reactions that render pathogenic organisms harmless. Chlorine is the most common disinfectant used in the conventional water treatment system. Chlorine in reaction with water produces free chlorine.

$$Cl_{2(aq)} + H_2O \leftrightarrow HOCl + H^+ + Cl^- \quad K_{HOCl} = 4.0 \times 10^{-4}$$

$$HOCl \leftrightarrow H^+ + OCl^- K_{OCl} = 10^{-7.5}$$

Cl_2, HOCl, and OCl^- are together called free available chlorine. Out of them, undissociated HOCl is about 80–100 times more potent disinfectant than OCL^-. It is obvious that pH during chlorination is generally maintained at 7 as below pH 5, $Cl_{2(aq)}$ will not react with water and above pH 9.5, only OCL^- is found in the solution.

3.7 Specific Contaminant Removal from Groundwater

The water treatment process can be simply the combinations of the above-mentioned methods or can include several other treatment technologies depending on the contaminants and contamination levels. The treatment process for (a) iron and manganese removal, (b) arsenic removal, (c) fluoride removal and (d) uranium removal have been discussed in the following sections.

3.7.1 Iron and Manganese Removal

Iron and manganese can come in the water by the dissolution of rock containing the oxides, sulphides, carbonates and silicates of iron and manganese. Iron can present in water in two forms: ferrous (Fe^{2+}) and ferric (Fe^{3+}). However, ferrous is the solution phase form and ferric is the precipitated form. Manganese also can be in +2 and +4 form. Mn^{2+} is the solution phase form and Mn^{4+} is very less soluble or precipitated form. Aeration alone can oxidise ferrous and manganous forms to ferric and manganic forms and it can be subsequently removed by precipitation or sedimentation. However, to counteract the interference caused by carbon dioxide and hydrogen sulphide, aeration time should be increased. For effective removal of iron and manganese, other reducing agents like organic matters, ammonia and other metallic cations have to be oxidised/removed first.

Pre-chlorination could also be an option to oxidising the ferrous to ferric and other interfering reducing agents, which could effectively bring down the level of available iron in the water.

$$2Fe^{2} + 3Cl_2 \rightarrow 2FeCl_3 \downarrow$$

Addition of lime before aeration could remove the amount of carbon dioxide as calcite. Hence, the addition of lime before aeration could enhance the efficiency of iron and manganese oxidation by aeration.

$$CaO + H_2O \rightarrow Ca(OH)_2$$

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$$

Sometimes, to facilitate the oxidation of iron and manganese contact beds are used. Manganese zeolite can be an effective contact bed material which can facilitate manganese oxidation by catalytic reaction. Strong oxidants like chlorine dioxide and potassium permanganate are also used to remove manganese from water.

Zeolite method of iron or manganese treatment is used when they are present in water in reduced or soluble form. Usually, this process is adopted for water having not more than 10 mg/L of iron or manganese with 1 mg of iron/manganese per 30 mg of hardness. In this process, water percolates through the bed containing zeolite, which can remove the iron and manganese from water by ion exchange.

National Environmental Engineering Research Institute (NEERI) designed package iron removal plants also can be used to remove iron for small scale communities. This removal plants mainly consist of aeration, filtration and sedimentation. Plate settling devices are being used to enhance the capacity of settling chamber.

3.7.2 Arsenic Removal

Conventional treatment technologies for arsenic removal include several methods like oxidation, coagulation and flocculation, co-precipitation, adsorption, bio-sorption, ion-exchange, membrane filtration technique, bioremediation, electrocoagulation, foam flotation etc. In general, most of the available treatment units work according to the sequence of oxidation/reduction followed by adsorption or coagulation-flocculation-precipitation. Some of the biological treatment processes (bio-sorption and biological treatment by bacteria) were found to work exclusively and sometimes they can also be combined with other treatment technologies. Each of the above-mentioned technologies is discussed in the following sub-sections.

3.7.2.1 Oxidation

Arsenic is usually present in water in As^{3+} and As^{5+} forms and their exact ratio depend largely on redox condition, pH and oxic condition. As^{3+} is more mobile and harder to remove whereas As^{5+} is less mobile and can be more easily absorbed. Hence, oxidation As^{3+} to As^{5+} is a prerequisite for almost every arsenic removal technology. Arsenic oxidation can occur in several ways: by air, by ozone, by a chemical agent or even by bacteria.

3.7.2.1.1 Oxidation by Air Oxygen and Pure Oxygen

In the case of arsenic remediation, oxygen/air is considered as low-cost oxidant, but the efficiency is very poor. The researchers reported that oxidation of As^{3+} to As^{5+} by air oxygen is very slow and it can take a few weeks to complete.

3.7.2.1.2 Oxidation by Different Chemical Agents

As^{3+} can be oxidised to As^{5+} by several oxidising agents like potassium permanganate, free chlorine, chloramine, hydrogen peroxide, ozone, Fenton's reagent, activated carbon, iron and manganese compounds.

3.7.2.1.3 Microbial Oxidation

Different types of bacteria are able to oxidise As^{3+} to As^{5+}. However, depending on the pathogenicity very few were considered for drinking water treatment. Different iron-oxidising bacterial species, viz. *Thiomonas*, *Ralstoniapickettii*, *Gallionellaferruginea* (Katsoyiannis and Zouboulis, 2004), *Leptothrixochracea* etc. were used for oxidation of As^{3+} in drinking water.

3.7.2.2 Coagulation-Flocculation/Co-precipitation

Fe-Al-based coagulants are used to destabilise the colloids and remove arsenic from water. Such type of coagulants is ferric chloride, ferric sulphate, aluminium sulphate or lime. Lime (CaO) can easily neutralise the arsenate/arsenite and form calcium arsenate/calcium arsenite and subsequently precipitate. However, this process is pH-dependent and works at pH in the range of 11–12. The optimum pH range for arsenate removal by aluminiumsulphate was reported as 6–8. Fe-based coagulants were found to be more efficient and less pH-dependent on removing arsenic. Arsenic, in fact, has a higher affinity to be adsorbed to the ferrihydrite complex than aluminium complex, which is the reason behind the effectiveness of $FeCl_3$.

3.7.2.3 Adsorption

Adsorption is the traditional physico-chemical process in which solid particles were used to separate solute from solution. Effective adsorbents have a highly porous structure or high surface area to volume ratio. Several types of adsorption have been used in developing countries for removal of arsenic from water. Iron-based compounds, zero-valent iron (ZVI), activated alumina compounds, red mud have been used as an adsorbing agent for arsenic removal.

- Granular ferric hydroxide was used by several researchers as an adsorbent to remediate arsenic. It contains β-FeOOH, which can adsorb arsenic from water (Driehaus et al., 1998). ZVI was twice effective in remediating As^{5+} than As^{3+}.
- Activated alumina (AA) is a porous granular medium made up of aluminium trioxide (Al_2O_3), prepared through dehydration of aluminium hydroxide ($Al(OH)_3$) at high temperature (USEPA, 2012). As^{3+} is relatively difficult to be removed by AA in comparison with As^{5+} (Jiang, 2001). Jiang (2001) reported that the adsorption capacity of AA varied between 5 and 15 mg of As^{5+}/g of AA for water having As^{5+} concentration in the range of 20–100 μg/L.

- Red mud is the bi-product generated in bauxite refinery by Bayer process and contains aluminium and iron oxide. Adsorption of As^{5+} and As^{3+} by red mud depends on the pH. Heat-treated red mud performs better than the untreated red mud.
- Activated carbon normally employed for contaminants removal in the water treatment process has been controversial for the removal of arsenic. The research community is divided about the efficiency of the arsenic adsorption by activated carbon and few researchers raised the question about the mechanism of arsenic removal by activated carbon.

3.7.2.4 Bio-sorption

Different bacteria, fungi and algae can assist the bio-sorption process in two different ways. Either they can adsorb arsenic directly or arsenic can be adsorbed at the surface of the products/bi-products generated by them. *Lactobacillus acidophilus* can reduce the arsenic concentration in the water. Bacterial stain *Staphylococcus xylosus* can treat As^{5+} and Cr^{6+} simultaneously.

Biogenic schwertmannite ($Fe_8O_8(OH)_{4.42}(SO_4)_{1.79}$) generated by *Acidithiobacillus ferrooxidans* can also adsorb arsenic. *Acidithiobacillus ferrooxidans* can remove arsenic from the water at pH 7–10.

3.7.2.5 Ion Exchange

Ion exchange is another type of adsorption technique in which the exchange of ions happens between one electrolyte and one complex. The complex is known as ion-exchanger. Depending on the type of ion-exchanger it can be cation exchanger or anion exchanger. Ion-exchange resins, zeolites, montmorillonite, clay are some typical ion exchangers. In this method the water is allowed to pass through a column containing ion-exchange medium, which removes the arsenic from the water.

Cerium(IV) chloride loaded Amberlite IRC-718 resin, Cu(II) loaded Amberlite IRC-718 resin (Ramana and Sengupta, 1993), iron(III)-loaded chelating resin containing lysine-N^{α}, N^{α}-diacetic acid functional groups (Fe-LDA) (Matsunaga et al., 1996), La(III) loaded muromac A1 chelating resin (Trung et al., 2001) are some common examples of cation exchange resins. Depending upon the constituent, these types of resins can remove 98% of the arsenite and arsenate.

Titanium dioxide loaded onto an Amberlite XAD-7 resin is the example of anion exchange resin, which also could remove arsenic very easily.

$$2R - Cl + HAsO_4 \rightarrow R_2HAsO_4 + 2Cl -$$

3.7.2.6 Membrane Process

Membranes are also capable of removing arsenic along with all kind of dissolved solids. However, the influent water in the membrane technique process shall be free from suspended solids. Several types of membrane separation techniques are there, viz. reverse osmosis, microfiltration, ultrafiltration and electrodialysis. In membrane techniques, removal of As^{5+} is more than that of As^{3+} (Brandhuber and Amy, 2001; Seidel et al., 2001). The removal rate of As^{5+} is highly pH-dependent (Seidel et al., 2001), whereas removal rate of As^{3+} found to be very less and pH-independent in the range of 4–10 (Brandhuber and Amy, 2001). As^{5+} removal decreases with a decrease in pH. Consequently, it is necessary to provide pre-oxidation before any membrane process. Membrane filtration is a pressure-driven process and depending on the pressure it can be of two types: (a) high-pressure membrane filtration and (b) low-pressure membrane filtration.

3.7.2.7 Point-of-Use Technologies

In developing countries, cost-effective, reliable and easy to use technologies at the household level or point-of-use (POU) level are also widely explored for arsenic remediation. POU technologies depend mainly on either (i) oxidation followed by coagulation-flocculation/co-precipitation or (ii) adsorbents. Different types of POU technologies are mentioned below:

(a) WHO-SEARO instructions for arsenic removal
(b) DANIDA-DPHE arsenic removal unit in Bangladesh
(c) BUET modified Bucket Treatment Unit (BTU)
(d) Stevens Institute Technology
(e) Read-F Arsenic Removal Unit
(f) RKM Filter in West Bengal in India
(g) CMRI Filter
(h) JU-CSIR Filter
(i) AMAL domestic arsenic filter
(j) Pal Trockner
(k) Safi Filter
(l) SONO three-kolshi filter
(m) BUET iron coated sand filter
(n) Granet Home-made Filter
(o) Chari Filter
(p) Adarsha Filter
(q) Bijoypur Clay/Processed Cellulose filter

3.7.2.8 Electrocoagulation

Electrocoagulation (EC) is the contamination separation process where adsorbent is generated in-situ by providing electricity (Mollah et al., 2004). EC process uses a sacrificial anode, which dissociates upon the application of direct current (DC) and generates multivalent metal ions and electrons. In cathode, the water dissociates into; where, H^+ in combination with another H^+ can form H_2 gas. The electrodes (anode and cathode) can be made up of different metals like iron, aluminium, zinc, etc. Depending upon the type of contamination, electrode metals are chosen. The key reaction in anode and cathode are as follows:

$$\text{Anode}: \mathrm{M}(\mathrm{s}) \rightarrow \mathrm{M}^{n+} + n\mathrm{e}^-$$

$$2\mathrm{H}_2\mathrm{O} \rightarrow 4\mathrm{H}^+(\mathrm{aq}) + \mathrm{O}_2(\mathrm{g}) + 4\mathrm{e}^-$$

$$\text{Cathode}: n\mathrm{H}_2\mathrm{O} + \mathrm{ne}^- \rightarrow \left(\frac{n}{2}\right)\mathrm{H}_2(\mathrm{g}) + n\mathrm{OH}^-(\mathrm{aq})$$

Lawrence Berkeley National Laboratory (LBNL), University of California Berkeley (UCB) developed and patented the technology called Electrochemical Arsenic Remediation (ECAR) to efficiently reduce high levels of arsenic in groundwater below the WHO maximum limit (MCL) of 10 μg/L at extremely low cost (Amrose et al., 2013a, b, 2014; van Genuchten et al., 2012). In ECAR using iron electrodes, electrolytic oxidation of a sacrificial iron anode continuously dissolve iron in water and forms several corrosion products like ferric hydroxides, oxyhydroxides, and oxides (i.e., rust or hydrous ferric oxide or HFO). The combination of those corrosion products together forms an adsorbent (electrochemically generated adsorbent or EGA) which have a high affinity for As^{5+}. The reaction intermediates produced during the oxidation of Fe^{2+} by DO (Fenton-type reaction) plays an important role as a powerful oxidant which oxidises As^{3+} to As^{5+} and then the entire As^{5+} is adsorbed onto the surface of EGA and forms insoluble flocs, which is removed further in the settling chamber.

3.7.3 Fluoride Removal

Excessive amount of fluoride is removed from groundwater by several defluoridation techniques, like fluoride exchangers, anion exchangers, activated carbon, magnesium salts and aluminium salts.

3.7.3.1 Chemical Precipitation/Coagulation

CSIR-NEERI in Nagpur, India has developed a fluoride removal technique called Nalgonda process, which has been operated in a number of villages of India. This process uses commonly fill and draw type of units or hand pump attached units.

Addition of lime and aluminium salts followed by flocculation and sedimentation or filtration can also remove fluoride from water. Lime reacts with the fluoride impurities present in the water. Aluminium salts like aluminium sulphate or aluminium chloride can act as a coagulant and used to remove fluoride from the water. Lime and aluminium salts both can remove up to 95% of initial fluoride concentration.

3.7.3.2 Electrocoagulation (EC)

EC process produces destabilising agent containing metallic cations to neutralise the '–ve' surface charges of colloids. Aluminium electrode performs better for fluoride removal through EC. Key reactions involved are given below:

$$\text{Anode}: \quad Al \rightarrow Al^{3+} + 3e^-$$

$$Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+$$

$$Al(OH)_3 + xF^- \rightarrow Al(OH)_{3-x} \cdot F_x \downarrow + xOH^-$$

$$\text{Cathode}: \ 2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

Research in the past decade has established that EC can effectively remove fluoride. EC can reduce 10–20 μg/L fluoride concentration by 90–95%. Advantage of EC process to remove fluoride is that nothing is added to the water, no chemical handling and less amount of sludge is generated.

3.7.3.3 Adsorption

Adsorption is a conventional technique employed to remove fluoride. Many low-cost adsorbents like alumina, red mud, clays, soils, activated carbon, calcite, brick powder, activated coconut-shell, activated kaolinites, oxides ores, modified chitosan, bone char can remove fluoride from water by adsorption. Fluoride removal from water can happen in three ways: (a) the mass transfer of fluoride ions, (b) fluoride particles adsorption onto the surface of the adsorbent and (c) intraparticle diffusion from the exterior surface to the interior surface and possible exchange with the other materials.

Activated alumina has been one of the powerful adsorbents used for defluoridation. Granular activated carbon has a very high surface area, which facilitates the fluoride adsorption.

Activated carbons have also been known to remove fluorides. Activated carbon can remove 320 mg fluoride/kg of the dry weight of the adsorbent.

3.7.3.4 Ion Exchange

Ion exchange treatment can remove up to 95% of fluoride. However, the resins for fluoride removal are costly and thereby complete removal of fluoride by ion exchange will be a costly affair.

3.7.3.5 Membrane Technology

In recent years, membrane-based technologies like reverse osmosis (RO), microfiltration (MF), nanofiltration (NF) and electrodialysis have been used in removing fluoride from water effectively. The most predominant advantages of fluoride removal by membrane process are that it is a single-step process, it can remove fluoride very effectively (~98%), it can remove the bacteriological parameter, and no chemical is used in this process.

3.7.4 Uranium Removal

Many treatment technologies have been developed to treat uranium-contaminated water considering the disastrous effect of uranium in water. Iron-based technologies are considered one of the best because of the reduction capacity of iron. Several uranium removal technologies include adsorption, reduction, inhabitation, re-oxidation, biosorption, membrane filtration and incorporation in the stable mineral structure.

3.7.4.1 Reduction

Mobility of uranium depends mainly on its oxidation state. U^{6+} is more soluble and mobile and removed by reduction to the lesser oxidising state by some reducing agent. Fe^{2+} containing materials like mackinawite (FeS), pyrite (FeS_2), siderite ($FeCO_3$) and magnetite (Fe_3O_4) are considered to be a good reducing agent to reduce U^{6+} to U_3O_8, U_4O_9, or UO_2 (Chen et al., 2017). Fe(0) is considered as a more powerful reducing agent than Fe^{2+} in the reduction of U^{6+}.

3.7.4.2 Biological Reduction

Fe^{3+}-reducing bacteria like *Geobacter* species and *Shewanella* species and sulphate-reducing bacteria like *Desulfovibrio* species have been widely used to reduce soluble U^{6+} to insoluble U^{6+} in anaerobic condition.

3.7.4.3 Inhibition of Re-oxidation

Soluble and mobile U^{6+} is reduced to less soluble compounds. However, any addition of any oxidising material in the same environment can oxidise those compounds back to U^{6+}. Combination of Fe(III) with the sulphate-reducing condition (iron sulphide) have been used to maintain a reducing environment, which provides protection against oxygen intrusion and maintains reducing the environmental condition.

3.7.4.4 Adsorption

Iron and iron-based other compounds play a major role in treating water contaminated with uranium. Iron-based adsorbents like nanoscale zero-valent iron (*n*ZVI), Fe^{2+}/Fe^{3+} (oxyhydr)oxide, iron compounds and iron minerals adsorb uranium directly. The main advantage of uranium removal by adsorption is that it is fast and has high removal efficiency. However, in adsorption uranium is not completely removed rather it is transferred from one phase to another, which will be released in the environment depending upon the environmental condition of the disposal environment.

3.7.4.5 Bio-sorption

Very few studies have been found in research-level which can treat uranium-contaminated water. *Lemna* sp. and *Pistiastratiotes* are the bio adsorbents which can treat uranium-contaminated water or waste (Vieira et al., 2019). Bio-sorbents are easy to handle, stable and can be used in treating water containing uranium.

3.7.4.6 Incorporation into Stable Mineral Phases

Uranium can be removed by adsorption, biosorption or by reduction. However, the stability of them greatly depends on the environmental condition depending on which these products can be reoxidised.

Adsorbed uranium can be potentially incorporated into the crystallised amorphous stable structure of iron minerals, which provides the long-term uranium stabilisation option. However, further investigation in this study area is needed to understand the mechanism of this process.

4 Conclusions

Water pollution is reckoned to be a global problem, which differs with levels of development in the society. In general terms, water pollution has severe impacts on the usefulness and value of water resources, with negative impacts on ecosystems, fisheries, food production, health and social development, and economic activities. It is partly driven by inadequate economic development, especially industrial development, and uncontrolled urbanisation. Though, prevention of water pollution, particularly in the form of waste minimisation ranks high as compared to end-of-pipe treatment of effluents, treatment of water does not have much alternative in providing feasible solution towards water quality problems. While the surface water is by and large directly contaminated by anthropogenic interferences, groundwater contamination in most of the cases have some unique geogenic characteristics. This, in turn, has been responsible for pursuit of more diversified forms of treatment of groundwater. In the context of water treatment technology innovation and transfer, it should be kept in mind that culturally and locally adapted technologies for water treatment are most effective. Needless to mention that each applied technology must be specifically adapted to the people's socio-cultural background failing which the basic objective of water treatment will remain unaddressed and the issue of achievement of SDG an absurd proposition.

References

Abbaspour S. (2011). Water quality in developing countries, South Asia, South Africa, water quality management and activities that cause water pollution. *In:* 2011 International Conference on Environmental and Agriculture Engineering, IPCBEE vol. 15, © (2011) IACSIT Press, Singapore.

Amrose, S.E.E.S.E., Gadgil, A.J.A.J.J., Bandaru, S.R.S.R.S., Delaire, C., van Genuchten, C.M.C.M., Li, L., Orr, C., Dutta, A., Deb Sarkar, A., Das, A., Roy, J., Debsarkar, A., Das, A., Roy, J., Locally, Deb Sarkar, A., Das, A. and Roy, J. (2013a). Locally affordable and scalable arsenic remediation for South Asia using ECAR. *In:* 36th WEDC International Conference: Delivering Water, Sanitation and Hygiene Services in an Uncertain Environment, vol. 6.

Amrose, S.E., Bandaru, S.R.S.S., Delaire, C., van Genuchten, C.M., Dutta, A., DebSarkar, A., Orr, C., Roy, J., Das, A. and Gadgil, A.J. (2014). Electro-chemical arsenic remediation: Field trials in West Bengal. *Sci Tot Environ*, **488–489(1):** 539–546.

Amrose, S.E., Gadgil, A.J., Bandaru, S.R.S., Delaire, C., Van Genuchten, C.M., Li, L., Orr, C., Dutta, A., Deb Sarkar, A., Das, A. and Roy, J. (2013b). Locally affordable and scalable arsenic remediation for South Asia using ECAR. *In:* 36th WEDC International Conference: Delivering Water, Sanitation and Hygiene Services in an Uncertain Environment.

Brandhuber, P. and Amy, G. (2001). Arsenic removal by a charged ultrafiltration membrane influences of membrane operating conditions and water quality on arsenic rejection. *Desalination*, **140:** 1–14.

Bruni, M. and Spuhler, D. SSWM University Course: Rapid Sand Filtration. Retrieved from: https://sswm.info/sswm-university-course/module-6-disaster-situations-planning-and-preparedness/further-resources-0/rapid-sand-filtration.

Burch, J.D. and Thomas, K.E. (1998). Water disinfection for developing countries and potential for solar thermal pasteurization. *Solar Energy*, **64(1–3):** 87–97. doi:https://doi.org/10.1016/S0038-092X(98)00036-X.

Chen, A., Shang, C., Shao, J., Zhang, J. and Huang, H. (2017). The application of iron-based technologies in uranium remediation: A review. *Sci Tot Environ*, **575:** 1291–1306.

CivilDigital.Com. Design Fundamentals of Sedimentation Tanks. Retrieved from: https://civildigital.com/design-fundamentals-sedimentation-tanks/. Last Accessed: July 28, 2019.

CPHEEO (Central Public Health and Environmental Engineering Organization) (2009). Manual on Water Supply and Treatment. Third Revised and Updated Edition. Ministry of Urban Development, Government of India, New Delhi.

Driehaus, W., Jekel, M., Hildebrandt, U., Gmbh, G.E.H.W., Kg, C. and Straûe, H.H. (1998). Granular ferric hydroxide—a new adsorbent for the removal of arsenic from natural water. *J Water Supply: Res Technol – AQUA*, **47(1):** 30–35.

FAO (Food and Agriculture Organization of the United Nations) (2009). How to Feed the World in 2050. FAO, Rome. http://www.fao.org/wsfs/forum2050/wsfs-background-documents/wsfs-expert-papers/en/.

Graham, N. (Ed). (1988). Slow sand filtration, recent developments in water treatment technology. Elis Horwood limited/Wiley and sons Chichester England.

Jiang, J.Q. (2001). Removing arsenic from groundwater for the developing world—A review. *Water Sci Technol*, **44(6):** 89–98.

Katsoyiannis, I.A. and Zouboulis, A.I. (2004). Application of biological processes for the removal of arsenic from groundwaters. *Water Res*, **38(1):** 17–26.

Matsunaga, H., Yokoyama, T., Eldridge, R.J. and Bolto, B.A. (1996). Adsorption characteristics of arsenic(III) and arsenic(V) on iron(III)-loaded chelating resin having lysine-N^{α}, N^{α}-diacetic acid moiety. *Reactive Funct Polym*, **29(3):** 167–174.

Mollah, M.Y.A., Morkovsky, P., Gomes, J.A.G., Kesmez, M., Parga, J. and Cocke, D.L. (2004). Fundamentals, present and future perspectives of electrocoagulation. *J Hazard Mater*, **114(1–3):** 199–210.

Nkwonta, O. and Ochieng, G. (2009). Roughing Filter for water pre-treatment technology in developing countries: A review. *International Journal of Physical Sciences*, **4(9):** 455–463.

OECD (2012). Environmental Outlook to 2050: The consequences of inaction. OECD 2012. http://www.oecd.org/env/indicators-modelling-outlooks/oecd-environmental-outlook-1999155x.htm.

Pan America Environmental: Industrial Wastewater Treatment Systems. Dissolved Air Flotation Theory. Retrieved from: http://www.dissolved-air-flotation.com/dissolved-air-flotation-theory.html. Last Accessed: July 28, 2019.

Peavy, H.S., Rowe, D.R. and Tchobanoglous G. (1985). Environmental Engineering. McGraw-Hill, Michigan.

Ramana, A. and Sengupta, A.K. (1993). Removing selenium(IV) and arsenic(V) oxyanions with tailored chelating polymers. *J Environ Eng*, **118(5):** 755–775.

Seidel, A., Waypa, J.J. and Elimelech, M. (2001). Role of charge (donnan) exclusion in removal of arsenic from water by a negatively charged porous nanofiltration membrane. *Environ Eng Sci*, **18(2)**.

Shammas, N.K. and Wang, L.K. (2016). Water Engineering: Hydraulics, Distribution and Treatment. Wiley, New Jersey.

Shree Virkrupa Engineering. Centrally Driven Clarifiers. Retrieved from: http://www.agitatormanufacturer.com/centrally-driven-clarifiers.html. Last Accessed: July 28, 2019.

Sunderstron, D.W. and Klei, H.E. (1979). Wastewater Treatment. Prentice-Hall, Englewood Cliffs, New Jersey.

Trung, D.Q., Anh, C.X., Trung, N.X., Yasaka, Y., Fujita, M. and Tanaka, M. (2001). Preconcentration of Arsenic Species in Environmental Waters by Solid Phase Extraction Using Metal-loaded Chelating Resins. *Anal Sci*, **17:** 1219–1222.

UN WWAP (2003). United Nations World Water Assessment Programme. The World Water Development Report 1: Water for People, Water for Life. UNESCO. Paris, France.

USEPA (2000). Fact Sheet titled "The History of Drinking Water Treatment". United States Environmental Protection Agency (USEPA).

USEPA (2012). Arsenic Treatment Technology Evaluation Handbook for Small Systems. United States Environmental Protection Agency (USEPA), 152.

van Genuchten, C.M., Addy, S.E.A., Peña, J. and Gadgil, A.J. (2012). Removing arsenic from synthetic groundwater with iron electrocoagulation: An Fe and As K-edge EXAFS study. *Environ Sci Technol*, **46(2):** 986–994.

Vieira, L.C., de Araujo, L.G., de Padua Ferreira, R.V., da Silva, E.A., Canevesi, R.L.S. and Marumo, J.T. (2019). Uranium biosorption by *Lemna* sp. and *Pistia stratiotes*. *J Environ Radioactivity*, **203(March):** 179–186.

Wegelin, M. (1996). Surface Water Treatment by Roughing Filters: A Design, Construction, and Operation Manual Sandec Report No. 2/96. Swiss Centre for Development Cooperation in Technology and Management (SKAT), St. Gallen, Switzerland.

Chapter 6
Sustainable Municipal Waste Management in Indian Cities

Tapas Kumar Ghatak

1 Introduction

Municipal solid waste (MSW) and its management is a major issue for most of the urban local bodies (ULBs) in India, where un-intervened urbanisation along with a change of consumption pattern have impacted MSW generation substantially. We are in an era when plastic is an unavoidable commodity. From the morning toothbrush to every activity, polymers play an important role in our daily life. We cannot ignore the need of polymer in our daily life and also its impact on the waste plastic and its management.

Effective solid waste management (SWM) is a major challenge in most of the cities with high and increasing population density. A substantial increase in urban population with constant increment of in-migration of rural population along with unassessed floating population specially in large megacities, religious cities and hill cities have prevented any perfect policy framing and its execution. Achieving sustainable development within a country experiencing rapid population growth and improvement in living standards are made more difficult in India, because it is a diverse country with varied economic groups, cultures and traditions.

Despite significant development in social, economic and environmental areas, SWM systems in India have remained relatively unchanged. The informal sector has a key role in extracting value from waste, with approximately 90% of residual waste currently dumped rather than properly landfilled (Narayan, 2008). There is an urgent need to move towards more sustainable SWM and this requires new management systems and waste management facilities. Current SWM systems are inefficient, with waste having a negative impact on public health, the environment and the economy.

T. K. Ghatak (✉)
CREDAI, New Delhi, India

Environmental Cell, KMDA, Government of West Bengal, Kolkata, West Bengal

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_6

The Municipal Solid Wastes (Management & Handling) Rules, 2000 in India were introduced by the Ministry of Environment and Forests (MoEF), which have been duly modified in 2016 (MoEF, 2016), and are expected to address the challenges and show a workable path in the coming years. However, these recent modifications and the implementation of Solid Waste Management Rules 2016 by the Indian Government will surely improve the situation and the benefit is already visible.

This chapter reviews the challenges, barriers and opportunities associated with improving waste management in India. It is the output from an international seminar on ‘Sustainable solid waste management for cities: opportunities in SAARC countries’ organised by the Council of Scientific and Industrial Research-National Environmental Engineering Research Institute (CSIR-NEERI) and held in Nagpur, India in 2015. SAARC is the South Asian Association for Regional Cooperation and includes Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka and Afghanistan.

Thus, in a nutshell population explosion coupled with change in life style of people results in increased generation of solid wastes in urban as well as rural areas of the country. At present, the municipal solid waste disposal methods followed in many of the cities and towns are unsystematic and unscientific and involve dumping in low-lying areas. Most of the dumping sites are just uncontrolled dumps where a mixture of domestic, commercial, industrial and medical wastes is ‘thrown away’.

Apart from polluting air, soil and groundwater, open dumping of wastes generally becomes breeding ground for various dreadful disease-causing pathogens and vectors, particularly in the vicinity of the disposal sites. Thus, scientific disposal of solid waste is needed to make a sustainable future with healthy and hygienic environment.

Presently, land scarcity is a major problem to develop a landfill site. So, emphasis is being given on reduce, reuse and recycle policy of waste management. Moreover, the distance of landfill site from the source of waste generation increases the expense of transportation. Thus, decentralised waste management centre will surely reduce the burden of the land-fill. At the same time, it can be mentioned that proper utilisation of waste can generate revenue for the management. Only the hazardous and unmanageable waste should go for landfilling. Therefore, proper waste management can help in reducing at least 80% burden at landfill site, thus increasing the life of the site and at the same time helping to use the waste as resource. Solid Waste Management Rules, 2016 has more or less addressed all these issues and also encouraged an introduction of entrepreneurship model in waste management in Indian Cities and also in its non-urban areas.

2 Growth of Urban India and its Waste

The process of urbanisation in developed countries are characterised by high level of urbanisation and some of them are in final stage of urbanisation process. In majority of the developing countries, the rate of urbanisation is very fast and it is not accompanied by industrialisation but by rapid growth of service sector in economies

(Macbeth and Collins, 2002). Future growth of world's population is supposed to take place in the urban areas of less developed countries and the contribution of India in terms of urban population size, is quite substantial (Table 6.1). The population further increased to 1252 million in 2013 (Bhalla et al. 2013). Population growth is a major contributor to increasing MSW in India (Table 6.2).

2.1 Demographic Changes

India's total population has increased from 238.4 million in 1901 to 1028 million in 2001 whereas urban population has increased from 25.8 million in 1901 to 286.1 million in 2001 (nearly 30% of total population). India's urban population of 286 million was larger in size as compared to the combined total population of 12 countries in West Asia (=192.4 million) or five countries in East Asia (=206.8 million) excluding China (=1285 million), 40% of the European continent (=726.3 million) (Muttur, 2008). The percentage of urban population living in Class I cities (>100,000 population) has increased from 65% in 1991 to 69% in 2001 (Ministry of Housing and Urban Poverty Alleviation, 2007).

2.2 Growth of Urban Real Estate

India's globalisation and consequently urbanisation have shown remarkable selective growth by city sizes, regions and sectors. Higher growth and larger concentration of urban population in metropolitan areas are important features of India's urbanisation in post-globalisation period. The globalisation period has seen changes

Table 6.1 Population growth in India between 1911 and 2011

Census year	*Population × 10^6*	*Decadal growth × 10^6*	*Average annual exponential growth rate (%)*	*Progressive growth rate compared with 1911 (%)*
1911	252.0	13.7	0.56	5.75
1921	251.3	−0.8	−0.03	5.42
1931	278.9	27.6	1.04	17.02
1941	318.6	39.7	1.33	33.67
1951	361.1	42.4	1.25	51.47
1961	439.2	78.1	1.96	84.25
1971	548.1	108.9	2.20	129.94
1981	683.3	135.1	2.22	186.64
1991	846.4	163.1	2.16	255.05
2001	1028.7	182.3	1.97	331.52
2011	1210.2	181.4	1.64	407.64

(*Source*: Chandramouli, 2011)

Table 6.2 Predicted population growth and overall impact on waste generation

Year	*Population* ($\times 10^6$)	*Per capita generation (kg per day)*	*Total waste generation* ($\times 10^3$ *tonnes per year)*
2001	197.3	0.439	31.63
2011	260.1	0.498	47.30
2021	342.8	0.569	71.15
2031	451.8	0.649	107.01
2036	518.6	0.693	131.24
2041	595.4	0.741	160.96

(*Source*: Annepu, 2012)

in key urban sectors like housing, transport, commercial and information technology enabled services/business process outsourcing (ITES/BPO) segments. The opening up of 100% FDI in real estate had brought in big boom to the industry and was able to attract international private players to invest in Indian cities in joint venture with local partners (Chadchan and Shankar, 2012).

The vested interests in urban development have increased through the route of private sector participation in urban services sector. Privatisation has pushed the governments (national, state and local) to withdraw from certain development sectors like housing, infrastructure services including water supply, sanitation, sewage systems, urban transport, tourism, health services, telecommunication and electricity. The demand for infrastructure investment during the 11th Five Year Plan (2007–2012) was estimated to be US$ 492.5 billion (Planning Commission, 2008). To meet this growing demand, Government of India raised the investment in infrastructure from 4.7% of GDP to around 7.5–8% of GDP in the 11th Five Year Plan. In general, efforts towards infrastructure development have continued to focus on the key areas of physical and social infrastructure mostly in urban sectors. The spatial manifestation of investments and economic change are discernible through continuous or discontinuous sprawl with poly-nodal centres along the corridors (Fig. 6.1).

2.3 Waste Generation and Waste Characterisation Data

Estimating the quantity and characteristics of MSW in India and forecasting future waste generation are fundamentals to successful waste management planning (Rana et al., 2014). The quantity of MSW generated depends on living standards, the extent and type of commercial activity, eating habits and season (Kaushal et al., 2012). India generates approximately 133,760 tonnes of MSW per day, of which approximately 91,152 tonnes is collected and approximately 25,884 tonnes is treated (Kumar and Goel, 2009). MSW generation per capita in Indian cities ranges from approximately 0.17 kg per person per day in small towns to approximately 0.62 kg per person per day in cities (Table 6.3).

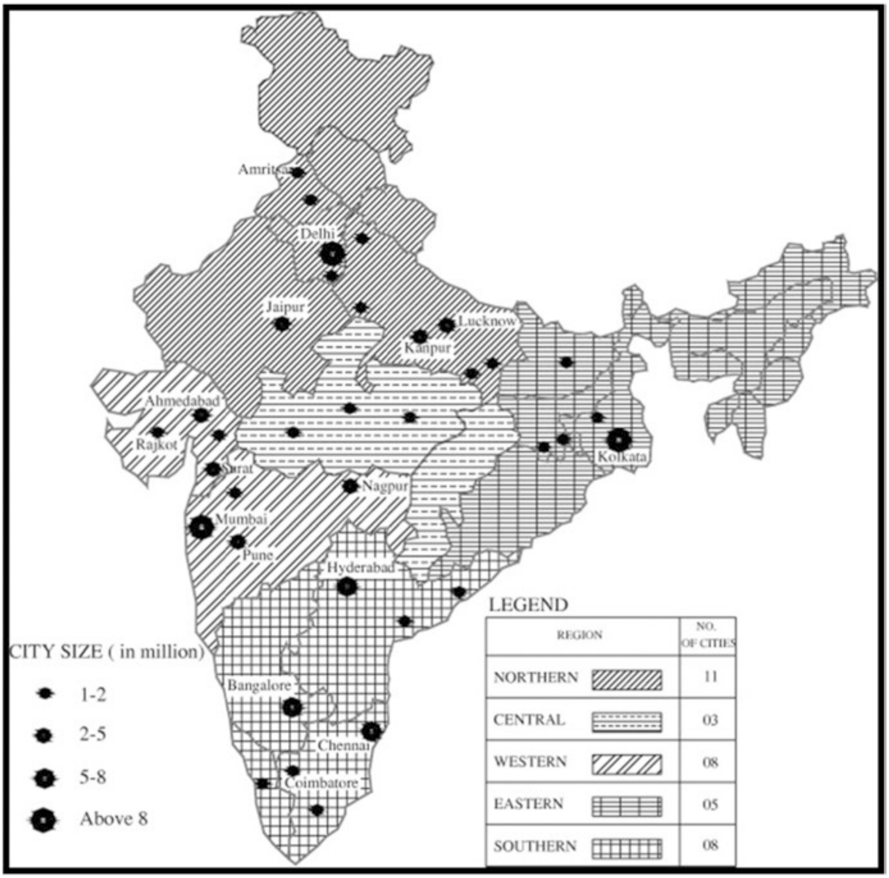

Fig. 6.1 Distribution of 35 million + cities across different regions. (*Source*: Author based on Census of India 1971, 1981, 1991, 2001)

Table 6.3 Waste generation per capita in Indian cities

Population	*Waste generation rate (kg per capita per day)*
Cities with a population <0.1 million (eight cities)	0.17–0.54
Cities with a population of 0.1–0.5 million (11 cities)	0.22–0.59
Cities with a population 1–2 million (16 cities)	0.19–0.53
Cities with a population >2 million (13 cities)	0.22–0.62

(*Source*: Kumar et al., 2009; Kumar and Goel, 2009)

2.4 Waste Generation Per Capita in Indian Cities

Waste generation rate depends on factors such as population density, economic status, level of commercial activity, culture and city/region. Figure 6.2 provides data on MSW generation in different states, that indicates high waste generation in Maharashtra (15,364–19,204 tonnes per day), Uttar Pradesh, Tamil Nadu, West Bengal (11,523–15,363 tonnes per day), Andhra Pradesh, Kerala (7683–11,522 tonnes per day) and Madhya Pradesh, Rajasthan, Gujarat, Karnataka and Mizoram (3842–7682 tonnes per day). Lower waste generation occurs in Jammu and Kashmir, Bihar, Jharkhand, Chhattisgarh, Orissa, Goa, Assam,

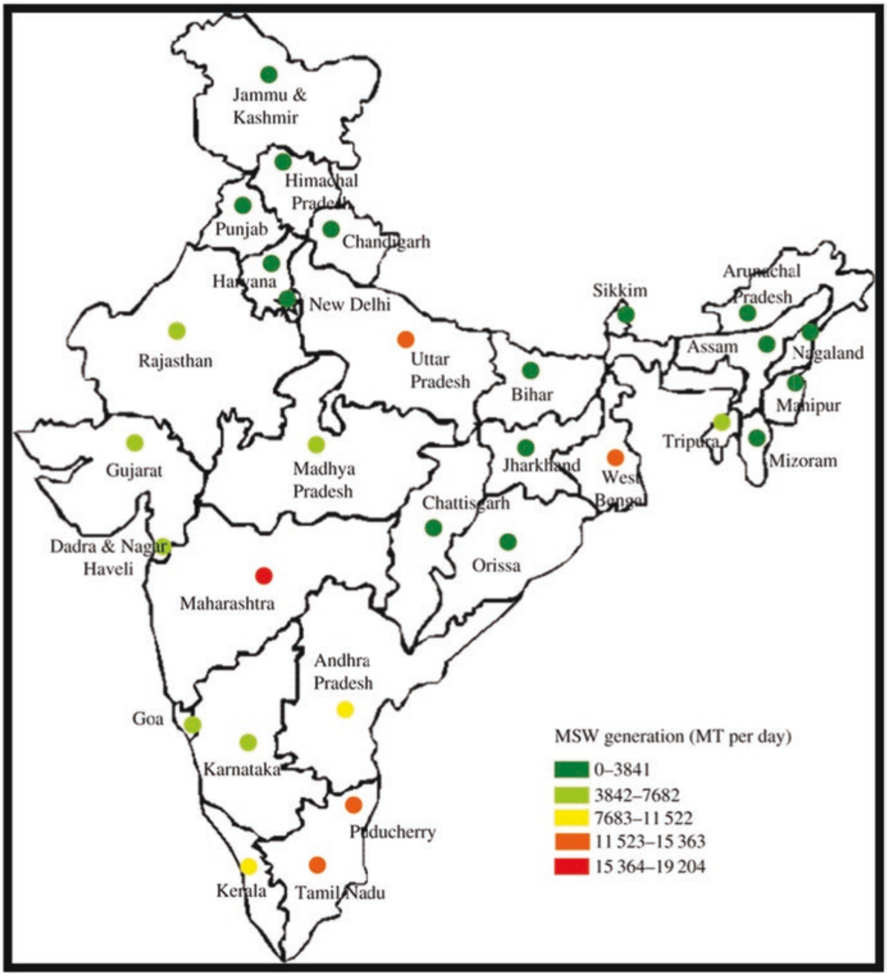

Fig. 6.2 State wise MSW generation (2009–2012) (*Source*: Kumar et al. 2017)

Arunachal Pradesh, Meghalaya, Tripura, Nagaland and Manipur (<3841 tonnes per day).

2.5 Characterisation of Waste

The economic impacts on waste composition is quite significant. High-income groups use more packaged products, resulting more waste in higher volumes of plastics, paper, glass, metals and textiles. Therefore, changes in waste composition have a significant impact on waste management practices (Rawat et al., 2013). MSW also contains hazardous wastes such as pesticides, paints, used medicine and batteries along with some unidentified waste like sanitary napkins, adult diapers (still not identified as medical waste). Compostable organics are generally fruits, vegetables and food waste. Most of these wastes are now required to be managed by Solid Waste Management Rules, 2016.

2.6 Salient Features of SWM Rules, 2016

The earlier MSW (M&H) Rules, 2000 were applicable to municipal authorities only. These covered 4041 urban local bodies in the country. The new Solid Waste Management Rules, 2016 are applicable beyond municipal areas and extend to urban agglomerations, census towns, notified industrial townships, areas under the control of Indian railways, airports, airbase, port and harbour, defence establishments, special economic zones, state and central government organisations, places of pilgrimage, religious and historical importance. Some of the significant changes in the rules which are expected to increase community (waste generator) participation and lead the waste management towards a sustainable format are as follows:

Rule 4 Section 1a. The source segregation of waste has been mandated to channelise the waste to wealth by recovery, reuse and recycle.

Rule 4 Section 6. New townships and group housing societies have been made responsible to develop in-house waste handling, and processing arrangements for bio-degradable waste.

Rule 4 Section 7. All resident welfare and market associations, gated communities and institution with an area >5000 m^2 should segregate waste at source – into valuable dry waste like plastic, tin, glass, paper, etc. and handover recyclable material to either the authorised waste pickers or the authorised recyclers, or to the urban local body. The bio-degradable waste should be processed, treated and disposed off through composting or bio-methanation within the premises as far as possible. The residual waste shall be given to the waste collectors or agency as directed by the local authority.

Table 6.4 Average (% by weight) composition of MSW in Indian metro cities

Percentage (%) by weight							
Compostable	*Inert*	*Paper*	*Plastic*	*Glass*	*Metals*	*Textile*	*Leather*
41	40	6	4	2	2	4	1

(*Source*: Sharholy et al., 2008)

Healthcare waste contains disposable syringes, sanitary materials and blood containing textiles and is governed by the Biomedical Waste Management Rules, 2016 and the Amended Rules, 2018 and 2019, and these are not to be mixed with MSW. The average composition of MSW produced by Indian cities is approximately 41 wt.% organic, approximately 40 wt.% inert, with approximately 19 wt.% potentially recyclable materials, as shown in Table 6.4 (Kumar et al., 2009). Most of the organic waste is generated from households, and inert waste is generated from construction, demolition and road sweeping. Waste samples collected from Delhi, Ahmedabad and Bangalore indicate that MSW composition varies between cities (Kumar and Goel, 2009; Rawat et al., 2013).

3 Current Waste Management Status in India

The MOEF issued Solid Waste Management Rules, 2016, which have already been discussed earlier in Section 2.6 to ensure proper waste management in India along with the pre-existing Municipal Solid Wastes (Management and Handling) Rules, 2000. These have clearly vested the power with the municipal authorities and made them responsible for implementing these rules and developing infrastructure for collection, storage, segregation, transportation, processing and disposal of MSW. Quite a few cities like Pune, Mumbai, cities in Kerala have initiated the process.

3.1 Role of the Informal Sector in Waste Materials Reuse and Recycling

The informal sector at present has a very important role in India and this must be integrated into formal and institutionalised SWM systems. The informal sector at present is characterised by small-scale, labour-intensive, largely unregulated and unregistered low-technology, untrained man powers leading to manufacturing or provision of materials and services. Waste pickers collect household or commercial/industrial waste and many hundreds of thousands of waste pickers in India depend on waste for an income without any health and social protection. Pickers extract potential value from waste bins, trucks, streets, waterways and dumpsites. Some work in recycling plants owned by unrecognised agencies. Waste picking is often the only source of income for families, providing a livelihood for significant numbers of urban poor and usable materials to other enterprises. Waste pickers in Pune collect organic waste for composting and biogas generation. Waste pickers also make a significant contribution by keeping cities clean.

On the contrary, waste segregation at source as defined in Solid Waste Management Rules, 2016 and use of specialised waste processing facilities to separate recyclable materials have a key role in the waste management. Disposal of residual waste after extraction of material resources needs much less engineered landfill sites with waste-to-energy facilities. Therefore, promotion of a team of young entrepreneurs is required to execute the above management step, which at present lies with a hand-picked people from the municipal corporation along with a few hired contractual agencies with minimum stake in the entire process. The potential for energy generation from landfill via methane extraction or thermal treatment, generation of bio-fertiliser from bio-degradable waste are few of the major opportunities. The key barrier to these opportunities is the shortage of qualified engineers/entrepreneurs and environmental professionals with the experience to deliver improved waste management systems in India. A few trials in selected cities are surely an encouraging step but miles to travel to reach even the first pillar of success.

3.2 Waste Collection and Transport

Waste collection, storage and transport are essential elements of any SWM system and can be major challenges in cities. The salient points of solid waste transportation route analysis in Kolkata Municipal Corporation (KMC) as a case study are as follows:

- The total major usable road length in KMC is about 4416 km and the waste transportation for all the 141 wards use about 1736 km, which is 39% of the total road length.
- A total number of 270 roads either in full or in part segments are being utilised for such transportation only during day time adding a very high load in the peak hours of the city traffic.
- Trip counts of the total wards in these roads are around 60,000 per year or about 170 trips per day.
- The running time varies from 25 to 60 minutes one-way with an average speed of 20 km/h and travels about 9–20 km one-way distance from a centralised point of each ward of KMC.
- This requires minimum one trip in some wards to four trips in some wards for removing all the waste generated in the ward.
- The entire process is being operated between 9 AM and 4 PM with peak hours through the busiest roads of the city.

Waste collection is the responsibility of the municipal corporations in India, and bins are normally provided for biodegradable and inert waste. The biodegradable as well as inert waste is collected by hired unidentified person without any ID proof from the generator of various category and dumped in the dumping ground not necessarily a scientific landfill site as defined in the rule. The required expenditure of the local body for waste collection, transport and disposal is much above the allocated budget and no waste management charge is collected from the generator. Improvements to waste collection and transport infrastructure in India will create jobs, improve public health and increase stake holder participation.

4 Waste Disposal: Landfills

More than 70% of collected urban waste is dumped at landfills, which are essentially non-segregate type, and most of them are full to the point of overflowing. Few of them are listed in Table 6.5.

In India >90% of waste is unsegregated and is dumped in an unsatisfactory and unscientific manner. It is estimated that approximately 1400 km^2 will be occupied by waste dumps by 2050 which was 400 km^2 in the early part of this century (Fig. 6.3).

Treatment of the waste prior to its disposal and well designed waste disposal sites with scientific disposal mechanism will not only protect public health but will also control pollution of the air, surface water, soil and groundwater. The treatment facilities before final disposal that are available in India are composting, vermicomposting, bio-methanation, pelletization and waste to energy (Table 6.6).

5 Challenges for Improved Waste Management in India

The waste management in India is presently quite poor because the best and most appropriate methods from waste collection to disposal are not being used. With the introduction of Solid Waste Management Rules, 2016, it is expected that a community-based participatory approach will allow to take a financially sustainable

Table 6.5 City wise availability of Land Fill Sites (LFS) and their area

S. No.	*City*	*No. of LFS*	*Area in hectares*
1	Delhi	3	66.4
2	Ahmedabad	1	84
3	Kolkata	1	27.4
4	Chennai	2	465.5
5	Hyderabad	1	121.5
6	Mumbai	2	140
7	Bangalore	2	47

(*Source*: Parvathamma, 2014)

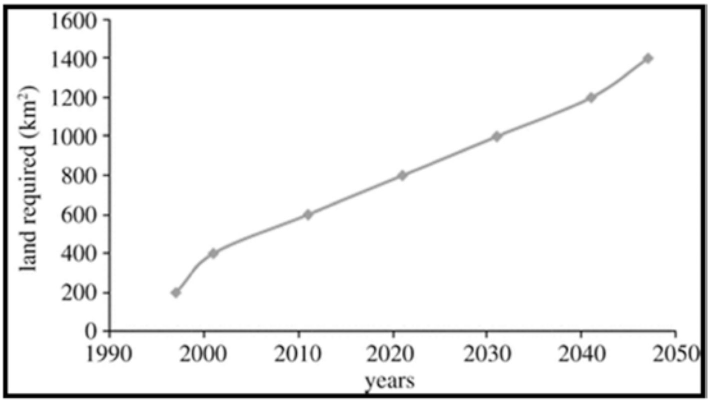

Fig. 6.3 Cumulative land required (km^2) for disposal of MSW (*Source*: Singhal and Pandey, 2001).

Table 6.6 State-wise[a] status of MSW processing facilities in India in 2011 (*Source*: Planning Commission, 2014)

State	*Composting*	*Vermicomposting*	*Biomethanation*	*Pelletisation*	*Waste to energy*
Andaman and Nicobar	1	Nil	Nil	Nil	Nil
Andhra Pradesh	24	Nil	Nil	11	2
Assam	1	Nil	Nil	Nil	Nil
Chandigarh	Nil	Nil	Nil	1	Nil
Chattisgarh	6	Nil	Nil	Nil	Nil
Delhi	3	Nil	Nil	Nil	3
Goa	14	Nil	Nil	Nil	Nil
Gujarat	3	93	Nil	6	Nil
Himachal Pradesh	10	Nil	Nil	Nil	Nil
Jammu and Kashmir	1	Nil	Nil	Nil	Nil
Jharkhand	4	Nil	Nil	Nil	Nil
Kerala	21	7	10	1	1
Madhya Pradesh	7	Nil	Nil	2	Nil
Maharashtra	6	2	5	5	2
Meghalaya	1	1	Nil	Nil	Nil
Nagaland	1	1	Nil	Nil	Nil
Orissa	1	Nil	Nil	Nil	Nil
Punjab	1	3	Nil	Nil	Nil
Sikkim	1	Nil	Nil	Nil	Nil
Tamil Nadu	162	24	Nil	3	Nil
Tripura	1	Nil	Nil	Nil	Nil
West Bengal	13	7	Nil	Nil	Nil
total	279	138	172	29	8

[a]All other states and UTs currently have no processing facilities.

step and a new mode of management with entrepreneurship approach will take a lead role. There is a lack of training in SWM and the availability of qualified waste management professionals is limited. A prospective plan of introducing a waste management cadre with a professional training in established institution will be a pillar of success in waste management in India. There is also a lack of accountability in current SWM system throughout India. Municipal authorities are responsible for managing MSW in India but have budgets that are insufficient to cover the costs associated with developing proper waste collection, storage, treatment and disposal. The lack of strategic MSW plans, waste collection/segregation and a government finance regulatory framework are presently the major barriers to achieving effective SWM in India.

Limited environmental awareness combined with low motivation has inhibited innovation and the adoption of new technologies that could transform waste management in India. Public attitudes to waste are also a major barrier to improve SWM in India.

5.1 Implementation Strategy of Plastic Waste Management

As understood earlier the major problem in the cities lies with the usage of poly bags. Since they do not have any formal recycling potential they remain unattended. These bag manufacturing units in most of the cities operate only with trade licenses and do not require Consent to Operate (CTO) or Consent to Establish (CTE) and thus do not come under the direct purview of State Pollution Control Board. Thus, problem of managing plastic waste needs to be addressed from different angles:

1. Implementing the ban of manufacturing and using poly bags less than 40 μm.
2. Ways to manage plastic waste generated from households and other institutions.
3. Rehabilitation of people involved in manufacturing and selling of poly bags.
4. Alternatives to poly bag, which can also be reused.
5. Addressing behavioural pattern in terms of usage of poly bags and also disposal of waste.
6. Involving rag pickers who are involved in collection and segregation and bringing them into the formal pay structure.

In order to take these steps, the other important factors to be considered and the interventions required are:

1. The political economy of the state.
2. Willingness of political party is essential for success of a planned initiative and the potential of success in this domain can be explored if ruling party takes a proactive role in implementing the recommendations.
3. Poly bag manufacturing units are generally very small and operate with only trade license. Closing them may be politically resisted, which can be mitigated

through generation of alternative livelihood or shifting to higher micron poly bags.
4. The greater problems are water logging, clogged drainage channels, and over-saturated landfills, which affect the entire city and need to be addressed. This will, in turn reduce environmental pollution and aid in creating a better quality of life for citizens.

The issue of plastic segregation and reuse or recycle needs to be addressed in the context of integrated solid waste management. Hence, the issues have been addressed in Plastic Waste Management Rules, 2016 from the context of waste generation and then each step of implementation is addressed. The following interventions have been promulgated:

1. Rural areas have been brought in ambit of these Rules since plastic has reached to rural areas also. Responsibility for implementation of the rules is given to the Gram Panchayat.
2. First time, responsibility of waste generators is being introduced. Individual and bulk generators like offices, commercial establishments, industries are to segregate the plastic waste at source, handover segregated waste, pay user fee as per bye-laws of the local bodies.
3. Plastic products are left littered after the public events (marriage functions, religious gatherings, public meetings etc) held in open spaces. First time, persons organising such events have been made responsible for management of waste generated from these events.
4. Use of plastic sheet for packaging, wrapping the commodity except those plastic sheet's thickness, which will impair the functionality of the product are brought under the ambit of these rules. A large number of commodities are being packed/wrapped in to plastic sheets and thereafter such sheets are left for littering. Provisions have been introduced to ensure their collection and channelization to authorised recycling facilities.
5. Extended Producer Responsibility (EPR): Earlier, EPR was left to the discretion of the local bodies. First time, the producers (i.e. persons engaged in manufacture, or import of carry bags, multi-layered packaging and sheets or like and the persons using these for packaging or wrapping their products) and brand owners have been made responsible for collecting waste generated from their products. They have to approach local bodies for formulation of plan/system for the plastic waste management within the prescribed time frame.
6. State Pollution Control Boards (SPCBs) will not grant/renew registration of plastic bags, or multi-layered packaging unless the producer proposes the action plan endorsed by the concerned State Development Department.
7. Producers to keep a record of their vendors to whom they have supplied raw materials for manufacturing carry bags, plastic sheets, and multi-layered packaging. This is to curb manufacturing of these products in unorganised sector.
8. The entry points of plastic bags/plastic sheets/multi-layered packaging in to commodity supply chain are primarily the retailers and street vendors. They have been assigned the responsibility of not to provide the commodities in plas-

tic bags/plastic sheets/multi-layered packaging which do not conform to these rules. Otherwise, they will have to pay fine.

9. Plastic carry bag will be available only with shopkeepers/street vendors pre-registered with local bodies on payment of certain registration fee. The amount collected as registration fee by local bodies is to be used for waste management.
10. Central Pollution Control Board (CPCB) has been mandated to formulate the guidelines for thermoset plastic (plastic difficult to recycle). In the earlier Rules, there was no specific provision for such type of plastic.
11. Manufacturing and use of non-recyclable multi-layered plastic to be phased out in two years.

The Ministry of Environment, Forest and Climate Change has notified the Plastic Waste Management (Amendment) Rules 2018 on March 27, 2018.The amended Rules lay down that the phasing out of Multilayered Plastic (MLP) is now applicable to MLP, which are "non-recyclable, or non-energy recoverable, or with no alternate use." The amended Rules also prescribe a central registration system for the registration of the producer/importer/brand owner. The Rules also lay down that any mechanism for the registration should be automated and should take into account ease of doing business for producers, recyclers and manufacturers. The centralised registration system will be evolved by the Central Pollution Control Board (CPCB) for the registration of the producer/importer/brand owner. While a national registry has been prescribed for producers with presence in more than two states, a state-level registration has been prescribed for smaller producers/brand owners operating within one or two states. In addition, Rule 15 of the Plastic Waste Management (Amendment) Rules 2018 on "explicit pricing of carry bags" has been omitted.

5.2 Current Scenario of e-Waste Management in India: Issues and Strategies

Electronic waste or e-waste refers to unwanted, obsolete or unusable electronic and electrical products, which includes discarded computer monitors, motherboards, mobile phones and chargers, compact discs, headphones, television sets, air conditioners and refrigerators. India's electronics industry is one of the fastest growing industries in the world. India generated about 2 million tonnes (MT) of e-waste in 2016 annually and ranks fifth among e-waste producing countries, after the US, China, Japan and Germany (Baldé et al. 2017). India also imports huge amount of e-wastes from other countries around the world. Out of the e-waste generated in India, only 0.036 MT was treated in 2016-17 (https://www.downtoearth.org.in/blog/waste/recycling-of-e-waste-in-india-and-its-potential-64034).

Till 2011 the e-waste generated in India was largely controlled by the unorganised sector who adopted crude practices that resulted in higher pollution and less recovery, thereby causing wastages of precious resources and damage to environment. Therefore, to channelize the huge e-waste generated in India for environmentally sound recycling the E-waste (Management & Handling) Rules, 2011 was notified. The rules place main responsibility of e-waste management on the producers of the electrical and electronic equipment by introducing the concept of ‘extended producer responsibility’ (EPR), which is the global best practice to ensure the take-back of the end-of-life products. Further amendment to this rule came in 2015, which resulted in the E-waste (Management) Rule in 2016. The amendment in rules was done to channelize the e-waste generated in the country towards authorized dismantlers and recyclers in order to formalize the e-waste recycling sector. Over 21 products have been included under the purview of the rule including components or consumables or parts or spares of electrical and electronic equipment (EEE), along with their products. In the 2016 rules new arrangement called Producer Responsibility Organisation (PRO) has been introduced to strengthen the EPR further. PRO will be a professional organisation authorised or financed collectively or individually by producers, which can take the responsibility for collection and channelization of e-waste generated from the ‘end-of-life’ of their products to ensure environmentally sound management of such e-waste. The Rules also indicate the targets (quantity of e-waste to be collected to fulfil the EPR) that have to be met by the producers. The target for the first two years is 30% of the quantity of waste generation as indicated in EPR Plan. This will increase by 10 per cent up to a maximum of 70% from seventh year onwards. The law also says that the responsibility of producers is not confined to waste collection, but also to ensure that the waste reaches the authorised recycler/dismantler.

Although new rules have come into place to safely process e-waste, about 80 per cent of the waste such as old laptops, cell phones, cameras, air conditioners, televisions and LED lamps continues to be broken down by the informal sector, adversely affecting the environment and human health.

India has 312 registered e-waste recyclers as on 27.06.2019, accredited by the state governments to process e-waste with total install capacity of 782080.62 MTA (http://greene.gov.in/wp-content/uploads/2019/09/2019091881.pdf). But many of India’s e-waste recyclers are not recycling waste at all. While some are storing it in hazardous conditions, others do not even have the capacity to handle such waste.

The Ministry of Electronics and Information Technology has initiated an e-waste awareness programme under Digital India, along with industry associations from 2015, to create awareness among the public about the hazards of e-waste recycling by the unorganised sector, and to educate them about alternate methods of disposing their e-waste. The programme stresses the need for adopting environment friendly e-waste recycling practices. The programme has adopted the best practices for e-waste recycling available globally, so that this sector could generate jobs as well as viable business prospects for locals.

The Ministry has also developed affordable technologies to recycle valuable materials and plastics in an environmentally sound manner which are been used at present. They are (i) processing technology for recycle of electronic wastes at NML Jamshedpur - facility includes eddy current separator, hammer mill, ion exchange column etc., (ii) processing technology for conversion of waste plastics from e-waste to value added products at Central Institute of Plastics Engineering &

Technology (CIPET), Bhubaneswar, and (iii) process technology for recovery of precious metals from printed circuit board (PCBs) at Centre C-MET, Hyderabad, with active participation of authorized recycler, M/s. E-parisara Pvt. Ltd., Bangalore.

6 Suggested Steps For Improved Waste Management In India

An execution plan, which will be required for waste management in India is the resource recovery from waste and a value addition to the generated waste with recycling, recovery and reuse. With the availability along with the legal support of Solid Waste Management Rules 2016, the execution role of ULBs is distinctly reducing in waste management sectors though the responsibility of the Commissioner as well as Chairman of the local bodies is becoming immensely pertinent for awareness promotion of the Rules 2016 and communication with the citizens of the city. Waste management needs to be regarded throughout Indian society as an essential service requiring sustainable financing. ULBs should develop a properly funded system that demonstrate the advantages of sound investment in waste management.

A strong and independent implementing authority is needed to regulate waste management who will not be directly involved in execution of waste management. SWM is expected to improve in India with a clear regulatory law through Solid Waste Management Rules, 2016 and its judicious enforcement. Strong waste regulations can drive innovation. The waste management sector needs to include attractive and profitable entrepreneur based models with clear performance requirements imposed by the Urban Local Bodies (Municipalities), with a provision of financial penalties when waste management services are not working effectively. Finance for waste management companies and funding for infrastructure must be raised from waste producers through a waste tax. An average charge of 1 rupee per person per day would generate close to 50,000 crores annually, and this level of funding would probably be sufficient to provide effective waste management throughout India.

Littering and waste in streets is a major problem in India that has serious impacts on public health and causes visual pollution. Academic institutes and NGOs may be encouraged to develop community participatory models which should include the role and responsibilities of each individual. One such scientific and innovative project called “Swachta Doot Aplya Dari’ which means sanitary worker at your doorstep was designed by Centre for Development Communication (CDC), Jaipur, Rajasthan and first implemented in Nagpur city. The key concept concept is daily door-to-door collection of segregated domestic wastes. The end consumer is both main contributor and main beneficiary, as he should segregate the waste instead of littering it and, in turn, profits from the cleanliness of the city. This model was selected as an example of good practice in waste management by UN HABITAT in 2007.

A successful waste management needs waste segregation at source, which is already a mandatory legal requirement, mentioned in Solid Waste Management Rules, 2016 to allow much more efficient value extraction and recycling. Separating dry (inorganic) and wet (biodegradable) waste would have significant benefits and should be the responsibility of the waste producer.

A sustainable waste management planning requires visionary project development by ULBs in consultation and support from the private sector and NGOs. The roles and responsibilities to deliver a sustainable system need to be defined, with an evaluation system to monitor progress with an elaborate public participation through workshops and focus discussions. Experiences will be required to be shared between different regions of India and different social groups. There are a number of research institutes, organisations, NGOs and private sector companies working on a holistic approach to SWM. Future waste management in India must extensively involve the informal sector throughout the system.

There is a need to develop training and capacity building at every level. School children should be made to understand the importance of waste management, the effects of poor waste management on the environment and public health, and the role and responsibilities of each individual in the waste management system. This will develop responsible citizens who will regard waste as a resource opportunity.

7 Conclusion

Population growth and particularly the development of megacities along with in migration and floating population in the city is making SWM in India a major challenge. The current situation is that the MSW Rule 2000, which was definitely inadequate to address the issues has now been replaced by Solid Waste Management Rules, 2016. The 2016 rules along with Plastic Waste Management Rules, 2016; Plastic Waste Management (Amendment) Rules 2018 and 2019 and E-waste (Management) Rules, 2016 have definitely helped to improve the management of municipal solid wastes in India. Waste management in India still lacks public participation in terms of sharing the cost involved through paying user fees and sharing some stake in the management process. In general there is a lack of involvement in waste management by the community. There is a need to promote community awareness and change the attitude of people towards waste, as this is the fundamental for developing proper and sustainable waste management systems.

However, the introduction of various rules related to municipal solid waste, plastic waste and e-waste is likely to play a significant role in management and handling of wastes. It is expected that a sustainable and economically viable waste management model describing the role of community and individual will evolve in the near future. Such a model must ensure maximum resource extraction from waste, combined with safe disposal of residual waste through the development of engineered landfill and waste-to-energy facilities. This will ensure attracting new entrepreneurs in the field of waste management who can ensure profit without any subsidy from the government or other donor agencies. Organisation like CII (Confederation of Indian Industries) and CREDAI (Confederation of Real Estate Developer Association of India) have already initiated such entrepreneurship in their respective domain. There are several start-ups working towards the goal of a landfill-free future in several cities of India. They are (i) Saahas Zero Waste (Bengaluru), (ii) Hasiru Dala (Bengaluru), (iii) Citizengage (Bengaluru), (iv) Namo E-waste (Delhi), (v) GEM Enviro Management (Delhi) (vi) Paperman (Chennai), (vii) Vital Waste (Kolkata), (viii) ExtraCarbon (Gurgaon), (ix) Lets' Recycle (Ahmedabad), (x) Shivalik Solid Waste Management Ltd. (Mumbai), (xi) Eco-Wise (Noida) etc. More such start-ups will come up along the length and breath of India if the Community Participation Model is adopted instead of isolated effort from municipal corporation with government funding without any scope of sustainability.

References

Annepu, R.K., (2012). Report on Sustainable Solid Waste Management in India. Department of Earth and Environmental Engineering, Columbia University.

Baldé, C.P., Forti, V., Gray, V., Kuehr, R., Stegmann, P. (2017). The Global E-waste Monitor 2017, United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna.

Bhalla, B., Saini, M.S. and Jha, M.K. (2013). Effect of age and seasonal variations on leachate characteristics of municipal solid waste. *Int J Res Eng Technol*., **2:** 223–232.

Chadchan J. and Shankar, R. (2012). An analysis of urban growth trends in the post-economic reforms period in India. *Int J Sustainable Built Environ*. **1(1):** 36–49.

Chandramouli, C. (2011). Provisional Population Totals, Census of India 2011, Paper 2 Vol. 1 of 2011 Rural Urban Distribution India Sr.1.

Kaushal, R.K., Varghese, G.K. and Chabukdhara, M. (2012). Municipal solid waste management in India—current state and future challenges: A review. *Int J Eng Sci Technol*, **4:** 1473–1489.

Kumar, S., Smith, S.R., Fowler, G., Velis, C., Kumar, S.J., Arya, S, Rena, Kumar, R. and Cheeseman C. (2017). Challenges and opportunities associated with waste management in India. *R. Soc, open sci,* **4**:160764.

Kumar, S., Bhattacharyya, J.K., Vaidya, A.N., Chakrabarti, T., Devotta, S. and Akolkar, A.B. (2009). Assessment of the status of municipal solid waste management in metro cities, state capitals, class I cities, and class II towns in India: An insight. *Waste Manage*, **29:** 883–895.

Kumar, K.N. and Goel, S. (2009). Characterization of municipal solid waste (MSW) and a proposed management plan for Kharagpur, West Bengal, India. *Resour Conserv Recycl*, **53:** 166–174.

Macbeth, H. and Collins, P. (2002). Human population dynamics: cross-disciplinary perspectives. Cambridge University Press.

MOEF (Ministry of Environment and Forests) (2016). The Gazette of India. Municipal solid waste (Management and Handling) Rules, New Delhi, India.

Ministry of Housing and Urban Poverty Alleviation (2007). National Urban Housing and Habitat Policy 2007. Ministry of Housing and Urban Poverty Alleviation, Govt. of India, New Delhi. Available from: http://www.credai.com/Others_events/HousingPolicy/HousingPolicy2007.pdf.

Muttur, R. (2008). Performance of Urban India during Globalization Period: An Economic Analysis. Discussion Paper Series. Centre for International Research on the Japanese Economy, University of Tokyo, Japan and Institute for Social and Economic Change, Bangalore, India. Available from: http://www.e.u-tokyo.ac.jp/cirje/research/dp/2008/2008cf543.pdf.

Narayan, T. (2008). Municipal solid waste management in India: From waste disposal to recovery of resources? *Waste Manage*, **29:** 1163–1166.

Parvathamma, G.I. (2014). An analytical study on problems and policies of solid waste management in India: special reference to Bangalore city. J. Environ. Sci. Toxicol. Food Technol. **8:** 6–15.

Planning Commission. (2014). Report of the task Force on waste to energy (Vol. I) in the context of integrated municipal solid waste management. Planning Commission Government of India. See http://planningcommission.nic.in/reports/genrep/rep_wte1205.pdf

Planning Commission. (2008). Eleventh Five Year Plan (2007–2012) Agriculture, Rural Development, Industry, Services and Physical Infrastructure, Vol. III, Planning Commission Government of India. Oxford University Press, New Delhi, 451p.

Rana, P.R., Yadav, D., Ayub, S. and Siddiqui, A.A. (2014). Status and challenges in solid waste management: A case study of Aligarh city. *J Civil Eng Environ Technol*, **1:** 19–24.

Rawat, M., Ramanathan, A.L. and Kuriakose, T. (2013). Characterization of municipal solid waste compost from selected Indian cities: A case study for its sustainable utilization. *Environ Protect*, **4:** 163–171.

Sharholy, M., Ahmed, K., Mahmood, G. and Trivedi, R.C. (2008). Municipal solid waste management in Indian cities: A review. *Waste Manage*, **28:** 459–476.

Singhal, S. and Pandey, S. (2001) Solid waste management in India: status and future directions. *TERI Inf. Monitor Environ Sci.* **6:** 1–4.

Chapter 7
Environmentally Sustainable Practices

Rishin Basu Roy

1 Introduction

Modern day living is characterised by comfort, ease and subsequent dependency on technology. Technology is now the key for a happy living although it has raised the cost of living beyond affordability for a major share of the population. It has also cast an inadvertent pressure on nature, as evident from the drastic changes in climate observed in recent times. Under such dire circumstances, a strong need has been felt to revert back to the sustainable ways of living that was in practise in ancient and medieval times. Centuries ago, man had designed and implemented strategies for efficient rainwater harvesting, cooling of buildings, environmentally sustainable practices as well as architectural wonders based on simple human knowledge without any technology-based solution that is available for the same today. This chapter provides a detailed discussion of various human designed, technology independent, self-sustainable lifestyle practices widely reported in both Indian and global architectural history, and also recommends many simple yet long ignored and forgotten techniques of engineering used by man in earlier times for pursuing sustainable living.

R. B. Roy (✉)
Department of Environmental Science, University of Calcutta, Kolkata, West Bengal India

Nature Mates Nature Club, Kolkata, West Bengal India

Svasara Jungle Resorts, Tadoba, Maharashtra India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_7

2 Ancient Ways of Rainwater Harvesting

2.1 Indian Perspective

India has been the pioneer of various sustainable practices that was eventually widely accepted across the world. Ample historical facts recorded in journals and documentaries on indigenous practices related to sustainable rainwater harvesting suggest that India was pioneer in devising techniques for the same. According to historical records, droughts and floods had been a regular phenomenon in ancient India that had triggered the people to engineer different techniques for rainwater harvesting in keeping with the unique geography of their regions.

In present times, Indian states are dependent upon technological support for extraction of surface water and groundwater (Kannan, 2011). However, instances of architectural skills and innovative techniques of India's cultural heritage have been evident in the drainage systems prevalent in the Indus valley civilisation, the Dholavira settlement as well as the sophisticated harvesting systems of Sringaverapurain, Allahabad where the natural land slope was used for storing flood water of river Ganga (Pal, 2016). Apart from the ancient Indian constructions for storing rainwater, traditional techniques had been applied for building unique water conservation systems in India much before the need for taking active initiatives for mitigating climate change had been felt.

In eastern India, most of the rural households have small ponds attached to the houses. These ponds store rain water which is used for all household activities. This pond not only serves the houses but has played an important role in recharging the aquifers as well.

The Jhalara stepwells in Jodhpur, Rajasthan, dating back to 1660 AD, has a rectangular shape with tiered steps on its four sides and has been utilised for collection of the seepage of the upstream reservoir for ensuring regular water supply for the entire community (Pal, 2016). Rajasthan has also used stepwells, for storing water by diverting the scanty rainfall received in this area to percolate to underground man-made tanks. Layered steps were part of the architectural design intended to minimise the water loss from evaporation considering the geographical peculiarity of Rajasthan. There are also *bandhis* or *talabs* that are types of reservoirs on ponds or lakes in Udaipur, India, meant for storing water for household consumption (Pal, 2016). Ancient Indian practices of rainwater harvesting also included indigenous designs of cylindrically paved pits (*tankas*) for storage of rainwater running down from the rooftops and courtyards for saving families from the pain of fetching water from far off sources (Pal, 2016). Step wells and old tanks of villages and rural areas have become a part of mainstream discussion from the time Indian cities have been experiencing water scarcity. Images of some of the step wells and village wells from different parts of western India have been shown in Fig. 7.1.

These step wells were seen where the day temperatures were found to soar high. These structures were also places of social gathering especially for women in ancient India. This community access has also played a silent role in shaping up the community by becoming a point of social interaction (The Hindu, 2018). *Chand Baori* of Jaipur, Rajasthan is also a place of tourist attraction. Therefore, apart from

Fig. 7.1 Picture showing (A) Vadodara stepwells in Gujarat [*Source*: C.P.R. Environmental Education Centre, Chennai, 2017]; (B) Abhaneri stepwell, Jaipur [*Source*: Jaipur tourism, 2020]; (C) Dada Harir Vav, Ahmedabad [*Source*: C.P.R. Environmental Education Centre, Chennai, 2017] and (D) Badlapur stepwell, Maharashtra. *Source*: Ashutosh, 2016

the usual ecosystem services, these stepwells also provide economic benefits in today's life.

2.2 Global Perspective

Capturing and storage of rainwater in deep pits or boreholes was also practiced in Mexico City (Rochat, 2020). There are ruins of sites where percolated water from underground was stored after the rains and later used for domestic purposes during long-term water shortage. Rome had also been a pioneer for many techniques of rainwater harvesting such as rooftop rainwater collection which did not require electric pumps or distillation processes (Rochat, 2020).Techniques of storing rainwater in detention basins constructed underground were also prevalent in Sri Lanka that served the purpose of making freshwater resources available for community use.

The examples of the unique systems and architectural forms prevalent in India and other countries are evidences of the skills and self-sustainability of human-made buildings achieved without dependence on technology. This established the fact that ancient cultural and traditional practices had produced many such innovative systems for rainwater harvesting without the help of advanced technologies.

3 Architectural Structure

3.1 Indian Perspective

The architectural history of India is as old as any other civilisation in the world. India has set the foreground for many kinds of techniques for construction and design of buildings that has paved the path for eventual achievement of architectural genius. The remains of architectural wonders in India can be dated back to the Harappan and Indus valley civilisations. The architectural remains are mainly of the famous rock cut structural designs of the *viharas* (Buddhist temple or monastery), *chaityas* (Buddhist or Jain shrine) or other religious edifices (Cultural India, 2020). It also suggested that the architectural design of the buildings had been inspired by ethnic, climatic, historical or geographic diversity as well as religious practices and beliefs. Accuracy of measurements and the architectural genius of the workers and designers are considered as the pillars of strength for these rock-cut structures. The Mahabalipuram *rathas* (chariots) are also astounding specimens of the rock-cut architecture developed in India (Cultural India, 2020).

Another architectural style developed in India has been that of caves and temples. Ancient architectural practices carried out in the third century BC in India have produced some of the finest architectures carved out of cave rocks. The Ajanta and Ellora caves are globally recognised as examples of best cave arts present in India (TOI, 2019).

The temple architecture in India has mainly been related to the Hindu architecture and therefore depicts their religious beliefs and practices. Architectural remains from the Gupta period exhibit buildings usually made from a single piece of rock that was strong enough to sustain any natural calamity (Cartwright, 2015). The design, materials and rocks used for construction establish the architectural wonder for the onlookers. The design and architectural set up of the temples, caves or rock-cut structures are existential proof of the efficiency of designing and artisanship that has faded away with the greater dependency on technology and loss of architectural ingenuity observed in present times.

3.2 Global Perspectives

Instances of highly impressive ancient structures present across this planet bear evidences of hard work and architectural ingenuity that make these structures withstand the damages of time. Such impressive structures, such as the Great Pyramid of Giza possess genius design and its strength is of great mystery and appreciation. Bolivia's ruined city of Tiahuanacu and Egypt's Elephantine Island are also considered as examples of resistant structures that have sustained natural calamities and have been impervious to the ravages of time. The Conical Tower in Zimbabwe; Achaemenid Tombs, Ishtar Gate in Iran; Temple of Amun Ra, Step Pyramid of

Zoser in Egypt are other examples of architectural masterpieces that cannot be perceived at present times in spite of having access to the most advanced technologies. There are several other examples of such architectural masterpieces that have stood the test of time and are evidence of millions of hours of hard work and genius of designing that went into their making.

4 Regulation of Temperature and Humidity in Buildings

4.1 Indian Perspective

The ancient Indian architectural designs can be of great learning for contemporary buildings in terms of cooling facilities (Glass and Webster, 2012). Modern need for convenience and comfort had led to the discovery of air conditioner and coolers. However, dependence on modern technology for such comfort has also pressurized nature as evident from the successive debates on climate change and global warming. Located in a subtropical region, India has always been a comparatively hotter place than many of its neighbouring nations. The point of deliberation here is of analysing how buildings were kept cool in the ancient period or before air conditioning came into use.

The answer to this question lies in the low technology architectural genius used in its simplest form for controlling the ambient temperature of buildings constructed during ancient and medieval times. One of the most significant ways of controlling building temperature had been the ancient practice of stepwell architecture (Glass and Webster, 2012). The step well or '*baoli*' was seen to be an integral part of the inner design of the buildings. These wells had steps running up to the ground level. When the water stored in these wells evaporated due to excessive heating, the temperature of the building was brought down. This was the fundamental technique of controlling temperature of buildings by using a simple and natural philosophy as well as basic design and engineering.

Many other systems of passive cooling independent of power consumption were also prevalent in ancient India. Buildings were raised on pillars above the ground in order to create shaded and airy pavilions (Glass and Webster, 2012). For creating a thermal blank (to release hot air as temperature drops), heat absorbing raw materials were used for construction. The issue with modern construction process is that people want their buildings to be constructed at low cost and in less time and therefore is excessively dependent on modern technology. Moreover, such simple designs and techniques have been forgotten and ignored. Centuries ago, *jaali* (latticed screens) was used in buildings for screening the excessive sunlight which also exhibited static technique of cooling in an environmentally sustainable manner (Alothman, 2017). The *zafris* or the wall ventilators and the windows also played an important role in this process. Different instances of such cooling structures have been shown in Fig. 7.2.

4.2 Global Perspective

Techniques similar to Indian cooling systems discussed above were also practiced in ancient Egypt. In Egypt, it was found that pillars present in buildings were thick enough to make the buildings take longer time to absorb heat, keeping the same cooler for a longer period of time. A small pool was usually housed inside every building for allowing the heat to escape by evaporation of the water as a technique of passive cooling. This was also the technique used in the construction of the famous bathhouses in Rome, which were an essential part of the community houses. In Mexico, humidity was controlled by making air pockets in the buildings that facilitated natural ventilation through the process of convection. The Japanese had developed another ingenious technique for keeping themselves secured from the excess sunlight and heat. They constructed underground pit houses or sunken houses that naturally regulated the temperature of the dwellings and protected the residents from excessive summer heat.

Fig. 7.2 (A, B) Zafris/wall ventilators; (C) window along with the wall ventilators and (D) wall size windows

5 Traditional Water-Cooling Systems

5.1 Indian Perspective

Without using mechanised cooling systems, architects had demonstrated creativity in water-cooling in ancient times. Evaluation of Indian history shows that design innovation had taken place a thousand years before technology occupied the greater part of human life. Indian history of mechanical architecture reveals that contemporary people had devised cooling systems by natural means with zero energy consumption. For ensuring environmental sustainability, water cooling concepts had been developed on the basis of the structure of stepwells almost 1500 years ago. Award-winning architect Manit Rastogi opined that *Baoli*, the Hindi word for stepwell had been coined thousands of years ago before people had even perceived technological solutions for water cooling systems. One of the classical examples of the in-house *Baoli* is present at Patan, Gujarat, India. This *Baoli* is famous by the name of *Rani Ki Vav* (Fig. 7.3).

Manit Rastogi has described an ancient traditional water-cooling system where the entire building is raised above the ground and the hollowed out underbelly forms natural thermal sinks. Water bodies were recharged by the help of recycled water through sewage treatment and in turn facilitated microclimate cooling. The material used for stabilising water bodies for achieving natural cooling are a mixture of local stone, glass, steel and concrete. Energy efficiency had been the prime concern of this process whereby water cooling was achieved without hampering environmental sustainability. Before technological innovation, natural processes used had provided environmental sustainability and incurred very low possibilities of pollution. For example, cooling water using a big clay pot has been a popular practice in many rural households in different parts of India. It is now being wondered why such approaches have been substituted by applications of modern technology which in turn has caused loads of diseases and disasters in human life. It may be assumed that people having access to technology have ignored environment for their own needs and become responsible for their destruction in the modern age.

5.2 Global Perspective

In the global context, similarities have been found in the water-cooling systems widely implemented in ancient India. The stepwell concept was innovated by the Egyptians nearly two thousand years ago. Application of direct cooling system by water evaporation in the desert areas of the United Arab Emirates is evident from historical records. Also according to historical records,'*Uchimizu*' has been one of the traditional water cooling techniques of Japan, that is practiced till date since the seventeenth century. Houses, temples and gardens of Japan are still sprinkled with water to cool the surfaces using this traditional technique (Solcerova et al., 2017).

Fig. 7.3 *Rani Ki Vav* stepwell at Patan, India. *Source*: Britannica Encyclopaedia, 2020

This Japanese water-cooling system shows that they had measured the temperature of the ground and designed big holes for obtaining cool groundwater for everyday use. Evaporation based water cooling systems were also used in Germany to distribute chilled water to the local people. On examining the traditional water-cooling systems utilised across the globe, it has been revealed that, contemporary architecture and design had provided efficient strategies for humans to carry out their activities without hampering the environment prior to development of technological advances.

6 Daily Livelihood Practices

6.1 Indian Perspective

Culture is the mirror of the society that reflects the livelihood of the people and their activity. Indian culture has been quite different from others wherein rituals flourish with inner thoughts. Traditional Indian culture never harmed the environment and the natural ecosystems. Rituals practised reveal their closeness to the environment. In south Indian culture, *rangoli* (traditional Indian decoration and patterns made with ground rice) designs drawn in front of every house are usually inspired by nature and indicates the virtue of cleanliness, which in turn is linked with proper hygiene. From the environmental point of view, the creation of *rangoli* in the house provides food for insects such as ants. The use of *panchgavya* (mixture of five cow products: dung, urine, milk, curd and clarified butter), copper vessels and *agnihotra* (a process of purifying the atmosphere through a specially prepared fire) highlight the underlying scientific reason behind these techniques. The practices of waking up early and finishing work within the day light period was a healthy, energy efficient way of life practiced in ancient times and had beneficial effect on both physical and mental health.

In *Santi-parva* of *Mahabharatam* (Chapter 184), there are mentions of some uses of home remedies, which have been actually established as efficient treatment for several diseases and infections. *Surya-pranam* (Salute to the Sun) is a practice in yoga indicating that morning exercises has been a regular ritual in Indian history. People of Varanasi used to pray to their God very early in the morning in front of the riverbank. These exercises have been found to increase the awareness of the body and the patterns in which muscles are engaged, making exercise more beneficial and safer.

In ancient buildings, air circulation and light were major concerns. For this, most of the buildings had big windows in east-west direction for light and north-south direction for ventilation and wind circulation. Cross-ventilation was a must in the ancient structures. One of the classical examples of this is from Kerala—the *Nalukettu* houses (Fig. 7.4). Typically, this was a four-block house supporting joint family structure. It used to have courtyard at the centre with four blocks at the north, south, east and west of the courtyard. This old heritage house is now making a comeback in recent constructions.

6.2 Global Perspectives

Livelihood perspectives have always been considered as a major aspect of rural development. In countries such as the United Kingdom, Australia and the United States, the conceptual root has been shaped with different collective forms by the influence of modernity. A number of core challenges have been identified as the major facets of the changing livelihood patterns observed in the modern world. Diverse cultural practices in a single area have created cultural challenges. However, some perspectives have not changed in the United Kingdom and the United States since the seventeenth century. Basic food habits and style of clothing are still followed in many of the urban and rural areas. These practices show that inspite of external influences, core practices of traditional culture are still pursued by the people. Such activities have dominated development and thinking for many decades. On evaluating the culture and livelihood of eastern countries, it is understood that culture has been handed down from one generation to another and its impact has remained strong in the minds of the people.

Fig. 7.4 A Nalukettu house of Kerala. *Source*: The Hindu, 2017

7 Environmentally Sustainable Practices

7.1 Indian Perspective

Archaeology of the Indus Valley Civilisation is the blueprint of ancient environmental sustainability practices carried out in Indian culture. Instances of traditional practices carried out in India for ensuring environmental sustainability are evident in the ancient Vedic period as well. Protection of flora and fauna had been a major aspect of ancient India as these elements were worshipped as God. Indian mythology portrays many Hindu gods and goddesses to possess particular animals or birds as their *vahana* (mode of transport). Therefore, wildlife protection was ensured through the strong religious association of the people with the concerned animals. The feeling of sacredness attached to wildlife has helped in conserving ecological balance. Association of snake with Lord Shiva is an instance of ancient belief that helps to protect wildlife.

In Indian culture, many trees are also worshipped as divine entities. People have strong faith on the life of plants that form a part of their daily worship. An example of this practice is the consideration of cactus in ancient India as Goddess *Manasa* (Goddess of snakes). *Tulsi* (Holy basil) or *Vrinda* is another sacred plant in Hindu belief. Hindus regard this plant as the avatar of Lakshmi, and thus the consort of the God Vishnu. Jain environmentalism is largely based on spirituality and guided by non-violence. In Jainism, the welfare of human and wildlife is of major concern. Many teachings of Buddhism also preach protection of wildlife as thankfulness to

God. Therefore, we can observe that environmental sustainability practices were prevalent in cultures of ancient India.

In the evaluation of modern India, sustainability is a major aspect of environmental protection. People of the modern age are using different types of initiatives to mitigate environmental pollution. The industrial revolution, which began in the eighteenth century had changed the society, introduced the practice of waste management and recycling and helped reduce the negative impacts of environmental pollution. The most emerging fact is that political ideologies have been used to reduce the adverse impact of environmental pollution. The most significant factor is to identify whether the process is suitable for providing environmental sustainability. In India, tree plantation is used as a part of the five-year evaluation plans for maintaining environmental sustainability through reduction of environmental pollution. The modernity of India shows that public concern has been raised through several campaigns for protection of wildlife. The procedure has a positive impact on environmental sustainability. Moreover, it has been evident that after the fourth industrial revolution, excessive exploration has created some major issues in the environment. Greenhouse gas emission is the major concern for India which can be reduced simply by afforestation and waste recycling. Maintenance of ecological balance has also become a major concern in the modern world that has been addressed by the implementation of several 'lean management' processes in the industrial areas of India. Political involvement has been evident from the fact that several bills have been passed by the Indian government for ensuring sustainable environmental management process.

7.2 Global Perspective

In the ancient culture of Greece, plant, water and wildlife were considered as divine entities. Similarly, the history of Spain reveals that naval crew and passengers carried cats with them as a sign of good hope. They worshipped cat as a representative of the Goddess of Sea. Evaluation of American culture also revealed that people believed wildlife and plants to be gifts from God. These believes helped maintain environmental sustainability based on religious faith.

8 Conclusion

The discussion presented in this chapter on rainwater harvesting, architectural structure, water cooling system, daily livelihood and environmentally sustainable practices of ancient India and other countries may be reimplemented in modern times with a blend of modern technology for conserving the dwindling natural resources, minimising the adverse impact of climate change and attaining sustainable development.

References

Alothman, H. (2017). An evaluative and critical study of Mashrabiya in contemporary architecture. A thesis submitted to the Graduate School of Applied Sciences of Near East University.

Ashutosh (2016). Badlapur Stepwell—A rare historical site. https://bijoor.me/2016/06/25/badlapur-step-well-a-rare-historical-site/. Accessed 16 February 2020.

Britannia Encyclopaedia (2020). Rani Ki Vav stepwell, Patan, India. https://www.britannica.com/topic/Rani-ki-Vavon. Accessed 16 February 2020.

Cartwright, M. (2015). Gupta Architecture. https://www.ancient.eu/Gupta_Architecture/. Accessed 16 February 2020.

C.P.R. Environmental Education Centre, Chennai (2017). http://www.cpreecenvis.nic.in/Database/Stepwells in Gujarat_3672.aspx. Accessed 16 February 2020.

Cultural India (2020). Panch Rathas at Mahabalipuram. https://www.cultural india.net/monuments/mahabalipuram-rathas.html. Accessed 16 February 2020.

Glass, N. and Webster, G. (2012). Ancient 'air-conditioning' cools building sustainably. https://edition.cnn.com/2012/02/28/world/asia/ancient-air-conditioning-archi-tecture/index.html. Accessed 16 February 2020.

Jaipur tourism (2020). https://jaipurtourism.co.in/chand-baori-abhaneri-step-well-jaipur. Accessed 16 February 2020.

Kannan, S. (2011). The technology of saving India's precious water supply. BBC News, Delhi. https://www.bbc.com/news/business-14847808. Accessed 16 February 2020.

Pal, S. (2016). Modern India Can Learn a Lot from these 20 Traditional Water Conservation Systems. https://www.thebetterindia.com/61757/traditional-water-conserv-ation-systems-india/. Accessed 16 February 2020.

Rochat, E. (2020). The History of Rainwater Harvesting. https://4perfectwater.com/blog/the-history-of-rainwater-harvesting/. Accessed 16 February 2020.

Solcerova, A., Emmerik, T., Hilgersom, K., Ven, F. and Giesen, N. (2017). How cool is Uchimizu? *Geophys Res Abstr*, **19:** EGU2017-5006.

The Hindu (2017). Heritage history: The Nalukettu houses of Kerala. https://www.thehindu.com/real-estate/heritage-history-the-nalukettu-houses-of-kerala/article19239576.ece. Accessed 16 February 2020.

The Hindu (2018). Create safe social spaces for women to interact. https://www.thehindu.com/news/cities/Madurai/create-safe-social-spaces-for-women-to-interact/article25630746.ece. Accessed 16 February 2020.

TOI (Times of India) (2019). Ajanta and Ellora Caves—facts you should know before visiting. https://timesofindia.indiatimes.com/travel/destinations/ajanta-andellora-cavesfacts-you-should-know-before-visiting/as70205380.cms. Accessed 16 February 2020.

Chapter 8
Energy Conservation and Its Impact on Climate Change

Arindam Dutta

1 Introduction

On a global scale, anthropogenic factors contribute maximum towards greenhouse gas emissions from the energy usage, two-thirds of which are from burning of fossil fuels for energy to be used for heating, electricity, transport and industry. Our energy generation capacity and energy demand can be affected by climate change. For instance, alterations to the water cycle have consequences on hydropower and increase in temperature has a direct effect on the energy demand for cooling during the summer season, while reducing the need for heating during winter. The greenhouse effect permits solar energy to penetrate the earth's atmosphere and then partially traps that as heat energy. This process has maintained global temperatures, on the earth, at a relatively stable scale—currently an average of 60°F (33 °C) and makes it possible for human populations to survive on this planet. However, release of CO_2 by industry and automobile, other gases such as methane traced from burning of fossil fuel and other human endeavours for industrialisation increase the heat enmeshment processes and thereby gradually escalating average worldwide temperatures.

Considering the aftermath of global warming, the United Nations summoned a series of international meetings to discuss and find a plausible solution to bring down the earth's temperature. Consequently, an international agreement termed as Kyoto Protocol has evolved. According to the treaty, a pact was formed by most of the nations, wherein they agreed to bring down their greenhouse gas (GHG) emissions by 5–8% below the 1990 levels. The United States and Australia backed out from participating in this mandatory reduction formula (however, Australia joined later). For Russia, no further upsurge in emission was allowed. Since China and India were developing economies, no emission reduction was mandated during the

A. Dutta (✉)
Department of Energy Management, Indian Institute of Social Welfare and Business Management, Kolkata, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_8

period 2008–2012. As per the treaty, each member country is assigned a cap or quota (in tons of CO_2) for emission, which must be limited within the stipulated quota. Otherwise, a country with higher emission than the permissible limit, can purchase credits from a country that has lower than the assigned quota of emission (called the cap-and-trade policy).

Paris Agreement in 2015 paved the way to build up measures to curb the climate change worldwide. The first ever of its kind, this agreement universally and legally bound 195 countries, which adopted it. It was agreed upon, in this meeting, to keep the global average temperature rise to well below 2 °C, while aiming for 1.5 °C, which was not possible to be reached without a major remodelling of the global energy production and consumption structure. To its support, European Union (EU) came up and set climate and energy targets for 2020 and proposed targets for 2030 as part of its overall efforts to move to a low-carbon economy and to bring down greenhouse gas emissions by 80–95 % by 2050. The first phase of climate and energy targets for 2020 includes a 20% cut in GHG emissions (compared with 1990 levels), 20% of energy consumption coming from renewable and a 20% improvement by increasing energy efficiency/process. Based on the current proposals being discussed in EU institutions, the next look out of 2030 boosts these targets to a 40% reduction in emissions, 27% of energy coming from renewable sources and a 27% by improving the energy process (or 30%, as proposed by the European Commission afterwards) compared with that of the set standard.

2 Environmental Issues

The three important global pollution problems, which are most referred to are as follows:

(i) Acid rain
(ii) Stratospheric ozone depletion
(iii) Climate change

2.1 Acid Rain

Acid is produced by boiler, furnace and transport vehicles through the combustion of fossil fuels. The acid rain is mainly caused by SO_2 and NO_x generation. The effects of this kind of precipitation are acidification of lakes and groundwater. Figure 8.1 schematically represents the process of acid rain. Major sources of acid rain include energy related activities. For instance, electric power generation for household heating and cooling adds up to 80% SO_2 emission whereas road transport itself is responsible for 48% NO generation (Anon, 1989). Other sources of acid rain are fossil fuel combustion and volatile organic compounds (VOCs). Probable

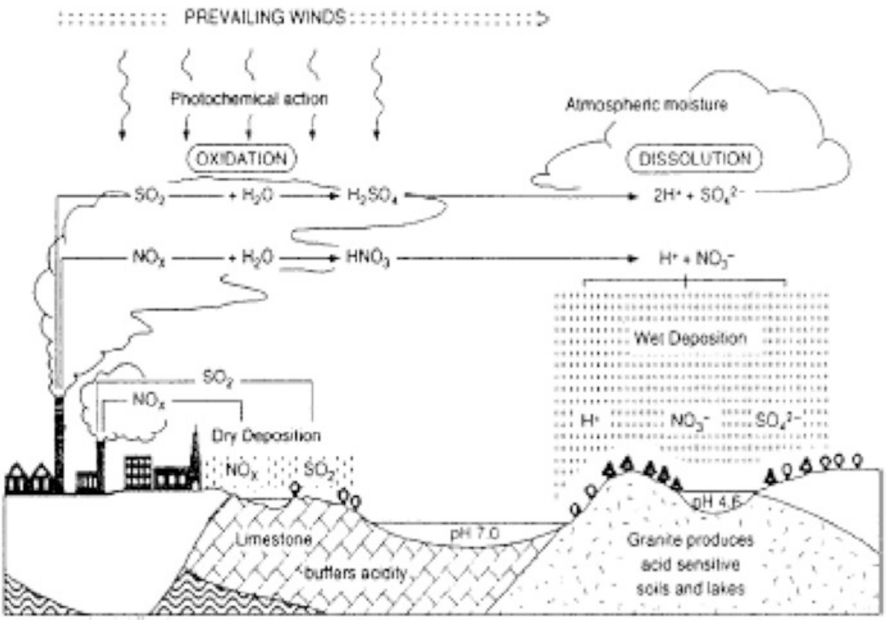

Fig. 8.1 Acid rain process.
Source: Perman et al., 1996

method to curtail acid rain is cleaning of coal, use of fluidised bed technology and opting for more renewable energy. In case of road transport promoting efficient and economical public transport or promoting energy efficient hybrid/electric car is the effective answer to reduce greenhouse gas emissions.

2.2 *Stratospheric Ozone Depletion*

Ozone is present in atmosphere roughly between altitudes of 12 km and 15 km. This layer absorbs ultraviolet radiation and infrared radiation and is depleted by the emissions of chlorofluorocarbons (CFCs), halons and N_2O. The scaled up ultraviolet radiation due to the depletion of ozone in stratosphere leads to skin cancer, eye damage and other derogatory effect on many biological species. Energy-related activities such as fossil fuel and biomass combustion accounts for 60% to 70% N_2O emissions. CFCs, which are used in air-conditioning and refrigerator play a major role in ozone depletion. A process of ozone depletion has been shown in Fig. 8.2. Equipment and technology, which do not use CFC are now popular in industry. In most of the countries, a complete ban has been levied on the usage of CFCs and halons production.

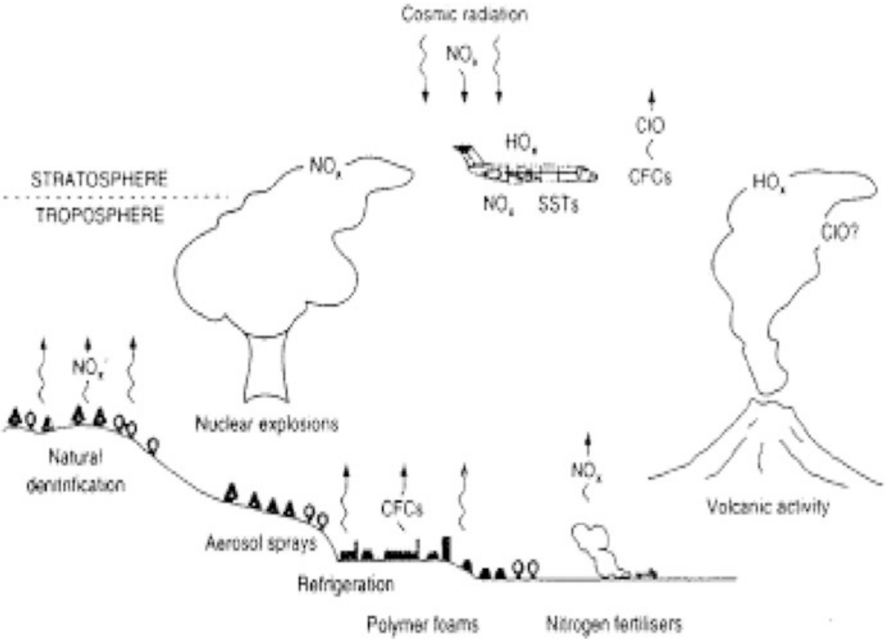

Fig. 8.2 Schematic representation of ozone depletion.
Source: Perman et al., 1996

2.3 Climate Change

The most crucial environmental problem due to energy usage is global warming or the greenhouse effect. Due to the energy utilisation, the greenhouse gases (such as CO_2, CH_4, CFCs, methane, N_2O, ozone etc.) are shooting up in a way that when these gases are entrapped within the earth's atmosphere, temperature of earth rises. Although CO_2 is the main culprit but methane is considered 20 times more harmful than CO_2, though its concentration in the atmosphere is low and due to lower density than air, migrates to the upper atmosphere. The major amount of CO_2 emission in the atmosphere owes its concentration to burning of fossil fuels. The IPCC of United Nations in 2014 established (with 95% certainty) that manmade generation of CO_2 is responsible for more than half of earth's temperature rise since 1951 (Intergovernmental Policy of Climate Change, 2014). Figure 8.3 depicts the pictorial representation of global warming or GHG generation. The earth's temperature increased by 0.6° C over the last decade and as a result sea level has been raised by approximately 20 cm (Colonbo, 1992). However, the long-term effect of global warming is very serious, which can be summarised as follows:

- The slow melting of the snow cover on the earth will adversely affect low-lying areas of the earth, by causing floods. This requires immediate attention because 100 million people of the world's population live within 3 ft of the mean sea level.

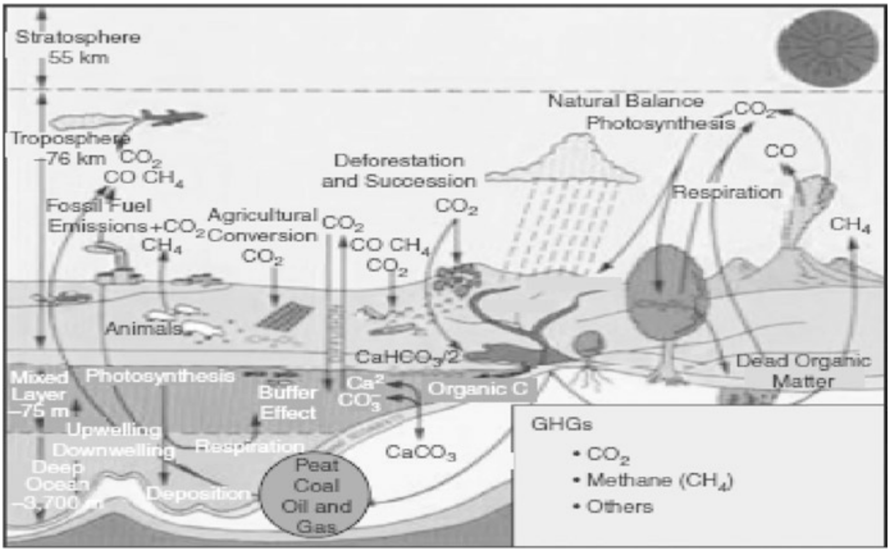

Fig. 8.3 Greenhouse gas (GHG) generation.
Source: Ulaby, 2006

- Severe droughts in tropical countries near the equator, such as Africa and India, will cause damage to vegetation and agriculture and will affect fresh water supplies.
- Cause more hurricanes, tornados, heavy rains and floods.
- Some animal species (such as polar bears, penguins and corals) will gradually become extinct.

All the energy intensive countries have taken measures to cut back their GHG emissions as per Paris Agreement. Most countries have taken initiative to generate more renewable energy to reduce emission. Government of India has announced a target of accelerating the overall renewable energy (RE) installed capacity from ~34 GW in 2015 to 175 GW by 2022, out of which 100 GW will be from solar energy (through National Solar Mission), 60 GW will be from wind energy (through National Wind Mission), 15 GW will be from other renewable energy such as from biomass (10 GW) and small hydro (5 GW). Other countries like China, Japan and USA have also taken drastic measures to scale down their GHG emissions. On the other hand, it is a fact that for renewable energy, one cannot control the time for which the sun shines or the wind blows hence the generation of energy from renewable source is variable. Some of the conservative grid operators and utilities consider power from renewable to be unmanageable. Another aspect is that the cost of generating renewable energy has fallen steeply during the past decade and it is estimated that within a few years, power generation from renewable energy will become cheaper than all possible sources of fossil fuels.

3 Energy—Key Factor of Climate Change

The link between the energy usage today and the earth's climate relies on the source of the energy. People use energy for different purposes such as heating, transportation, lighting, manufacturing, communication, and harvesting crops. Till today, the most common way of energy production is to burn fossil fuels like coal, oil and natural gas etc. Energy production and various process industries such as production of steel, ethylene, ammonia, pulp and paper etc. are primary emitters of GHG. Building sector is another major energy consumer in the world, which constitutes about 30–40% of world's total electrical energy. Figure 8.4 shows the distribution of carbon emission among the main emitters where it is found that China is responsible for 30%, followed by United States for 15% of the global emission. Most of the future increase in CO_2 emission is expected to come from rapidly developing countries like China and India.

Based on the total global GHG emissions of 2010 the percentage-wise breakup of GHG emissions depending on important economic activities are electricity and heat production (25%), agriculture and forestry (24%) industry (21%), and transportation (14%) (Fig. 8.5).

In the 21st Conference of the Parties (COP21) held in Paris in December 2015, more than 150 countries have participated and submitted pledges for around 90% global economic activity as well as that of global energy related CO_2 emissions.

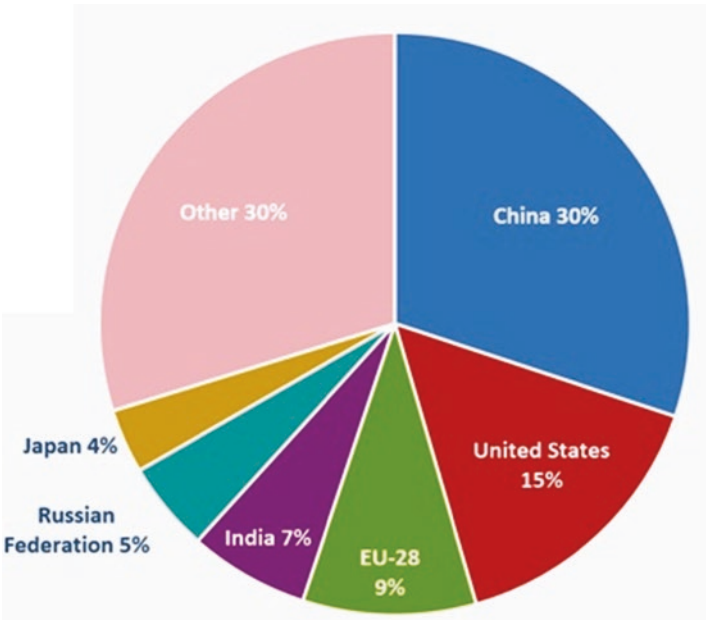

Fig. 8.4 Percentage of global CO_2emissions by country/region.
Source: Boden et al., 2017

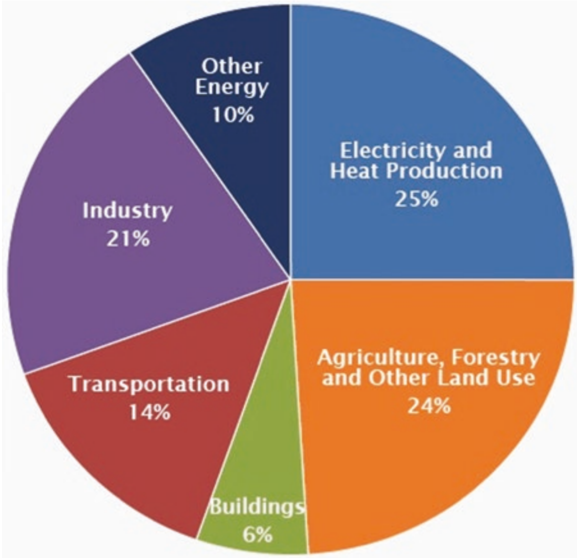

Fig. 8.5 Sector wise percentage of global CO_2 emissions. *Source*: **IPCC, 2014**

International Energy Agency (IEA) presented the summary of all the energy sector impacts of national climate pledges in the form of INDC (Intended Nationally Determined Contribution) (IEA, World Energy, 2015). They have submitted 125 INDC in total. Several pledges conditionally, at least partially, depend on financial support or other factors. All the INDC submissions (which cover 150 countries) include reportage of emissions by energy sector and many include recommendation to reduce that. The most common recommendations found are regarding energy renewable integration (40% of pledges) and improved efficiency in energy use (33% of submissions). Other measures which can bring down energy-related GHG emissions in the short term, such as reduction of inefficient coal power plants, lowering methane emissions from oil and gas production, fossil-fuel subsidy reform or carbon pricing are recommended in the INDCs of few countries. Some recommendations for energy use, which can serve to be helpful in the long run in transforming this sector such as nuclear power, carbon capture and storage, alternative vehicle fuels (advanced biofuels, electric vehicles etc.) are rarely found mentioned in the set targets. There are also several instances where an overall GHG target is mentioned within an INDC without proper specifications about the expected contribution of the energy sector vis-à-vis non-energy sector sources responsible for these emissions. One key instance is the contribution to GHG emission expected from land-use, land-use change and forestry which for some countries can be very significant. Total GHG emissions in the energy sector are estimated to be 42 Gt CO_2-eq in 2030 (Table 8.1). Countries responsible for more than half of global economic activity like the European Union, the United States, China, Japan, Korea etc., are expected to either see their energy-related GHG emissions plateau or be in declining phase by 2030. These climate measures aim to facilitate the necessary decoupling between

Table 8.1 Global energy CO_2 emission projected scenario as per INDC

	2014	*2020*	*2025*	*2030*
Energy-related GHG emissions	35.5	36.9	37.5	38.4
Process-related CO_2 emissions	2.8	3.2	3.4	3.5
Total	38.2	40.1	40.9	41.9

Source: World Energy, 2015

economic growth and energy-related GHG emissions—emissions per unit of economic output being 40% lower than today by 2030.

The IEA also estimated that energy sector needs to invest near about $14 trillion in energy efficiency and low-carbon technologies from 2015 to 2030, which is almost 40% of total energy sector investment for the full implementation of climate pledges**.** An estimated $8.3 trillion is needed to improve and facilitate energy efficiency in transport, buildings and industry sectors, while a great extent of the remaining investment is for decarbonising the power sector. It is estimated that in the power generation sector, more than 60% of total investment will be for generation of renewable energy, which is about $4.0 trillion. One-third of the investment will be for wind power, 30% for solar power which predominantly includes solar photovoltaic's and around one-fourth for hydropower.

4 Current Perspective of Climate Change

Analysis by World Energy points out that the endeavours taken in the INDC scenarios are not sufficient to push the global energy system onto a consistent pathway with the world's 2 °C climate goal. The IEA has therefore presented the Bridge Scenario in the Special Report on Energy and Climate Change (World Energy, 2015), which suggests how INDCs could be enhanced by taking other output oriented measures. The 'Bridge Scenario' proposes a collection of actions based on known technologies and policy measures that are already tested. They proposed that execution of step by step known methods can fix the temperature rise within 2 °C. The Bridge Scenario results in a peak in energy-related GHG emissions around 2020. In this context, IEA also highlighted that how just five energy sectors measures (based on proven technologies) could help to reduce energy-related GHG emissions, at a very negligible investment.

The proposed measures are to:

- Increase energy efficiency in the buildings, factories and industries, transport etc. sectors.
- Reduce rapidly less efficient coal-fired power plant and impose ban on their construction.
- Increase the investment in renewable energy sector to touch the set target of $400 billion in 2030.
- Reduce gradually the fossil-fuel subsidies to end-users by 2030.
- Reduce methane emissions from gas and oil production.

Table 8.2 Projected de-carbonisation through INDC and bridge scenario

Metric		*2014*	*2030* *INDC*	*Bridge*	*Unit*
Total energy sector	Energy and Process related green house gas emissions	38.2	41.9	35.8	Gt $CO_{2\text{-eq}}$
	Carbon intensity of primary energy supply	2.36	2.14	2.01	t CO_2/toe
	Energy intensity of GDP	0.176	0.127	0.120	toe/$1000
Power	CO_2 emissions per unit of electricity	518	382	306	g CO_2/kWh
Transport	New passenger cars: CO_2 emissions per vehicle-kilometre	155	110	90	g CO_2/v-km
	Carbon intensity of total transport fuel demand	2.9	2.7	2.7	t CO_2/toe
Buildings	Residential: energy demand per dwelling*	8,265	7,850	7,400	kWh/dwelling

* Exclude traditional use of solid biomass.
Abbreviation: toe= tonnes of oil equivalent, g CO_2/kWh= grams of CO_2 per kilowatt-hour, g CO_2/v-km= grams of CO_2 per/ vehicle-kilometre, t CO_2/toe= tonnes of CO_2 per tonnes of oil equivalent

Source: World Energy, 2015

Although several of the aforementioned measures are contained within few submitted INDCs, yet there is always a further scope to broaden the adoption target. An excess amount of $3 trillion (around 20%) of the total investment in energy efficiency and low-carbon technologies is needed up to 2030 in order to reflect the set ambition in the INDCs equal to that of the IEA's Bridge Strategy. Around 70% of the extra investment is needed for improving energy efficiency and almost 30% deployment is required in renewable sectors. Table 8.2 indicates the projected difference between INDC and Bridge Strategy in de-carbonisation of energy industry.

Advances in reducing energy-related GHG emissions must, ultimately, be permanent rather than temporary.The reorientation of the global energy system to one that is consistent with global climate goals is one of the main challenges observed by energy sector today. Case studies on GHG emission reduction in energy sectors are briefly discussed in the next section.

5 Illustrative Case Studies

The sustainable development of a society is possible through the provision of cogeneration/tri-generation rather than through separate processes for heat production and electricity generation. Rosen (1994) through his study proved that cogeneration can decrease the annual electricity consumption by as much as 30%. The annual fuel consumption and their related emission also can be reduced by 47%.

With regard to greenhouse gas emission reductions, one of the main contributions of the European Union's efforts is the Effort Sharing Decision. The decision sets an annual greenhouse gas emission target for all EU Member States for 2020. The decision covers sectors such as buildings, agriculture and waste, transport etc., which are responsible for around 55% of the EU's overall emissions. Within the system, companies can get or buy emission allowances, which they can trade with others. The companies emitting more than their allowances have to pay a huge fine. By putting a monetary value on carbon, the European Union creates incentives for companies to find the most cost-effective emission reduction and to invest in clean, low-carbon technologies. According to the literature review, emissions have decreased by 24% between 2005 and 2015 and at present they are just below the target set for 2020 (European Environment Agency, 2017). The decrease of GHG emissions were driven mainly by using soft coal like lignite and other fuels which emits less CO_2 and generation of more power from renewable sources.

As depicted in Fig. 8.5, the agriculture and forestry account for 24% of total GHG emissions. Irrigation is mainly responsible for GHG emissions in agricultural sector. The environmental impact caused by the use of diesel pump is often not known to people. The diesel-based irrigation pumps which are very popular in agro-based countries like India, result in the emission of an estimated 3.29 million metric tonnes of carbon. This amount of emission is responsible for approximately 1% of India's total carbon emission (Shah, 2009). All agricultural-based countries have taken various initiatives to shift from diesel or electric pump to solar pumps, which have a zero-carbon footprint. The Infrastructure Development Company Ltd. (IDCOL, 2015) in Bangladesh, has reached almost 3500 people by deploying 277 solar pump sets through water service entrepreneurship model in 2015. A farmer may use the solar pump for irrigating their own land as well as sell irrigation water to nearby poor farmers. Again, a group of 15-20 farmers may form an association and share the cost of a single irrigation pump that waters their fields. At present Government of Bangladesh is promoting solar-powered irrigation power pumps using a public-private partnership model. The Government aims to provide 50,000 solar pumps by 2025 through water service entrepreneurship model.

Building sector is also a source of large carbon emission and play a substantial role in climate change. Through a case study, Dutta et al. (2014) showed that by adopting programmable logic controller (PLC) – based automated shading, there is a provision to save 8% of cooling load and lowering the temperature by 1.5°C temperature in a government guest house building in India. The building has the shape of an inverted English alphabet, 'U' from the entrance point of view. The building has three wings and each of the wing consists of three floors. The authors have proposed moveable shading by venation blinds for east and west facades as the north and south facades are already in shaded zone. The moveable shading will be fully automated and will follow the sun path. The shading schedule has been calculated based on the solar radiation data and sun path diagram of that location. So, when the solar direct radiation is maximum then the venation blind will provide 90% shading and thereby reduce the cooling load of air conditioners and CO_2 emission.

6 Conclusion

Climate change is now a global problem and the main barrier to sustainable development of mankind. All countries are responsible for the causes and will also bear the brunt of the consequences of climate change. Currently, greenhouse gas emissions are approximately equally divided between developed and developing countries, but emissions by developing countries will increase rapidly in the near future. Energy conservation and their proper utilisation are not only an important step to reduce GHG emissions but also intimately related to sustainable development. To attain sustainable development for a society not only great efforts have to be given on use of renewable energy resources, but also a way to increase the energy efficiencies of the processes used. The root cause analysis of three main environmental issues such as acid rain, stratospheric ozone depletion, climate change and their ill effects have been discussed in this chapter. It has been seen that industrial revolution has done many good things but the effects of that to the environment is also dangerous. In this scenario, the 21st Conference of the Parties (COP21) held in Paris in December 2015 is a noteworthy step of mankind to try to save the mother earth. In that conference, near about 150 countries have participated and submitted pledges for around 90% global economic activity as well as that of global energy related CO_2 emissions. Though all the proposed recommendations for GHG reduction have not been implemented yet due to number of barriers like limited access to capital, lack of management attention, and insufficient availability of knowledge or qualified service providers. In this regard International Energy Agency has played an important role to ensure affordable and clean energy for its 30-member countries and beyond. They have presented the summary of all the energy sector impacts of national climate pledges in the form of INDC. Though the World Energy points out that the endeavours taken in the INDC Scenario are not sufficient to push the global energy system onto a consistent pathway with the world's 2 °C climate goal. The IEA therefore proposed 'Bridge Scenario', which is now followed by most of the countries to mitigate GHG emissions. The 'Bridge Scenario' proposes a collection of actions, drawing solely on known technologies and policy measures that are tried and tested to keep the earth's temperature increase within 2°C. The illustrative case studies described in the chapter give us an idea that irrespective of the developed and developing country, all are now trying to take notable actions to minimise the effect of environmental deterioration. Though there is a long way to go, stabilising carbon dioxide accumulations in the atmosphere at levels below 500 ppm will require drastic action to reduce emissions, implying major changes in global patterns of energy use and other policies to promote carbon reduction.

References

Anon (1989). Energy and the Environment: Policy Overview, International Energy Agency (IEA), Geneva.

Boden, T.A., Marland, G. and Andres, R.J. (2017). National CO_2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751–2014, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, doi: https://doi.org/10.3334/CDIAC/00001_V2017.

Colonbo, U. (1992). Development and the global environment. *In:* Hollander, J.M. (Ed.), The Energy-Environment Connection. Island Press, Washington, pp. 3–14.

Dutta, A., Samanta, A., Saha, S. and Biswas, J. (2014). Evaluation of impact of shading devices on energy consumption of buildings in tropical regions, *J Energy Resour Technol*, **136(2):** 024503.

European Environment Agency (2017). https://www.eea.europa.eu/signals signals-2017/articles/energy-and-climate-change. Accessed 15 December 2018.

IDCOL (Infrastructure Development Company Ltd.) (2015). IDCOL Solar Irrigation Projects. Presentation by Farzana Rahman, source: www.icimod.org/resource/17186.

IEA's World Energy Outlook Special Report on Energy and Climate Change (published in June 2015). Accessed 20 February 2018.

Intergovernmental Policy of Climate Change. https://www.ipcc.ch.Accessed March 2019.

IPCC (2014). Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Accessed 12 January2018.

Perman, R., Ma, Y. and McGilvray, J. (1996). Natural Resource and Environmental Economics, Longman, London.

Rosen, M.A. (1994). Assessment of various scenarios for utility-based cogeneration in Ontario. *Energy*, **19(1143):**9.

Shah, T. (2009). Climate change and groundwater: India's opportunities for mitigation and adaptation. *Environ Res Lett*, **4(035005):**13.

Ulaby, F.T. (2006). Global CHANGE: How radar connects to carbon economics, presented at the IEEE Proc. Editorial Board Presentation, Piscataway, 9 June.

Chapter 9
Issues, Dimensions and Approaches of Assessing Urban Water Security in Developing and Emerging Countries: An Inclusive Perspective

Subham Mukherjee, Trude Sundberg, and Brigitta Schütt

1 Introduction

Water security entails ensuring every citizen with the amount of quality water they need to safely live their everyday life (Narain, 2010). In urbanized areas, unrestricted population growth (Falkenmark and Widstrand, 1992; Ravell, 2014), poor governance (Bakker and Morinville, 2013; Biggs et al., 2013; Cook and Bakker, 2012) and mismanagement of the water supply system (Piesse, 2015) as well as social inequality (Blanca, 2016; Goff and Crow, 2014; Jepson et al., 2017) are among the factors that cause and influence water insecurity. In addition, superordinate physical processes like effects of climate change accelerate the insecurity of water (Bar and Stang, 2016; Turral et al., 2011). Overall, urban water security (UWS) can be conceptualized as being the result of socio-economic activities in metropolitan, urban and sub-urban areas (Grey and Sadoff, 2007).

This chapter focuses on challenges of urban water insecurity in emerging countries. These countries frequently are subject to a dearth of financial potential to mitigate water-related problems. Water security is one of the most concerning topics in these countries, and already disadvantaged parts of the population are disproportionately affected (Obani and Gupta, 2016; Pahl-Wostl et al., 2016). However, due to a range of constraints, including economic conditions and socio-political circumstances, accomplishing urban water security status is not given the priority it merits in most emerging countries (Pahl-Wostl et al., 2016).

S. Mukherjee (✉) · B. Schütt
Institute of Geographical Sciences, Physical Geography, Freie Universität Berlin, Berlin, Germany
e-mail: subham.m@fu-berlin.de; brigitta.schuett@fu-berlin.de

T. Sundberg
School of Social Policy, Sociology and Social Research (SSPSSR), University of Kent, Kent, UK
e-mail: t.sundberg@kent.ac.uk

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_9

Rapid and continuous changes dominated by the economic part of the development are forming new urban geographies in emerging countries. As a result, new geographies are created on top of old, colonial geographic areas for the production and consumption of the resources. These economic developments are leading to spatial and social inequalities and increase water insecurity as well as environmental problems such as pollution and waste management. The rising pressures and issues in water security signify that urban environmental problems are becoming critical to manage.

This chapter reviews different practices to evaluate the UWS as they relate to concepts of sustainability. We also review in what ways water insecurity is related to societal issues in emerging countries. Quantification of UWS is the heart of any water management approach (Mukherjee et al., 2018). This chapter forms part of a growing body of quantitative approaches to analyse water security. Addressing the lack of research taking a holistic approach by including physical and social, economic and political factors, this chapter outlines an assessment framework of water insecurity in urban areas that considers all related disciplines and their interrelationships. A conceptual model is provided that encompasses the complexity of the interrelated issues associated with UWS. Incorporating socio-economic indicators in its proposed quantitative framework intends to achieve a holistic measurement model. The chapter starts out with a discussion on the UWS and the environmental sustainability issues of the cities in emerging countries. The next sections discuss the various dimensions, approaches and indicators used in similar studies. Finally, the chapter proposes a comprehensive framework for measuring and evaluating the status of UWS, particularly for emerging countries.

2 Issues Of Urban Water Security

There is no universally accepted definition of water security. All the current definitions make use of different approaches to measure water security based on different sets of goals, such as 'water supply security' (e.g. Lundqvist et al., 2003; Padowski et al., 2016; Grafton, 2017), 'urban water sustainability' (Yang et al., 2016) etc. (see Appendix 1 for definitions of water security). Even though the definitions differ, there are a few common factors which are integrated in all of them, such as safeguarding clean and adequate water accessibility, minimizing water-related threats and implementing policies for governing the water as a vital resource. Adequacy of water and sanitation is the priority in an equity-based goal of human prosperity and financial improvement, to guarantee security against water-borne contamination and water-related catastrophes, and, maintaining ecosystem services (Brears, 2017).

Over the past decades, definitions of water security have shifted from a focus on human livelihood and its involvement in the physical water management to its engagement with the ecosystem (Appendix 1). Water security has become a main factor in social, political, public health, economic, environmental and other concerns—and acts as a central link between them (Lundqvist et al., 2003). In consequence, we find that a range of core issues is required to be addressed in order to achieve and maintain water security in different geographic scales and contexts. When it comes to research on water security in urban areas, the main issues considered in previous studies include:

- *Supply* of enough water for socio-economic development and other different activity areas like energy, transport, industry, tourism etc.;
- *Equal and impartial access* to safe and enough drinking water at affordable costs to meet basic needs including sanitation and hygiene, and to maintain health and levels of well-being;
- Protection of *human rights* for safe access to adequate water *for all*;
- Preservation and protection of *ecosystems* in water allocation and management to maintain their ability to deliver and sustain functioning of essential ecosystem services including cultural ecosystem services;
- Collection and *treatment of waste water* for safeguarding human life and the environment from pollution;
- Collaborative approaches within and between countries to promote sustainability and cooperation for *transboundary (intra or inter states) water resources management*;
- Uncertainties and *risk management* for water-related hazards, such as floods, droughts and water-borne diseases within a given time duration and
- Good *governance and accountability*, appropriate and effective legal regimes, transparent, participatory institutions, properly planned, operated and maintained infrastructural facilities; and capacity development.

As can be seen from the above, researchers have approached water security from a range of angles, however we argue that as current pluralistic societies face many challenges studies analysing water insecurities should reflect these pluralities by applying comprehensive approaches to research. Water security in today's urbanized areas is driven by various environmental, economic, political and social forces. They form a complex system of closely coupled processes and feedback effects that are not yet sufficiently understood. Knowledge of these interactions is essential since the water as a resource is the base for all human activities. While seeking to achieve water security at a global scale, specific attention is required to analyse the aggregated effect of water management decisions and the effects at micro level. This is crucial for decision makers to consider as they seek to achieve the sustainable development goals (SDGs).

Water security is crucial to address in emerging countries. The highest number of people affected by water related risks in urban areas—such as scarcity of required quality water or exposure to meteorological hazards such as floods—are from emerging and developing countries (ADB, 2013; WHO, 2017). Moreover, almost 99% of the 3.4 million people lethally affected by water-related hazards are from the developing countries (WHO, 2008). Gaps between national and regional water policies and the absence of enough management plans are major causes for water insecurity in these countries. Issues include not having the necessary funding for the upkeep of water purification, distribution, and water extraction facilities, to reduce or mitigate the problems associated with waste water generation and related threats to downstream areas; approximately 1.1 billion people are affected by these issues (Watkins, 2006). Technical and managerial inefficiency in water-supply infrastructure which endangers quality issues related to water-environment sectors sculpts the symptoms of water insecurity in the urban areas of developing and emerging countries (Lundqvist et al., 2003; Mukherjee et al., 2018; Shaban and Sattar, 2011).

Securing water, for both society and environment, emphasizes the integrated management of water resources to maintain sustainable growth (Sarvajayakesavalu, 2015; Barbier and Burgess, 2017). SDGs elude to the multidimensionality and crucial importance of water security to achieve sustainable development and underlines the need for a holistic approach such as that presented here. SDG 6 calls particularly for clean water and sanitation for all people, paying special attention to the needs of women and girls and those in vulnerable situations (Goal 6.2) by supporting and strengthening the participation of local communities for improving water and sanitation management (Goal 6B). Other SDGs also include different water and sanitation targets, such as

- end of malaria and other water-borne diseases (Goal 3.3),
- reduction in number of deaths from water and other pollution and contamination related risks (Goals 3.9 and 6.3),
- proper management of water related disasters (Goal 11.5), chemical wastes to minimize the hazardous impacts on water (Goal 12.4),
- with the focus on protecting the poor and people in vulnerable situations (Goal 11.5) and
- conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services including wetlands (Goals 6.4 and 15.1).

Particularly focusing on urban areas, SDG 11 aims at ensuring the development of sustainable cities and communities by focusing on ensuring access to safe and affordable housing, upgrading slum settlements, investing in public transport, creating green public spaces, and improving urban planning and management in a way that is both participatory and inclusive. Heading for 'urban water security' faces complex relations inside and amongst the human and water relationship in urban areas, including a high spatiotemporal variability. This cooperation changes regionally in time and space including physical characters as well as urban development, demography, socio-economy and administration and might be affected from past urban developments (Brears, 2017). Thus, UWS is nothing but a '*persistent condition in a limited urban region under which water ecosystems can ensure the adequate access, safety, and affordability of water to meet minimum livelihood standards and human feelings of psychological security*' (Huang et al., 2015, p. 3903).

3 Dimensions For Quantitative Assessment Of Urban Water Security

For the concept of water security there is no established or widely approved set of dimensions for assessment. Accordingly, here we set out to establish a comprehensive framework to study this complex issue. An urban area is defined as a socio-ecological system interacting between different socio-environmental dimensions (Romero-Lankao and Gnatz, 2016). In the literature, assessment dimensions of urban water systems include environment, society, culture, economy, politics, technology and governance (Romero-Lankao and Gnatz, 2016; Cunha et al., 2015). However, scholars have differed in how they measure and which dimensions they include to assess the sustainability of urban water systems. The Global Water Partnership (GWP) (2002), separates socio-economic dimension into social and economic categories for all scales. Gray and Sadoff (2007) propose to use health, livelihood, ecosystem and production (Pahl-Wostl and Knüppe, 2016) and Shaban and Sattar (2011) argue that infrastructure for water supply and waste water management also should play a vital dimensional role. In addition, management of risks emanating from climate change issues are also mentioned as an important dimension to consider (Shaban and Sattar, 2011). Therefore, in order to integrate socio-cultural-economic-political issues in UWS assessment, the following challenges are amongst the most urgent issues identified to date:

1. Secured access to enough and quality water to cover basic human needs for all despite of socio-economic, political and cultural odds,
2. Technological as well as governance efficiency and
3. Systems transformation to provide sustainable water services.

In the following we will discuss different dimensions related to availability of water, risks associated with water, issues related to water management in the developing countries and the dynamic relationship between the bio-physical environment, society as well as accessibility issues related to gender, culture and politics, which are needed to be considered at the end to achieve a comprehensive and holistic analysis of UWS.

- *The availability of fresh water*

  As cities grow and their populations increase, so does demand for water. A recent report from the World Bank (2017) points out that around 50% increase in urban water demands is anticipated within the next 30 years. By 2025, annual demand for municipal water in the world's large cities is expected to have increased by nearly 80 billion cubic meters, from around 190 billion cubic metres per year in 2012 to about 270 billion cubic metres per year in 2025 (Bergkamp et al., 2015). Many cities, regions, and countries around the world are faced with a trifecta of pressures: rapid urban population growth, economic expansion, and competing demands. These forces of change are tightening the availability of water resources in areas where tackling water scarcity is already a critical challenge (World Bank, 2017).The mission of securing and planning a sustainable water supply for urban areas in water scarce regions, particularly developing and emerging countries, is clearly no easy feat. Particularly for developing and emerging countries, water scarce cities are facing these challenges every day. Regions as diverse as the Middle East and North Africa, South and Central Asia, and parts of Latin America are still trying to explore new approaches for a water-secured future. Another aspect of water supply is leakage in the distribution system. Leakage-loss-rates of 50% are not uncommon in urban distribution systems. Around 250–500 million m^3 of drinking water gets lost in many large and mega cities each year. Saving this amount could provide an additional 10–20 million people with drinking water sole in the mega cities (UN Water, 2015). With the concentration of large numbers of people and economic activities to relatively small geographical areas, augmentation of supply of water, i.e. availability of freshwater, for the cities is the first dimension to be considered for any assessment approach (Lundqvist et al., 2003).

- *The importance of risk*

Water related risk has been mentioned as a crucial dimension by a range of authors. According to UN Water (2015), in 2014, 828 million people lived in slum conditions, lacking basic services and this number grows by 6 million each year. Many slum dwellers die each year as a result of inadequate drinking water and sanitation services. Many slums are built in flood-prone areas and the areas and people in them are particularly vulnerable and at risk (UN Water, 2015). Cook and Bakker (2012) identified vulnerability to water related hazards (such as flood etc.), development-related human needs and sustainability as the major dimensions to assess water security. Whilst Lautze and Manthrithilake (2012) emphasize basic needs, environment, risk management and independence dimensions are to be considered for assessing UWS. They also suggest including a 'risk-management' indicator that is particularly linked with water related disasters (Lautze and Manthrithilake, 2012). Hall and Borgomeo (2013) argue that the risk dimension is the defining attribute among all dimensions of UWS. Therefore, Lautze and Manthrithilake's (2012) 'risk' indices can be interpreted as indicators (i) of not satisfying basic needs (for given proportions of time and quintiles of the population), (ii) of harmful environmental impacts, and (iii) to the reliability of water supplies from the actions of neighbouring countries.Underlining the importance of risk, Hall and Borgomeo (2013, p. 1), water security signifies '*the absence of intolerable risks* (related to water insecurity) *leads to consideration of a broad range of risks and context-specific evaluation of their tolerability*'. However, the approach has not specified the *time* dimension in their risk management indices; neither any specific limit in terms of how to deal with a risk when it emerges, nor to prevent it.

- *UWS assessment with a developmental lens*

The Asian Water Development Bank (ADB) (2013) proposes five key dimensions to analyse water security at a country level scale focusing on poverty reduction in people's lives, livelihood and governance. The overall framework proposed by Asian Water Development Bank (2013) is a comprehensive approach where all the considered dimensions are related and interconnected. However, UWS is accounted exclusively from a water management perspective measuring the adequacy and efficiency of water supply, pollution management, wastewater treatment and drainage services to the urban dwellers. Other aspects of water security such as health and sanitation, resilience to water-related disasters like floods or water-borne diseases are not accounted for in their urban water security measurement scheme. Similarly, the indicators for the environmental water security are derived only for the measurement of environmental health in terms of water body restoration and considerations of water as resource; other ecosystem services are not included in this scheme. According to UN Water Report (2015), 95% of the urban expansion in the next decades will take place in developing and emerging countries. In Africa and Asia, the urban population is expected to double between 2000 and 2030. Between 1998 and 2008, 1052 million urban dwellers gained access to improved drinking water and 813 million to improved sanitation. However, the urban population in that period grew by 1089 million people and thus undermined the progress. Since 2014, 497 million people in cities rely on shared sanitation (UN Water, 2015), in 1990 this number was 249 million; in consequence the framework of Asian Water Development Bank (2013) lacks a detailed assessment of issues related to sanitation and hygiene at the city level scale.

- *The importance of overlapping relations of the environment and the social*

One of the most widely used dimensions of UWS is environment (among others Garrick and Hall, 2014; Pahl-Wostl and Knüppe, 2016; Romero-Lankao and Gnatz, 2016). The analysis of environmental vulnerability related to water insecurity has primarily been applied to assess health hazards related to climate change (e.g. Patz and Balbus, 1996; Dickin and Schuster-Wallace, 2014; Garrick and Hall, 2014). Many of the previous studies focus either on the risk of water insecurity for the society (e.g. Grey et al., 2013) or give attention to water conflicts as a threat to international security and peace (e.g. Tignino, 2010). Water pollution is included in this dimension as pollution of rivers and seas remains a big problem affecting especially coastal cities, where e.g. more than 60% of the Latin American population lives (UN Water, 2015). Therefore, it is a fact that the risks related to water insecurity out of climatic and human-made disasters are high in low- and middle-income countries, where up to 50% of the urban population lives in slums (World Bank, 2011). Here, social dimension of the UWS issues overlap with environmental vulnerability issues. The urban poor are vulnerable to water insecurity and related hazards due to the location of their suburbs within cities and the lack of reliable basic services and education (World Bank, 2011).

A holistic study on water insecurity needs to understand people's struggle to survive in difficult circumstances because the impact of the water insecurity stressors varies for different social groups. Different social groups have unequal access to resources, leading to unequal strengths and capabilities in coping with stressors (Udas et al., 2018). Ciurean et al. (2013) highlight effective adaptation policies for climate change that consider the assessment of social vulnerabilities through a bottom-up approach in relation to physical vulnerabilities. Leb and Wouters (2013) argue that social inequity, economic inefficiencies and unbearable environmental conditions disrupt the pathways to achieve water security, which in turn affect national security negatively. The conceptual framework presented in this chapter builds on these studies and expands on the social dimension to better understand and assess water security issues.

- *Gender-based vulnerability and UWS*

When it comes to water security, social, political, cultural and economic vulnerabilities need to be considered. Gender based vulnerability as a subset of social vulnerability is part of a process that creates differential vulnerabilities for people belonging to different gender categories (Sugden et al., 2014; Goodrich et al., 2017). Here, it is crucial to apprehend that 'gender' is not just an indicator for women and men; rather, it encompasses heterogeneity in gender categories and intersectional approaches are needed to understand the intersecting factors and positions that create vulnerabilities to water insecurity (Ravera et al., 2016). It is well known that floods and droughts have an adverse gendered impact on health (WHO, 2014a, b). However, less is known about the variations within gender and the influence of other intersecting factors such as ethnicity and socio-economic factors on water hazards and injustice.

We also know that our relation to, use of and access to water differ according to gender, i.e. water collection is in its majority carried out by women (UN Women, 2018) which means that gender matters in water security. Thus, without considering the facts of inequalities in the society and their individual impacts, the inclusive character of an assessment of water security, particularly for the urban areas, are incomplete. The importance of gender continuum in understanding water insecurity has not been analysed to any extent in water security studies thus far, a shortcoming, our framework seeks to address. We underline the importance of the intersectional position and gender to understand individuals' and groups' vulnerability to water insecurity. Among the issues we seek to explore is the complexity of gender and how it affects water insecurity, which we will do by opening the gender concept to include people across the gender continuum, something which has not been done so far.

- *Cultural UWS*

Culture is understood as a system of shared values, beliefs, behaviour and symbols that the members of society, groups or individual families use to interact within their social environment (Spencer-Oatey, 2012). It is a comprehensive outcome of societal values, traditional practices, local belief, taboos associated with sexual orientations, gender issues as well as other differences (Schelwald and Reijerkerk, 2009; Warner et al., 2008). Social aspects affect social and interpersonal behaviour and herewith the behaviour related to use and views of water (Pfau-Effinger, 1998; Van Oorschot et al., 2008). Thus, these socio-cultural factors are not only constructed by social norms and interpersonal interactions but also institutionalized into policies and public institutions (Van Oorschot et al., 2008). All these aspects have only rarely been studied related to water security, something that has resulted in inadequate knowledge about how these aspects influence water security. We argue that this is crucial for the understanding of how people relate to water, and different water sources (i.e. the position of the Ganges in India), who uses water, how and when water security occurs. Culture is crucial to consider as it influences not only individual and group behaviour, but also through its institutionalization into systems of governance affecting how water security is dealt with in different areas.

- *Politics and UWS*

Water security characteristically is a political issue (Bogardi et al., 2012; Leb and Wouters, 2013) and persistently visible in transboundary conflicts (Singh, 2008; Abdolvand et al., 2015). In the case of urban areas, water security is an issue for conflicts between coexisting social, cultural, religious and political groups. It is also an issue that is dealt with by and through different levels of governance, i.e. local, regional, national and international, creating a complex web of politics of water.Here, we see politics as a determinant of water accessibility and management, as politics relates to the way people deal with each other, select others for elected offices, form political parties, negotiate, contend with other parties and the entire system whereby this happens. On the other hand, governance refers to the social, economic, administrative as well as political systems that affect water's use and management within the city. Thus, governance is a determinant of the equity and efficiency in water resources and services allocation and distribution, and ultimately balances water use between social, economic and political activities and ecosystems (Bakker and Morinville, 2013).

Water security as a key component of human security must be addressed into the assessment framework (Biggs et al., 2013; Leb and Wouters, 2013). The socio-economic and political issues of UWS that power dynamics at the international, national, regional and even local level also impact the equitable allocation of water to stakeholders, including business, communities and ecosystems (WWF, 2016). Singh (2017) argues that for a proper water resources management, socio-political issues need to be considered to the same degree as technical and financial issues. Financial challenges can undermine the effectiveness of infrastructural or technological actions to achieve UWS (Singh, 2017). For example, in 2014, 27% of the urban dwellers in the developing and emerging countries did not have access to piped water at home and 828 million people lived in slums or informal settlements that were scattered around the cities whereas they paid up to 50 times more for a litre of water than their richer neighbours, since they often had to buy their water from private vendors (UN Water, 2015). Hence, wherever water is concerned, the effective use of the available water resources is important as water plays a crucial role for many objectives regarding the urban human habitat (Bengtsson and Shivakoti, 2015). Nevertheless, to take full advantage of such synergies requires carefully conceived cross-sectoral engagements to reach the goal of UWS, which is based on good understanding of inter-linkages between various objectives (Bengtsson and Shivakoti, 2015). In our comprehensive framework we will encompass measurements of governance and politics, both explicitly, to enable recommendations for better solutions to achieve water security for all.

4 Conceptualization of an Inclusive Framework to Quantify Urban Water Security

The inclusive assessment framework for UWS needs to address the complex and interwoven *environmental, social, cultural, political, economic, governance and technologic* dimensions to create a tool that can measure the complex web of issues contributing to UWS. The supply and usage of quality water as a renewable resource at the minimum replaceable limit to fulfil the population's need/demand needs to be considered as a basic human right. Therefore, availability and accessibility of adequate water as well as affordable to all must be accounted for. The next important issue to be considered is the urban ecosystem services at a minimum depleting rate of the non-renewable, where allocation of enough water is necessary to maintain a sustainable urban ecosystem service. Waste water management concerns the alarming levels and concentration of pollutants generated in these growing urban agglomerations specifically for the poor areas within and outside of the main city due to the lack or poor waste management. Thus, properly planned infrastructural and technological capabilities concerning water-borne diseases and natural hazard must be a crucial response from governance and institutions for the proper management of water resources (Bakker and Morinville, 2013).

4.1 Issues of Concern for Conceptualization of the Inclusive Framework

The measurement approaches for a quantitative assessment of the sustainability of urban water systems as provided by the literature (see Appendix 2) focus predominantly up to a meso (regional) level. Therefore, the variations within a city level scale, such as neighbourhood effects, intersectional issues and cultural aspects within the urban ecosystem services were missed. Case-specific quantitative index models, which reflect coupled human-water-system dynamics in comparative temporal and spatial scales are rare to find. Besides, the trade-offs between different water issues related to ecosystem services as well as socio-economic potentialities need to be addressed in selecting indicators and developing overall indices.

The assessment approaches listed in Appendix 2 are primarily looking at the sustainability of urban water systems. The focus is hence distributed either on the environment or the policy or the urban water system services issues more than on holistic procedure. The different measurement approaches for sustainability (Appendix 2) and their compatibility with the dimensions and issues are compiled in Table 9.1.

4.2 Considering Culture as a Dimension

To include social indicators, which are not commonly included in water security research, provides an improved tool to assess UWS and is the precondition to develop sustainable strategies that enable water security for all. Culture affects the access, use, consumption and, importantly, vulnerabilities when it comes to water security. For example, there are clear differences of attitudes towards the use of water, sanitation and hygiene facilities and the handling of excreta between diverse cultures. Despite an instinctive repulsion towards excreta, different cultures influence different attitudes towards handling of excreta and maintenance of personal hygiene in terms of water usage (Warner et al., 2008). Cultural values related to gender affects who uses water, how, where and when, i.e. who washes the clothes, using water from where and at what time. Thus, cultural values, gender and water insecurity are tightly interlinked and need to be explored and included in the measurement tool. Culture affects water security also in terms of how we see and define our water sources, e.g. the meaning of the river Ganges in India. In addition, culture is institutionalized into governance and governmental institutions. In consequence, we need to identify how cultural norms may enable or hinder UWS as a part of the comprehensive UWS assessment.

4.3 Water Justice and Gender

The approaches of urban water security to date mainly focus on the assessment of the urban water system and its sustainability from either environmental or economic perspectives (Table 9.1). However, as the UNESCO proposal for the global sustainable development goals on water-Target 1 claims; "universal access to safe drinking water and sanitation for all" and, thus, points out that the right to clean water is fundamental. Violations of the right to water can be traced back to injustices

Table 9.1 Compilation of approaches, dimensions and issues of urban water security

Approach	**Dimensions*							***Issues*									
	Env.	*Soc.*	*Cult*	*Pol.*	*Econ.*	*Gov.*	*Tech.*	*Av*	*Ac*	*HR*	*WQ*	*WM*	*NH*	*WD*	*Mg*	*Tech*	*UES*
Integrated Urban Water System Modelling (IUWSM) (Behzadian and Kapelan, 2015; Last, 2010; Makropoulos et al., 2008; Mitchell et al., 2001; Rozos and Makropoulos, 2013; Urich et al., 2013; Venkatesh et al., 2014; Willuweit O'Sullivan, 2013)	X				X	X	X	X			X	X				X	
United Nations Commission on Sustainable Development (UN-CSD) (UN-CSD, 2001)	X	X			X	X		X	X		X		X	X	X		X
Ecological Network Analysis (ENA) (Zhang et al., 2010; Bodini et al., 2012; Pizzol et al., 2013)	X				X			X	X							X	X
System Dynamics (SD) (Baki et al., 2012; Sahin and Stewart; 2013)	X	X	X		X	X	X	X							X	X	
Territorial Material Flow Analysis (UM-MFA) (Ayers and Ayers, 2002; Codoban andKennedy, 2008; EIU, 2011; Kennedy et al., 2007; Kennedy et al., 2015; Mollay et al., 2011; Newman et al., 1996; Newton et al., 2001; Pina and Martinez, 2014; Singh et al., 2009; Wernick and Irwin, 2005)	X				X	X	X	X	X		X	X				X	
Water Mass Balance (UM-WMB) (Bhaskar and Welty, 2012; Chrysoulakis et al., 2013; Kenway et al., 2011; Marteleira et al., 2014; Thériault & Laroche, 2009)	X					X	X	X	X			X			X	X	
Life Cycle Assessment (LCA) (Fagan et al., 2010; Lane et al., 2015; Lundin, 2003)	X				X	X	X	X	X		X	X	X	X	X	X	X
Water Footprint (WF) (Hoff et al., 2014; Vanham, 2012)	X	X			X			X	X	X	X					X	X

Environmentally Extended Input-Output Analysis (EIO) (Lenzen, 2009; Lenzen and Peters, 2009)	X	X			X												
Aqueduct water risk indicators (Gassert et al., 2013)	X	X			X	X	X	X	X				X		X	X	X
Index of water security threats (Vorosmarty et al., 2010)	X	X			X	X	X	X	X							X	X
Pressure-State-Response (PSR) (OECD, 2004; OECD, 2003)	X	X			X	X	X	X	X		X	X	X	X	X	X	X
Driver-Pressure-State-Impact-Response (DPSIR) (Marsili-Libelli et al., 2004; Pirrone et al., 2005; WWAP, 2006; WWAP, 2002)	X	X			X	X	X	X	X		X	X	X	X	X	X	X

*Dimensions: Env: environmental; Soc: social; Cult: cultural; Pol: political; Econ: economics; Gov: governance: Tech: technology

**Issues: Av: availability; Ac: accessibility; HR: human rights; WQ: water quality; WM: waste management; NH: natural hazards; WD: water-borne diseases; Mg: management; Tech: technology; UES: Urban Ecosystem Services.

including poverty and other social exclusion issues (Leb and Wouters, 2013). Overall, the role of gender in water insecurity issues is crucial. In the social sciences it is recognized through studies on how gender shapes issues of water access, use, governance, and adaptation to water insecurities and environmental crises (Alston 2006; Fletcher, 2018; Sommer et al. 2015, WWAP, 2015; UNEP, 2016). Gender roles and relations are important explanatory issues for UWS as water access, needs, and uses are all shaped and influenced by gender roles and are in relationship to any given society (Ray, 2007; Wallace and Coles, 2005). The importance of gender is further underlined by the fact that water security risks are higher amongst women and third gendered people (Demetriades and Esplen, 2010; Denton, 2002; MacGregor, 2009); in consequence women and third-gender people are often more vulnerable and exposed to risks related to water (Fletcher, 2018; Sommer et al., 2015). This includes a high vulnerability of women and third gendered people due to natural disasters like floods and droughts (Fletcher, 2018). Accordingly, urban water security cannot be achieved without accounting for gender equality and social inclusion within an assessment framework (Pangare, 2016). The inclusion of gender mainstreaming in UWS research is an opportunity to involve women and third gendered people in the design, planning, implementation of water services, management of natural resources, and in the development of disaster risk reduction strategies; gender-insensitive policies will only impede global efforts to eradicate poverty and achieve water security. Investing in the infrastructure needed to provide adequate water and sanitation facilities can also sharply reduce health costs and improve productivity (Pangare and Pangare, 2008). Previous studies in different disciplines have highlighted that vulnerabilities and experiences of water security vary according to a range of socio-economic issues (Demetriades and Esplen, 2010; Denton, 2002; MacGregor, 2009; Pangare, 2016). The approach of the proposed framework addresses the role of poverty and gender and the combination of intersectional vulnerabilities by including variables related to gender issues rarely included in empirical studies on water security.

4.4 Including Governance Measurements

Water crisis is not always or only due to physical scarcity of water but is also frequently due to inadequate or inappropriate water governance (AWDO, 2007). When it comes to urban water governance, different aspects need to be considered. First, urban water governance is related to and influences the extent to which the goals of UWS can be reached. Secondly, it influences and is directly related to the management and coordination of UWS. In consequence, urban water governance is a crucial dimension to be included in any UWS assessment scheme. We will include indicators directly related to the organization and management structures and we will explore other processes in which governance matters, such as in how successfully achieving UWS, and to what extent urban water governance contributes to higher or lower levels of UWS. In line with the comprehensive approach pursued stakeholders in different positions (e.g. NGOs, civil servants and people living in water insecure areas) need also to be included to identify the ways in which urban water governance matters. For example, due to increasing urbanization, the municipal water demand in Chinese cities are projected to grow 70% in 2030 (Wang et al., 2017). Although China's need for renewable freshwater continues to escalate, availability is barely one-third of the world's average. Shanghai falls among China's 36 worst cities regarding water quality (Zhen et al., 2017), and between 2010 and 2012 it was reported by the city's water census that 3% of local surface water was clean for fish farms or household use. Shanghai typifies the water governance problem China is facing from one mega city to the next and, hence, backs the urgent need for a comprehensive UWS assessment framework for the policy makers.

4.5 Achieving Sustainable UWS

Sustainability analysis to achieve UWS needs to account for the inter-relationship between water systems and economic production in a way that includes health and welfare. Reviewing various approaches related to UWS and sustainability it becomes evident that there are understated assumptions regarding what UWS means and how it can be achieved. For example, United Nations Commission for Sustainable Development (2011) considers sustainable development as directly compatible with economic growth. Hueting and Reijnders (2004) oppose this and consider sustainable development as an assumption 'neither demonstrated nor plausible'. Otherwise, any action taken by a city administration to augment the supply and ensure the sustainability of the urban water system can have an opposite effect, such as increasing the gap between demand and supply, or producing more pollution. Moreover, low or absence of proper maintenance of the storm-water management system can have a stronger adverse effect in slum areas than other parts of the city. It affects supply and water quality which raise the insecurity of water in the city. These social, environmental and economic effects that affect the city's water security are vital to include in measurements to understand what actions should be considered to maintain a water secured city. Hence, the concept of risk should be deployed across'the environmental, social and medical sciences', and therefore the framework should be compatible with an interdisciplinary approach to analyse UWS (Hall and Borgomeo, 2013).

In the proposed conceptual framework, social equity, cultural, political and economic aspects are considered for the development of the resource management plans (Leb and Wouters, 2013). Underlying this concept is also an acknowledgment that it is difficult to separate the social and cultural aspects from each other. They are intertwined, and their combination impacts the water security in a society—for example, through sanitation and hygiene behaviour of a certain population. The relationships between culture and policies in each society are factors that have been studied in other public policy areas, such as welfare policies (Hiroko, 2011). Including gender values and norms in an UWS assessment matrix, and to account for how it influences water security and the vulnerability and behaviour related to water security is deemed crucial in the proposed conceptual framework. Van Oorschot et al. (2008, p. 11) argue that culture affects and combines 'the short-term effects of social interactions at the micro level with the more enduring cultural values and models at the macro level of society'. Accordingly, it becomes crucial to incorporate measures that can start unpacking and understanding these complex interactions, and to take them into account when designing policies and campaigns that can help to achieve UWS. In consequence, the proposed framework will include intersectional measurements and will, thus, include questions considering ethnicity/origin/race and socio-economic vulnerability to water insecurities. This concept also reviews factors that can enhance our understanding of a person or group's vulnerability in relation to UWS.

4.6 The Need for New Data at City Levels

There is an intrinsic importance of baseline data collection for the appropriate assessment of water security (Mukherjee et al., 2018). Achieving water security is definitely a paradigm shift for emerging and developing countries from the ways this valuable resource is being 'managed' so far (Mukherjee et al., 2018). Despite the deep-rooted affinity to underestimate the necessity of research of water security at all levels, the value for baseline data collection remains indispensable for the sustainable management of the water resources for the security of the inhabitants of a country. It is also crucial to include city level data in analyses of water security to ensure a more comprehensive understanding of what drives and determines water security, such as availability and accessibility of quality water at the household level. Coherent collection of long-term data coupled with local knowledge is the priority for such researches. The primacy of institutional responsibilities for data collection, the level of existing data availability, and data sharing options between different institutions need to be addressed. Also, these aspects are important to frame conditions to provide appropriate recommendations that can ensure an appropriate data collection technique as well as appropriate mechanisms for data sharing. It has therefore been decided that intensive survey at household level and existing data from the authorities from the lowest level will be required and henceforth, combined to create data that satisfy the need for detail that is required to create an improved UWS index.

4.7 Conceptualizing the Inclusive Framework for Urban Water Security Assessment

The formation of our quantitative inclusive framework is based on the ecosystem services and system approach. The concept of urban water security, here, emphasizes the basis of sustainability of ecosystems, focusing on reducing the probability or risk of ecological disaster caused by human-induced stresses. To assure long-term sustainability, UWS assessment needs to be addressed from an integrated social-ecological systems perspective (Pahl-Wostl and Knüppe, 2016).The main spirit of all the definitions of water security published so far (Appendix 1) maintains a trade-off between usage and management of water resource for both the human and the environment (Stewart-Koster and Bunn, 2016; Grey and Sadoff, 2007; Naiman et al., 2002). Therefore, managing the conflict between supply (enough quality and quantity) and risk (anthropogenic and environmental) to the provision of water ecosystem services in an urban area is a challenge for the water scientists and managers (Stewart-Koster and Bunn, 2016). Pahl-Wostl and Knüppe (2016) argue that the ecosystem services need to be served as a connection for integrating fragmented institutional settings to support and negotiate about trade-offs for water security without jeopardizing the environment. From this point of view, urban ecosystem services principles are central to define an inclusive and holistic sustainable approach for the quantification of urban water security. Thus, a modified version of Driver-Pressure-State-Impact-Response (DPSIR) as a framework is proposed here to assess the dynamic interactions and feedback effects between water and people in an urban area.

This quantitative framework will encapsulate the urban water security dimensions and factors of a system approach (Driver, Pressure, State, Impact and Response) into three major matrices: Pressure (Driver and Pressure), Process (State) and Impact (Impacts and Responses). ‘Pressure’ matrix will deal with the Driver and Pressure factors of the problems, the ‘Process’ matrix will comprise the State factors and the ‘Risk’ matrix will involve Risks and Response factors from the both physical and socio-economic dimensions of UWS. Rather than setting a simple DPSIR framework, we added to the DPSIR a more integrated and bottom-up approach to assess the scenario quantitatively. This conceptual framework will include the most affected and vulnerable groups for better understanding of the issues related to UWS. The concept includes the identification of the issues faced by these groups and how they are being perceived within themselves. The issues are then put together into three main queries:

1. What are the drivers and pressure factors on the water services?
2. What are the state (i.e. uses and consumption) factors of the water resources available and supplied? and,
3. What are the impacts and associated risks and the responses from the governance and instructional perspectives?

The answers are expected in numbers and will include all the dimensions (and issues) mentioned above. In this way, the mitigation decision will be easier to take than under the present conditions. The framework of the quantitative indicator system will have to include the following measurements:

- *Pressure matrix*

The pressure matrix will cover Drivers and Pressures associated with the urban water system of a city, which determine the ultimate security from water for the environment and the citizens. *Driver* factor (D) illustrates the social-economic and political scenarios in the communities in and around the city as well as the consistent changes in lifestyle, consumption, and production patterns. Decadal population growth, population density, gross domestic production, per capita income, Gini coefficient and other factors that directly or indirectly influence urban ecosystem services and over all urban water security will be included.

Pressure factors can be congregated in bio-physical and socio-economic aspects. *Pressure* indicators (P) try to find the reason behind the status of the water security in a city, measuring the impacts that human activities exert on urban water systems. Special focus is on the effect of human activities on ecosystem services and on the water demand (quantity) and increasing exposure to water-related hazards (quantity, quality). Conflicts between water availability and accessibility often occur in any mega cities in developing and emerging countries despite of having an adequate amount of fresh water resources available. As a result, the total water-resource utilization, water-quantity ratio of inputs and outputs in a city area, per capita water-resource use, and ecological water demand and related data are required to be included in the index of UWS evaluation. The gap between demand-supply related to physical, social such as caste, religions, sexual minority issues should also be considered. In addition, some specific socio-economic pressures, such as the presence of water-intensive industries, widespread open defecation or gender issues in access to water and sanitation need to be included as pressure indicators. Land subsidence due to unsustainable groundwater abstraction, huge building construction, encroachment of wetlands suitable for urban expansion need to be considered as effects causing water stress in cities, both in terms of flood problems and water scarcity. Besides, in case artificial drainage systems occur, inadequate environmental flow in and around the city also need to be considered as pressure for the urban water security.

- *Process matrix*

The Process matrix expresses what is happening to the state at the various scales of city's urban water security status. The Process matrix will cover the *State* indicators (S) of the urban water security, which reflect the ecological health as well as socio-economic status of the city. Regarding water quality, pollutant emissions are the main stressor. Therefore, various sources of pollutants should be considered. Water quality indicators can be obtained from conventional water monitoring and sampling. The State indicators will concern the infrastructure to manage the quality and quantity of water as well. The quantity of water in a city can be described in terms of water stocks and flows and exchanges with areas outside the municipal boundaries considering groundwater and surface water. Groundwater extraction from wells within and outside municipal boundaries is an important source for urban water supply. Surface water and groundwater quality will be compared to ambient water quality standards including both, chemical and biological pollutants. Biological contamination is particularly relevant for shallow groundwater wells, often used by households in cities with inadequate water supply systems, which are contaminated from leaking sanitation infrastructure (leaking sewers, septic tanks, latrines, etc.).Water supply infrastructure from the abstraction points to the household-levels, sanitation infrastructure and flood protection infrastructure need to be considered when evaluating the state of urban water infrastructure. Relevant indicators for the state of the infrastructure include coverage of water supply systems in terms of connection rates and supply capacity, drinking water quality standards, percentages of wastewater collection and treatment, distinguishing between primary, secondary and tertiary treatment, leakages in drinking water supply and sewerage systems, and adequacy of storm water and flood protection infrastructure. Lastly, there is a strong link between solid waste management in a city and the amount of garbage in streams, canals and wetlands. Therefore, indicators related to the site, and treatment facilities associated with city's solid waste management is an integral part of the Process matrix.

- *Impact matrix*

The impact matrix will cover a significant number of indicators for a comprehensive analysis of impact and responses from the government and non-governmental institutions associated with the urban water systems. *Impact* indicators (I) characterize the changes in the state which reflect on the functioning of the urban water system from all individual, societal, institutional and ecosystem perspectives. It can be bio-physical (e.g. floods etc.) or societal factors (e.g. accessibility due to the societal discrimination) which affect the quality and quantity of ecosystem services and, certainly, the livelihood of the inhabitants. The *Impact* factor expresses the risks accompanying the manifestation of insecurity from water in a city in terms of disasters or scarcity. Unlike, State indicators, Impact indicators will not only focus on the bio-physical part of the entire water system in a city but will also include the provision of risks and problems associated with water-borne diseases. Risks related to water quality and sanitation which are related to the physical infrastructure and financial condition of the city governance for managing uncertain calamities like floods are also needed to be included in the assessment. For cities like Kolkata, the risks related to urban water system are also not linear in character. There are possibilities to have malfunctioning of water supply system in terms of breaking down during high demand period or is contaminated due to the leakage. These aspects along with the affordability for poorer households, should be considered for the assessment as risks to UWS.

- *Response matrix*

  Response indicators (R) are majorly decisions and policies which are taken repetitively to act for or against the impacts on the water security. They control the *drivers*, decrease pressures and reduce negative impacts of malfunctioning urban water services and functions (Sekovski et al., 2012) through regulation, prevention or mitigation to maintain/restore the state of the sustainable urban water security. Response towards gender mainstreaming in the policy related to urban water management will also be taken into consideration here. The focus of these response indicators should not only be on the governmental response while societal response is equally important. Generally, urban water systems are complex and dynamic, response indicators should cover the innovative and developmental decisions taken for all technical, institutional and organizational dimensions considering their own timeframes and scopes.Further, many responses require dealing with uncertainty and ambiguity, e.g. when it concerns policy-making for future climate change issues. Therefore, a significant number of indicators must cover all the existing policy or decision-making focused on future uncertainty for resilient, adaptive and robust urban water systems for sustainable functionality.

To design a resilient and valid quantitative assessment framework, we need to focus on the sustainable water future of the urban area from social, economic and environmental perspectives including the management of infrastructure required to achieve sustainable urban form and structure (Mukherjee et al., 2018). UWS issues are linked with different urban ecosystem services, which signify the sustainability of the quality of life. This sustainability is reliant upon input and output of the urban area. The urban input-output system depends on the lifestyles (according to the socio-economic standard and their 'needs/demands') and the usage/accessibility of technology to control the consumption of resources and creation of wastes (including pollution). Therefore, urban water and sustainability measurement approaches vary with the different value-added activities in different socio-economic pockets of a single urban area depending on their resource-consumption rates and the production of the wastes and pollution. Systematic measurement of these different urban characteristics in different socio-economic and environmental compartments of an urban area are necessary to identify and assess the water resource efficiency. Our proposed assessment framework is inclusive in character because it focuses not only on the physical/environmental side of the urban water system but also on socio-economic, political and cultural aspects that are related to and impact water security. Overall, the proposed framework is conditioned to add to our understanding of barriers impeding UWS for all communities at household level.

5 Conclusions

UWS is a complex system where a multiple of actors and factors are at play. This makes addressing water insecurity issues a difficult task. It is also a task where we need to disentangle this web of factors to create strategies capable of addressing the issues impeding a water secure future. This chapter reviewed existing research and identified gaps. A multitude of approaches to measure UWS are available. Only a few studies have identified the need for water security as the main factor for growth and sustainability for the society. The proposed assessment framework has been conceptualized to facilitate active discussion and mitigation approaches between participating experts and the stakeholders. This framework is proposed to consider the strategies for cities that assures water security for all but not in exchange for ecological integrity. This inclusive conceptual framework needs to be developed at a micro level to identify the best measurements for a holistic measurement tool. On this basis, it can be scaled up to regional and national levels to be incorporated in planning and management decisions.The importance to engage wider public in debates on emerging scientific issues such as UWS is to provide a successful adaptive plan for capacity building and making the society more resilient to the climate change related disasters in developing and emerging countries. It also underlines the importance and relevance of science for policies. Through this strong linkage, it will be ensured that the citizens keep informed on the development and the role of the scientists. Simultaneously, the policy makers will play a role in broadening the understanding of the needs to make the city more sustainable and provide the assurance to achieve water security for all.

The focus of the proposed integrated assessment framework of UWS is to associate and amalgamate human-oriented and environmental perspectives. The focus of the proposed conceptual framework will be on each key dimension to achieve goals of UWS. The bottom-up concept of the assessment will foster the idea of integration through a decentralized and holistic management technique. Integration of local ideas will be involved in the procedure to touch the various aspects of needs, demands, risks and developmental perspectives. This way, the 'integration' will bridge 'people, planet and profit'.

Acknowledgements This research is supported and funded by DAAD. We thank our colleagues from Freie University Berlin who provided insight and expertise that greatly assisted the research. We thank Dr. Jonas Berking for assistance with providing comments that greatly improved the research and manuscript and sharing his pearls of wisdom with us during this research.

Appendix 1: Definitions of Water Security

1. Water security is ‘a situation of reliable and secure access to water over time. It does not equate to constant quantity of supply as much as predictability, which enables measures to be taken in times of scarcity to avoid stress’ (Applegren, 1997).
2. A comprehensive definition (of water security) goes beyond availability to issues of access. Access involves issues that range from a discussion of fundamental individual rights to national sovereignty rights over water: It also involves equity and affordability, and the role of states and markets in water allocation, pricing, distribution and regulation. Water security also implies social and political decision-making on use—the priority to be accorded to competing household, agricultural or industrial demands on the resource (Gutierrez, 1999).
3. Water security is ‘a condition in which there is a sufficient quantity of water, at a fair price, and at a quality necessary to meet short and long term human needs to protect their health, safety, welfare, and productive capacity at the local, regional, state and national levels’ (Witter and Whiteford, 1999).
4. Water security ensures ‘every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced’(GWP, 2000).
5. Water security means that every person has access to enough safe water at an affordable cost to lead a healthy and productive life and that the vulnerable are protected from the risks of water related hazards (Ministerial Declaration of The Hague, 2000).
6. Household water security is ‘the reliable availability of safe water in the home for all domestic purposes’ (WHO, 2003).
7. Water security is a situation of reliable and secure access to water over time. It does not equate to constant quantity of supply as much as predictability, which enables measures to be taken in times of scarcity to avoid stress (Abrams, 2003).
8. The water security can be defined as the ability of different sections of population to access sufficient quantities of clean water to maintain adequate standards of food, sanitation, health and production of goods (Institute for the Analysis of Global Security, 2004).
9. There are three important elements of ‘water security’: (1) water security is based on three core freedoms: freedom from want, freedom from fear and freedom to live in human dignity; (2) ensuring water security may lead to a conflict of interests, which must be capable of being identified and effectively dealt with at the international, national and local levels; (3) water security, like water, is a dynamic concept, and one that needs clear local champions and sustained stewardship (Wouters, 2005).
10. Water security means the ability to supply water, according to a specified quality, to homes and industry under conditions satisfactory to the environment and at an acceptable price. The definition of water security includes: (a) population-

wide security, that is, everyone can obtain secure water for domestic use; (b) economic security, namely water resources can satisfy the normal requirements of economic development; (c) ecological security, namely water resources can meet the lowest water demands of ecosystems without causing damage (Xia et al., 2007).

11. Water security is linked to a safe water supply and sanitation, water for food production, hydro-solidarity between those living upstream and those living downstream in a river basin and water pollution avoidance so that the water in aquifers and rivers remains usable, i.e. not too polluted for use for water supply, industrial production, agricultural use or the protection of biodiversity, wetlands and aquatic ecosystems in rivers and coastal waters (Falkenmark, 2006).
12. Water security is 'the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies' (Grey and Sadoff, 2007).
13. Water security is 'availability of, and access to, water sufficient in quantity and quality to meet the livelihood needs of all households throughout the year, without prejudicing the needs of other users' (Calow et al., 2010).
14. Water security is just what we choose to eat [and] nothing to do with the environment or science etc.'… 'Water security is linked with food trade—as "energy security" is (more obviously, perhaps) linked with oil trade.'… 'Secure use of water is defined by political processes. Water security is achieved outside the watershed (in the 'problemshed') (Allan, 2011).
15. Water security is 'sustainable access, on a watershed basis, to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health' (Norman et al., 2011).
16. Social and physical processes combine to create or deny water security. Sustainable water security is interpreted as a function of the degree of equitability and balance between interdependencies of the related security areas, played out within a web of socioeconomic and political forces at multiple spatial levels. The 'web' of water security identifies the 'security areas' related to national water security. These include the intimately associated natural 'security resources' (water resources, energy, climate, food) as well as the security of the social groups concerned (individual, community, nation). The 'web' recognises the interaction occurring at all spatial scales, from the individual through to river basin and global levels. In this sense, an individual's water security may coexist with national water insecurity, as in the case of wealthy farmer-sheikhs with the deepest wells (who may be temporarily water secure) in the dry highlands of Yemen (which is not, overall, water secure) (Zeitoun, 2011).
17. Water security is essential for human access for health, wellbeing, economic and political stability. It is essential to limit risks of water-related hazards. A complete and fair valuation of the resource, sustainability of ecosystems at all parts of the hydrologic cycle and an equitable and cooperative sharing of water resources is very necessary (Water Aid, 2012).

18. Societies can enjoy water security when they successfully manage their water resources and services to (1) satisfy household water and sanitation needs in all communities; (2) support productive economies in agriculture, industry and energy; (3) develop vibrant, liveable cities and towns; (4) restore healthy rivers and ecosystems and (5) build resilient communities that can adapt to change (ADB, 2013).
19. Water security is defined as the capacity of a population to safeguard access to adequate quantities of water of acceptable quality for sustaining human and ecosystem health on a watershed basis, and to ensure efficient protection of life and property against water related hazards—floods, landslides, land subsidence) and droughts (UN Water, 2013).
20. Water security is the 'sustainable use and protection of water resources, safeguarding access to water functions and services for humans and the environment, and protection against water-related hazards (flood and drought)' (Wheater and Gober, 2013).
21. The capacity of a population to safeguard access to adequate quantities of water of acceptable quality for sustaining human and ecosystem health on a watershed basis, and to ensure efficient protection of life and property against water related hazards—floods, landslides, land subsidence, and droughts (UNESCO-IHP, 2017).

Appendix 2: A Summary of Key Approaches for Quantitative Assessment of Sustainability of Urban Water Systems

Category	*Approach*	*Objective*	*Features*	*References*
Urban Water System Modelling	Integrated Urban Water System Modelling (IUWSM)	Quantification of water flows through urban water infrastructure, i.e. water supply, drainage, wastewater etc. to manage supply against demand or plan infrastructure	Bottom-up simulation of the volumes of water managed by the urban water system, to achieve a supply-demand balance of the water system	Behzadian and Kapelan, 2015; Last, 2010; Makropoulos et al., 2008; Mitchell et al., 2001; Rozos and Makropoulos, 2013; Urich et al., 2013; Venkatesh et al., 2014; Willuweit O'Sullivan, 2013

(continued)

Category	*Approach*	*Objective*	*Features*	*References*
Sustainability frameworks	United Nations Commission on Sustainable Development (UN-CSD)	Assessment of a policy for Reporting, Comparison and Decision-Making towards sustainability	Consideration of four dimensions of sustainability, namely Environmental, Social, Economic and Institutional	UNCSD, 2001
Complex systems approach	Ecological Network Analysis (ENA)	Quantifies indicators that represent the relationships between components of the urban water system to characterize how the system functions	Top-down collation of secondary data for anthropogenic water flows between socioeconomic components of the urban water system into input-output tables, from which system-wide performance indicators are generated	Zhang et al., 2010; Bodini et al., 2012; Pizzol et al., 2013
	System Dynamics (SD)	Quantifies trends in anthropogenic urban water flows under varying socioeconomic parameters	Bottom-up dynamic simulation of the anthropogenic water flows under changing variables, based on inter-relationships and feedback loops	Baki et al., 2012; Sahin and Stewart, 2013
Urban Metabolism	Territorial Material Flow Analysis (UM-MFA)	Quantification of city-scale water flows (alongside other resource flows), for monitoring change over time and benchmarking between cities and urban typologies	Top-down collation of secondary data for centralized water flows (total and per capita potable water inflows and wastewater outflows), as part of a wider MFA of all urban resource flows	Ayers and Ayers, 2002; Codoban and Kennedy, 2008 EIU, 2011; Kennedy et al., 2007; Kennedy et al., 2015; Mollay et al., 2011; Newman et al., 1996; Newton et al., 2001; Pina and Martinez, 2014; Singh et al., 2009; Wernick and Irwin, 2005

(continued)

Category	*Approach*	*Objective*	*Features*	*References*
	Water Mass Balance (UM-WMB)	Quantification of city-scale water flows and metabolic performance indicators, for visioning and for screening improvement opportunities	Top-down collation of secondary data for all water flows (anthropogenic and natural), and changes in storage, to achieve a water mass balance of the urban entity	Bhaskar and Welty, 2012; Chrysoulakis et al., 2013; Kenway et al., 2011; Marteleira et al., 2014; Thériault & Laroche, 2009
	Life Cycle Assessment (LCA)	Quantification of environmental impact indicators across the life cycle of urban water systems, for understanding their wider environmental implications	Bottom-up estimates of resource inputs to, and waste/pollutant outputs from, all processes in the life cycle of urban water services followed by characterization of their impacts	Fagan et al., 2010; Lane et al., 2015; Lundin, 2003
Consumption approach for Bio-physical Accounting	Water Footprint (WF)	Quantification of indirect water required to produce goods and services consumed by the city or its inhabitants	Bottom-up estimates of single metric of water extracted from the global hinterland, representing the water required to produce the goods and services consumed by urban dwellers	Hoff et al., 2014; Vanham, 2012
	Environmentally Extended Input-Output Analysis (EIO)	Quantification of economic water flows (and other resources) through economic supply chains	Top-down collation of economic flows from economic input-output tables are multiplied by virtual water use associated with those economic exchanges	Lenzen, 2009; Lenzen and Peters, 2009

(continued)

Category	*Approach*	*Objective*	*Features*	*References*
Risk based approach	Aqueduct water risk indicators	Quantification of the coincidence of hazards at high resolution	Key Dimensions are Chronic water stress, flood, drought/seasonal variability, environmental degradation, inadequate water supply and sanitation, and the role of institution and infrastructure	Gassert et al., 2013
	Index of water security threats		Key Dimensions are Chronic water stress environmental degradation, and infrastructure	Vorosmarty et al., 2010
System approach	Pressure-State-Response (PSR)	Quantification of environmental progress and performance with international comparison. Monitoring policy integration.	Describes the causal chain of an effect considered as negative for sustainability. Four kinds of descriptive indicators are: 1) core set 2) key indicators 3) sectorial indicators and 4) decoupling set	OECD, 2004; OECD, 2003
	Driver-Pressure-State-Impact-Response (DPSIR)	Assessment of the sustainable development (SD), making science understandable to the public and demand management for SD	Descriptive indicators, showing the state of water resources and its links with diverse water related issues: 1) Basic indicators 2) Key indicators 3) Developing indicators and 4) Conceptual indicators	Marsili-Libelli et al., 2004; Pirrone et al., 2005; WWAP, 2006; WWAP, 2002

References

Abdolvand, B., Mez, L., Winter, K., Mirsaeedi-Gloßner, S., Schütt, B., Rost, K.T. and Bar, J. (2015). The dimension of water in Central Asia: Security concerns and the long road of capacity building. *Environ Earth Sci*, **73(2):** 897–912. doi: https://doi.org/10.1007/s12665-014-3579-9.

Abrams, L. (2003). Water scarcity. www.africanwater.org/drought_water_scarcity.htm. Accessed 10 October 2017.

Allan, T. (2011). Virtual Water: Tackling the Threat to Our Planet's Most Precious Resource. IB Tauris and Co. Ltd, New York, USA.

Alston, M. (2006). The gendered impact of drought. *In:* Bock, B.B. and Shortall, S. (eds.), Rural Gender Relations: Issues and Case Studies. CABI, Oxfordshire/Cambridge, MA, pp. 165–180.

Applegren, B. (1997), Keynote paper – Management of water scarcity: National water policy reform in relation to regional development cooperation, Second Expert Consultation on National Water Policy in the Near East, Cairo, 24–25 November 1997. FAO, Rome.

ADB (2013). Asian Water Development Outlook – Measuring Water Security in Asia and the Pacific. Asian Development Bank: Manila, Philippines.

Asian Water Development Outlook – Bridges, G. (2007). Asian Water Development Outlook 2007—Country Paper Pakistan. Manila, Philippines: Asian Development Bank. Available from http://www. adb. org/Documents/Books/AWDO/2007/cr08. pdf.

Ayers, R.U. and Ayers, L.W. (2002). A Handbook of Industrial Ecology, Edward Elgar Publishing Limited. Cheltenham.

Baki, S., Koutiva, I. and Makropoulos, C. (2012). A hybrid artificial intelligence modelling framework for the simulation of the complete, socio-technical, urban water system. Paper presented at iEMSs 2012, 1–5 July, Leipzig, Germany.

Bakker, K. and Morinville, C. (2013). The governance dimensions of water security: A review. *Phil Trans R Soc A*, **371:** 20130116. doi: https://doi.org/10.1098/rsta.2013.0116.

Barbier, E.D. and Burgess, J.C. (2017). The sustainable development goals and the systems approach to sustainability. Economics Discussion Papers, No. 2017-28, Kiel Institute for the World Economy. http://www.economics-ejournal.org/economics/discussionpapers/2017-28. Accessed 16 April 2018.

Bar, I. and Stang, G. (2016). Water and Insecurity in the Lavant. European Union Institute for Security Studies (EUISS).

Behzadian, K. and Kapelan, Z. (2015). Modelling metabolism-based performance of an urban water system using WaterMet2. Resources, *Conserv Recycl*, **99:** 84–99.

Bengtsson, M. and Shivakoti, B.R. (2015). Balancing Trade-offs to Action, 135.

Bergkamp, G., Diphoorn, B. and Trommsdorf, C. (2015). Water and development in the urban setting. *In:* Jägerskog, A., Clausen, T.J., Holmgren, T. and Lexén, K. (eds.) (2015). Water for Development – Charting a Water Wise Path. Report No. 35. SIWI, Stockholm.

Bhaskar, A.S. and Welty, C. (2012). Water balances along an urban to-rural gradient of Metropolitan Baltimore, 2001–2009. *Environ Eng Geosci*, **18(1):** 37–50.

Biggs, E.M., Duncan, J.M.A., Atkinson, P.M. and Dash, J. (2013). Plenty of water, not enough strategy: How inadequate accessibility, poor governance and a volatile government can tip the balance against ensuring water security: The case of Nepal. *Environ Sci Policy*, **33:** 388–394.

Blanca, F.M. (2016). Water security in an urbanized world: An equity perspective. Submitted in February 2016 to *Habitat Int*, https://doi.org/10.14279/depositonce-5767.

Bodini, A., Bondavalli, C. and Allesina, S. (2012). Cities as ecosystems: Growth, development and implications for sustainability. *Ecol Model*, **245:** 185–198.

Bogardi, J.J., Dudgeon, D., Lawford, R., Flinkerbusch, E., Meyn, A., Pahl-Wostl, C., ... and Vörösmarty, C. (2012). Water security for a planet under pressure: Interconnected challenges of a changing world call for sustainable solutions. *Current Opinion in Environmental Sustainability*, **4(1):** 35–43.

Brears, R. (2017). Urban Water Security. Willey.

Calow, R.C., MacDonald, A.M., Nicol, A.L. and Robins, N.S. (2010). Ground water security and drought in Africa: Linking availability, access and demand. *Ground Water*, **48(2):** 246–256.

Chrysoulakis, N., Lopes, M., San Jos´e, R., Grimmond, C.S.B., Jones, M.B., Magliulo, V. and Klostermann, J.E.M. (2013). Sustainable urban metabolism as a link between bio-physical sciences and urban planning: The BRIDGE project. *Landscape Urban Planning*, **112:** 100–117.

Ciurean, R.L., Schröter, D. and Glade, T. (2013). Conceptual frameworks of vulnerability assessments for natural disasters reduction. *In:* Approaches to Disaster Management – Examining the Implications of Hazards, Emergencies and Disasters. IntechOpen.

Codoban, N. and Kennedy, C. (2008). Metabolism of neighborhoods. *J Urban Planning Dev*, **134(1):** 21–31.

Cook, C. and Bakker, K. (2012). Water security: Debating an emerging paradigm. *Global Environ Change*, **22:** 94–102.

Cunha, M.R., da Cruz, N.F. and Pires, J. (2015). Measuring the sustainability of urban water services. *Environ Sci Policy*, **54:** 142–151. ISSN: 1462-9011.

Demetriades, J. and Esplen, E. (2010). The gender dimensions of poverty and climate change adaptation. *In:* Mearns, R. and Norton, A. (eds.), Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World. The World Bank, Washington, DC, pp. 133–144.

Denton, F. (2002). Climate change vulnerability, impacts, and adaptation: Why does gender matter? *Gender Dev*, **10(2):**10–20.

Dickin, S.K. and Schuster-Wallace, C.J. (2014). Assessing changing vulnerability to dengue in northeastern Brazil using a water-associated disease index approach. *Global Environmental Change*, **29:** 155–164.

Economic Intelligence Unit (2011). Asian Green City Index. Assessing the environmental performance of Asian's major cities. Siemens AG, Economic Intelligence Unit, Munich, Germany.

Fagan, J.E., Reuter, M.A. and Langford, K.J. (2010). Dynamic performance metrics to assess sustainability and cost effectiveness of integrated urban water systems. *Resources Conserv Recycling*, **54(10):** 719–736.

Falkenmark, M. and Widstrand, C. (1992). Population and water resources: A delicate balance. Population Reference Bureau,Washington, DC, USA.

Falkenmark, M. (2006). The new blue and green water paradigm: Breaking new ground for water resources planning and management. *J Water Resources Planning Manag*, **132(3):**129–132.

Fletcher, A.J. (2018). More than women and men: A framework for gender and intersectionality research on environmental crisis and conflict. *In:* Fröhlich, C., Gioli, G., Cremades, R. and Myrttinen, H. (eds.), Water Security Across the Gender Divide. Springer International Publishing, Cham, pp. 35–58.

Garrick, D. and Hall, J.W. (2014). Water security and society: Risks, metrics, and pathways. *Annual Review of Environment and Resources*, **39:** 611–639.

Gassert, F., Reig, P., Luo, T. and Maddocks, A. (2013). Aqueduct country and river basin rankings: A weighted aggregation of spatially distinct hydrological indicators. Work Paper. World Resource Institute,Washington, DC.

Global Water Partnership (2000). Towards water security: A framework for action. Report 91-630-9202-6. Global Water Partnership, Stockholm.

Goff, M. and Crow, B. (2014). What is water equity? The unfortunate consequences of a global focus on 'drinking water'. *Water Int*, **39(2):** 159–171. doi:https://doi.org/10.1080/02508060.2014.886355.

Goodrich, K.M., Farmer, L.B., Watson, J.C., Davis, R.J., Luke, M., Dispenza, F., ... and Griffith, C. (2017). Standards of care in assessment of lesbian, gay, bisexual, transgender, gender expansive, and queer/questioning (LGBTGEQ+) persons. *Journal of LGBT Issues in Counseling*, **11(4):** 203–211.

Grafton, R.Q. (2017). Responding to the 'wicked problem' of water insecurity. *Water Resources Management*, **31(10):** 3023–3041.

Grey, D. and Sadoff, C.W. (2007). Sink or Swim? Water security for growth and development. *Water Policy*, **9:** 545–571.

Grey, D., Garrick, D., Blackmore, D., Kelman, J., Muller, M. and Sadoff, C. (2013). Water security in one blue planet: Twenty-first century policy challenges for science. *Philos Trans R Soc A*, **371:** 20120406.

Gutierrez, E. (1999). Boiling Point: Issues and Problems in Water Security and Sanitation, Water Aid Briefing Paper, Global Water Partnership, London.

Hall, J., Borgomeo, E. (2013). Risk-based principles for defining and managing water security. *Philos Trans R Soc A*, **371:** 20120407.

Hiroko, T. (2011). Gender-related social policy. *In:* The Routledge Handbook of Japanese Politics. pp. 228-238. Routledge.

Hoff, H., Döll, P., Fader, M., Gerten, D., Hauser, S. and Siebert, S. (2014). Water footprints of cities—Indicators for sustainable consumption and production.*Hydrol Earth Syst Sci*, **18(1):** 213–226.

Huang, M., Piao, S., Sun, Y., Ciais, P., Cheng, L., Mao, J., ... and Wang, Y. (2015). Change in terrestrial ecosystem water-use efficiency over the last three decades. *Global Change Biology*, **21(6):** 3903.

Hueting, R. and Reijnders, L. (2004). Broad sustainability contra sustainability: The proper construction of sustainability indicators. *Ecol Econ*, **50:** 249–260.

Institute for the Analysis of Global Security (2004). The Connection: Water and Energy Security. http://www.iags.org/n0813043.htm. Accessed 10 February 2019.

Jepson, W., Budds, J., Eichelberger, L., Harris, L., Norman, E., O'Reilly, K., Pearson, A., Shah, S., Shinn, J., Staddon, C., Stoler, J., Wutich, A. and Young, S. (2017). Advancing human capabilities for water security: A relational approach. *Water Secur*, **1:** 46–52.

Kennedy, C.A., Stewart, I., Facchini, A., Cersosimo, I., Mele, R., Chen, B., Uda, M. et al. (2015). Energy and material flows of megacities. *Proc Natl Acad Sci USAm*, **112(19):** 5985–5990.

Kennedy, C., Cuddihy, J. and Engel-Yan, J. (2007). The changing metabolism of cities. *J Ind Ecol*, **11(2):** 43–59.

Kenway, S., Gregory, A. and McMahon, J. (2011). Urban water mass balance analysis. *J Ind Ecol*, **15(5):** 693–706.

Lane, J.L., de Haas, D.W. and Lant, P.A. (2015). The diverse environmental burden of city-scale urban water systems. *Water Res*, **81:** 398–415.

Last, E.M. (2010). City water balance. A new scoping tool for integrated urban water management options. Thesis, School of Geography, Earth and Environmental Sciences, the University of Birmingham, Birmingham, UK.

Lautze, J. and Manthrithilake, H. (2012). Water security: Old concepts, new package, what value? *Nat Resour Forum*, **36:** 76–87.

Leb, C. and Wouters, P. (2013). The water security paradox and international law: Securitisation as an obstacle to achieving water security and the role of law in de-securitising the world's most precious resource. *In:* Lankford, B.A., Bakker, K., Zeitoun, M. and Conway, D. (eds.), Water Security: Principles, Perspectives and Practices. Earthscan Publications, London.

Lenzen, M. (2009). Understanding virtual water flows: A multiregion input-output case study of Victoria. *Water Resources Res*, **45(9):** W09416.

Lenzen, M. and Peters, G.M. (2009). How city dwellers affect their resource hinterland. *J Ind Ecol*, **14(1):** 73–90.

Lundin, M. (2003). Indicators for Measuring the Sustainability of Urban Water Systems – A Life Cycle Approach. PhD Dissertation, Chalmers University of Technology.

Lundqvist, J., Appasamy, P. and Nelliyat, P. (2003). Dimensions and approaches for third world city water security. *Phil Trans R Soc Lond*, **358:** 1958–1996.

MacGregor, S. (2009). A stranger silence still: The need for feminist social research on climate change. *Sociol Rev*, **57:** 124–140.

Makropoulos, C.K., Natsis, K., Liu, S., Mittas, K. and Butler, D. (2008). Decision support for sustainable option selection in integrated urban water management. *Environ Modell Softw*, **23(12):** 1448–1460.

Marsili-Libelli, S., Betti, F. and Cavalieri, S. (2004). Introducing river modellng in the implementation of DPSIR scheme of the water framework directive. International Congress "Complexity and Integrated Resource Management". International Environmental Modeling and Software Society, Osnabrück, June 2004.

Marteleira, R., Pinto, G. and Niza, S. (2014). Regional water flows—Assessing opportunities for sustainable management. *Resources Conserv Recycl*, **82:** 63–74.

Ministerial Declaration of The Hague (2000). Water Security in the 21st Century Second World Water Forum. http://www.waternunc.com/gb/secwwf12.htm. Accessed 12 February 2019.

Mitchell, V.G., Mein, R.G. and McMahon, T.A. (2001). Modelling the urban water cycle. *Environ Modell Softw*, **16(7):** 615–629.

Mollay, U.C., Schremmer, P., Pinho, D., Stead, P., Schmidt, S., Davoudi, C. et al. (2011). Planning resource-efficiency cities. Synthesis report for the sustainable urban metabolism for Europe (SUME) project. European Communities' Seventh Framework Programme, Vienna.

Mukherjee, S., Bebermeier, W. and Schütt, B. (2018). An overview of the impacts of land use land cover changes (1980–2014) on urban water security of Kolkata. *Land*, **7:** 91.

Naiman, R.J., Bunn, S.E., Nilsson, C., Petts, G.E., Pinay, G. and Thompson, L.C. (2002). Legitimizing fluvial ecosystems as users of water: An overview. *Environmental Management*, **30(4):** 455–467.

Narain, V. (2010). Periurban water security in a context of urbanization and climate change: A review of concepts and relationships. Peri Urban Water Security Discussion Paper Series, Paper No. 1, Saci WATERs, India.

Newman, P.W.G., Birrell, B., Holmes, D., Mathers, C., Newton, P.W., Oakley, G., O'Connor, A., Walker, B., Spessa, A. and Tait. D. (1996). Human settlements (chapter 3). *In:* Australian state of the environment report 1996. Commonwealth of Australia, Canberra.

Newton, P.W., Baum, S., Bhatia, K., Brown, S.K., Cameron, A.S., Foran, B., Grant, T. et al. (2001). Human settlements theme report. *In:* Australia state of the environment report 2001. CSIRO on behalf of the Department of the Environment and Heritage, Canberra.

Norman, E.S., Bakker, K. and Dunn, G. (2011). Recent developments in Canadian water policy: An emerging water security paradigm. *Can Water Resources J*, **36(1):** 53-66.

Obani, P. and Gupta, J. (2016). Human security and access to water, sanitation, and hygiene: Exploring the drivers and nexus. *In:* Pahl-Wostl, C., Bhaduri, A. and Gupta, J. (eds.), Handbook on Water Security. Edward Elgar Publishing, Cheltenham and Northampton, pp. 201-2014. ISBN: 978-1-78254-800-3.

Organisation for Economic Co-operation and Development (2003). OECD Environmental Indicators. Development, Measurement and Use. Reference Paper. OECD, Paris.

Organisation for Economic Co-operation and Development (2004). OECD Workshop on Material Flows and related indicators. Chair's summary. OECD, Helsinki.

Padowski, J.C., Carrera, L. and Jawitz, J.W. (2016). Overcoming urban water insecurity with infrastructure and institutions. *Water Resources Management*, **30(13):** 4913–4926.

Pahl-Wostl, C. and Knüppe, K. (2016). Water security and environmental water needs: The role of the ecosystem services concept and transformation of governance systems. *In:* Pahl-Wostl, C., Bhaduri, A., Gupta, J. (eds.), Handbook on Water Security. Edward Elgar Publishing, Cheltenham and Northampton, pp. 226–238. ISBN: 978-1-78254-800-3.

Pahl-Wostl, C., Bhaduri, A. and Gupta, J. (eds.) (2016). Handbook on Water Security. Edward Elgar Publishing, Cheltenham and Northampton. ISBN: 978-1-78254-800-3.

Pangare, G. and Pangare, V. (2008). Informal Water Vendors and Service Providers in Uganda: The Ground Reality. Research Paper for the Water Dialogues, UK http://www.waterdialogues.org/documents. Accessed on 07 March 2018.

Pangare, V. (2016). Gender Equality, Water and Climate Change Adaptation in Megacities. Water, Megacities and Global Change: Portraits of 15 Emblematic Cities of the World. UNESCO/ARCEAU IdF, France. http://unesdoc.unesco.org/images/0024/002454/245419e.pdf. Accessed 7 March 2018.

Patz, J.A. and Balbus, J.M. (1996). Methods for assessing public health vulnerability to global climate change. *Climate Research*, **6(2):** 113–125.

Pfau-Effinger, B. (1998). Gender cultures and the gender arrangement—A theoretical framework for cross-national gender research. *Innovation: The European Journal of Social Science Research*, **11(2):** 147–166.

Piesse, M. (2015). Water Security in Urban India: Water Supply and Human Health. Future Directions International. http://futuredirections.org.au/wp-content/uploads/2015/09/Water_Security_in_Urban_India_Water_Supply_and_Human_Health.pdf. Accessed on 07 March 2018.

Pina, A.W.H. and Martinez, P.C.I. (2014). Urban material flow analysis: An approach for Bogota, Colombia. *Ecol Indicators*, **42:** 32–42.

Pirrone, N., Trombino, G., Cinnirella, S., Algieri, A., Bendoricchio, G. and Palmieri, L. (2005). The DPSIR approach for integrated catchment coastal zone management: Preliminary application to the Po catchment – Adriatic Sea. *Regional Environ Change*, **5:** 11–137.

Pizzol, M., Scotti, M. and Thomsen, M. (2013). Network analysis as a tool for assessing environmental sustainability: Applying the ecosystem perspective to a Danish water management system. *J Environ Manage*, **118:** 21–31.

Ravell, J. (2014). Population growth, urbanisation and water security: A case study of Greater Brisbane. Water Supply & Urbanization.

Ray, I. (2007). Women, water and development. *Annu Rev Environ Resources*, **32:** 421–449.

Ravera, F., Iniesta-Arandia, I., Martín-López, B., Pascual, U. and Bose, P. (2016). Gender perspectives in resilience, vulnerability and adaptation to global environmental change. *Ambio*, **45(3):** 235–247.

Romero-Lankao, P. and Gnatz, D.M. (2016). Conceptualizing urban water security in an urbanizing world. *Current Opinion in Environmental Sustainability*, **21:** 45–51.

Rozos, E. and Makropoulos, C. (2013). Source to tap urban water cycle modelling. *Environ Modell Softw*, **41:** 139–150.

Sahin, O. and Stewart, R. (2013). Life cycle assessment of urban water supply vulnerability costs: A systems dynamics approach. Paper presented at 8th Conference on Sustainable Development of Energy, Water and Environment Systems, 22–27 September, Dubrovnik, Croatia.

Sarvajayakesavalu, S. (2015). Addressing challenges of developing countries in implementing five priorities for sustainable development goals. *Ecosyst. Health Sustain*, **1(7):** 1–4. doi: https://doi.org/10.1890/EHS15-0028.1

Schelwald-Van Der Kley, L. and Reijerkerk, L. (2009). Water: A Way of Life. Sustainable Water Management in a Cultural Context. CRC Press, Leiden.

Shaban, A. and Sattar, S. (2011). Water security and sustainability in urban India. *International Journal of Global Environmental Issues*, **11(3-4):** 231–254.

Singh, R., Maheshwari, B. and Malano, H.M. (2009). Developing a conceptual model for water accounting in peri-urban catchments. Paper presented at MODSIM 2009, 13–17 July, Cairns, QLD, Australia.

Singh, S. (2017). Financial inclusion as practice: Microfinance and mobile money. *In:* Paul Battersby and Ravi K. Roy (eds.), International Development: A Global Perspective on Theory and Practice. pp. 230–244. Sage, Los Angeles. United States.

Sommer, M., Ferron, S., Cavill, S. and House, S. (2015). Violence, gender and WASH: Spurring action on a complex, under-documented and sensitive topic. *Environ. Urban*, **27(1):** 105–116. doi.org/10.1177/0956247814564528.

Spencer-Oatey, H. (2012). What is culture? A compilation of quotations. Global PAD Core Concepts. http://www.warwick.ac.uk/globalpadintercultural. Accessed 23 October 2018.

Stewart-Koster, B. and Bunn, S.E. (2016). The ecology of water security. *In:* Handbook on Water Security. Edward Elgar Publishing.

Sugden, F., Maskey, N., Clement, F., Ramesh, V., Philip, A. and Rai, A. (2014). Agrarian stress and climate change in the Eastern Gangetic Plains: Gendered vulnerability in a stratified social formation. *Global Environmental Change*, **29:** 258–269.

Thèriault, J. and Laroche, A.M. (2009). Evaluation of the urban hydrologic metabolism of the Greater Moncton region, New Brunswick. *Can Water Resources J*, **34(3):** 255–268.

Tignino, M. (2010). Water, international peace, and security. *Int Rev Red Cross*, **92:** 879. doi:https://doi.org/10.1017/S181638311000055X.

Turral, H., Burke, J. and Faurès, J.M. (2011). Climate Change, Water and Food Security. FAO, Rome.

Udas, P.B., Prakash, A. and Goodrich, C.G. (2018). Gendered vulnerabilities in Diaras. *Economic and Political Weekly*, **53(17):** 47.

UN (United Nations) Water (2013). Water Security and the Global Water Agenda: A UN-Water Analytical Brief. UN Univ. Inst. Water Environ. Health, Hamilton, ON.

UN (United Nations) Water Report (2015). The United Nations World Water Development Report 2015: Water for a Sustainable World. UNESCO, Paris. http://unesdoc.unesco.org/images/0022/002257/225741E.pdf. Accessed 2 May 2018.

United Nations Commission for Sustainable Development (2011). Indicator of Sustainable Development. Guidelines and Methodologies. United Nations.

UNCSD (United Nations Commission on Sustainable Development) (2001). Indicators of sustainable development: Guidelines and methodologies. UN – Dept. of Economic, and Social Affairs Staff. United Nations Publications.

UNEP (United Nations Environment Programme) (2016). Global Gender and Environment Outlook. Nairobi, Kenya.

UNESCO-IHP (2017). IHP-VIII Water Security-Responses to Local, Regional, and Global Challenges (2014–2021): Themes and Focal Areas. UNESCO, Paris.

UN (United Nations) Women (2018). Turning promises into action: Gender equality in the 2030 Agenda for Sustainable Development. UN Women.

Urich, C., Bach, P.M., Sitzenfrei, R., Kleidorfer, M., McCarthy, D.T., Deletic, A. and Rauch, W. (2013). Modelling cities and water infrastructure dynamics. *Proc ICE–Eng Sustain*, **166(5):** 01.

Van Oorschot, W., Opielka, M. and Pfau-Effinger, B. (2008). The culture of the welfare state: Historical and theoretical arguments. Culture and welfare state: Values and social policy in comparative perspective, **1:** 1–28.

Vanham, D. (2012) A holistic water balance of Austria—How does the quantitative proportion of urban water requirements relate to other users? *Water Sci Technol*, **66(3):** 549–555.

Venkatesh, G., Saegrov, S. and Brattebo, H. (2014). Dynamic metabolism modelling of urban water services—Demonstrating effectiveness as a decision-support tool for Oslo, Norway. *Water Res*, **61:** 19–33.

Vorosmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D. and Prusevich, A. (2010). Global threats to human water security and river biodiversity. *Nature*, **467:** 555–561.

Wallace, T. and Coles, A. (2005). Water, gender and development: An introduction. *In:* Coles, A. and Wallace, T. (eds.), Gender, Water and Development. Berg, New York, NY, pp. 1-20.

Wang, T., Liu, S., Qian, X., Shimizu, T., Dente, S.M., Hashimoto, S. and Nakajima, J. (2017). Assessment of the municipal water cycle in China. *Sci Total Environ*, **607:** 761–770.

Warner, W., Heeb, J., Jenssen, P., Gnanakan, K. and Conradin, K. (2008). M4-2: Socio-Cultural Aspects of Ecological Sanitation. PDF-Presentation. Aarau: seecon. http://www.sswm.info/sites/default/files/reference_attachments/WARNER%20et%20al%202008%20Socio%20Cultural%20Aspects.pdf. Accessed 20 June 2018.

Water Aid (2012). Sanitation and water for poor urban communities: A manifesto. London.

Watkins, K. (2006). Beyond Scarcity: Power, Poverty and the Global Water Crisis: Human development report. United Nations Development Programme. Palgrave Macmillan.

Wernick, I.K. and Irwin, F.H. (2005). Material Flows Accounts. A Tool for Making Environmental Policy. World Resources Institute, Washington.

Wheater, H. and Gober, P. (2013). Water security in the Canadian Prairies: Science and management challenges. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, **371(2002):** 20120409.

Willuweit, L. and O'Sullivan, J.J. (2013). A decision support tool for sustainable planning of urban water systems: Presenting the dynamic urban water simulation model. *Water Res*, **47(20):** 7206–7220.

Witter, S.G. and Whiteford, S. (1999). Water security: The issues and policy challenges. *International Review of Comparative Public Policy*, **11:** 1–25.

WHO (World Health Organization) (2003). Guidelines for safe recreational water environments: Coastal and fresh waters (Vol. 1). World Health Organization.

WHO (World Health Organization) (2008) World Health Organization Global Burden of Disease. 2004 Update. WHO Press, Geneva/New York.

WHO/UNICEF (World Health Organization/ United Nations Children's Fund) (2014a). Progress on Drinking-Water and Sanitation – 2012 Update. United States of America: WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation.

WHO/UNICEF (World Health Organization/ United Nations Children's Fund) (2014b). Progress on Drinking Water and Sanitation: 2014 Update. WHO Press, Geneva/New York.

WHO/UNICEF (World Health Organization/ United Nations Children's Fund) (2017). Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. Geneva.

World Bank (2011). World development report 2011: Conflict, security, and development. World Bank.

World Bank-World Health Organization. (2017). UN-Water global analysis and assessment of sanitation and drinking-water (GLAAS) 2017 report: Financing universal water, sanitation and hygiene under the sustainable development goals. Geneva: World Health Organization.

WWAP (World Water Assessment Program) (2002). Water for People, Water for life. United Nations World Water Development report. UN, Paris.

WWAP (World Water Assessment Program) (2006). Water: A Shared Responsibility. United Nations World Water Development report. UN, Paris.

WWF (World Wildlife Fund) (2016). Water security at basin scale: The importance of power, politics and communication. Business, business & government, rivers & freshwater. http://blogs.wwf.org.uk/blog/business-government/basin-water-security-stewardship-can-help-achieve/. Accessed 2 May 2018.

Wouters, P. (2005). Water security: What role for international water law? *In:* Dodds, F. and Pippard, T. (eds.), Human and Environmental Security: An Agenda for Change. Earthscan, London.

Xia, J., Lu, Z., Changming, L. and Yu, J. (2007). Towards better water security in North China. *Water Resources Management*, **21(1):** 233–247.

Yang, W., Hyndman, D., Winkler, J., Viña, A., Deines, J., Lupi, F., . . . Liu, J. (2016). Urban water sustainability: Framework and application. *Ecology and Society*, **21(4)**. www.jstor.org/stable/26270037. Retrieved May 3, 2020.

Zeitoun, M. (2011). The global web of national water security. *Global Policy*, **2(3):** 286–296.

Zhang, Y., Yang, Z. and Fath, B.D. (2010). Ecological network analysis of an urban water metabolic system: Model development, and a case study for Beijing. *Sci Total Environ*, **408(20):** 4702–4711.

Zhen, N., Barnett, J. and Webber, M. (2017). The dynamics of trust in the Shanghai water supply regime. *Environ Manage*, 1–12.

Chapter 10
Remote Sensing and GIS in Environmental Management

Surajit Chakraborty

1 Introduction

According to the United Nations, the earth's population is expected to grow to 9.7 billion people in 2050. As our population grows, new challenges to monitoring the environment and climate change will arise. Responsible and successful environmental management is necessary for protecting and restoring the natural environment. The interdependency of the earth's ecosystems and the human impact on the environment present complex challenges to governments and businesses as well as scientists and environmentalists in every discipline. As a result, there is a growing need for remote sensing of the environment at a global and local scale.

Remote sensing has a wide range of applications for environmental planning and management. Coastal applications, ocean applications, hazard assessments, mining, waste and natural resource management are just a few of the broad areas under which fall an array of analyses such as monitoring shoreline changes, measuring ocean temperatures, tracking the impacts of natural disasters and charting wildlife habitats. These types of analyses aid in the effective planning and management of the land and water, and its resources. At local and regional scales, acidification of surface waters, loss of biotic integrity and habitat fragmentation, eutrophication of lakes and streams, and bioaccumulation of toxic substances in the food constitute some of the many examples of how human-induced changes have affected the earth's systems and its environment (Tim and Mallavaram, 2003).

Nowadays, better sun-synchronous satellite sensors and the numerous satellite platforms are providing data and products of high spatiotemporal accuracy in cost-effective way, which are essential for many scientific fields of interest, especially in environmental studies (Kolios, 2018). More specifically, the advanced capabilities of the multispectral (or hyperspectral) satellite imagery make it possible to monitor

S. Chakraborty (✉)
Department of Environment Management, Indian Institute of Social Welfare and Business Management, Kolkata, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_10

spatial patterns and landuse/landcover changes using advance methodologies and spatial analyses even in inaccessible areas. These days a wide range of sensors operating in many satellite platforms provide multispectral imagery as well as microwave information. Moreover, polar-orbiting satellites, which carry lidars (Schutz et al., 2005; Popescu et al., 2011; Papagiannopoulos et al., 2016) has enhanced the capabilities of satellite in monitoring land/ocean/atmosphere. The increasing use of the remotely sensed images is because of the availability of wide range of spectral regions, ranging from visible to thermal infrared (passive radiometers), presence of microwave sensors and satellite Lidar/Radar technologies on board of sun-synchronous satellite. These remotely sensed datasets along with the use of the Geographical Information Systems (GIS) has expanded the horizon of many scientific communities regarding the choice of imagery sources and their ability to detect spectral, spatial and temporal characteristics of the examined parameters and phenomena.

Modern satellite images are valuable tools to monitor and map changes in land surface characteristics like vegetation, forest fire, desertification, urban sprawl, landuse/landcover changes etc. (Stavros et al., 2013; Jafari and Bakhshandehmehr, 2013; Sepehr et al., 2014). Furthermore, it must be mentioned that many satellite image products especially of high spatial resolution (finer than 10 m) are provided at costs, which in many cases are not affordable. Nevertheless, up to now, some satellite missions and instruments have already gained the preference of the majority of the scientist in monitoring land surface characteristics and spatiotemporal changes, by providing full image products of high quality and at no cost. The latest Landsat-8 series, which carries the Operational Land Instrument (OLI) and the Thermal Infrared Sensor (TIRS) provides multispectral images at spatial resolution of 30 m and radiometric accuracy capable to capture accurately, significant land changes at local to regional scales free of cost. It is also important to mention the case of Sentinel satellites, which can provide a huge amount of choices to monitor the environment at different spatial resolutions ranging from hundreds of kilometres (coarse resolution) to 10 m (high resolution). Another interesting satellite is the Advanced Land Observing Satellite (ALOS), which carries—among others—the Advanced Visible and Near Infrared Radiometer (AVNIR), providing multispectral images of 10 m spatial resolution.

Despite advances in geographical studies, the methods of traditional geography have become insufficient to apprehend its reality and complexity, considering technological and scientific changes that have happened during the last 30 years. However, this does not mean that these changes are not useful for geographic research. It has become evident now that GIS are developing spatial studies to appeal to such technologies as remote sensing and computer sciences (MEC, 1999).

Although this chapter is mainly concerned with GIS and remote sensing used for environmental management, the field of remote sensing is very wide in data acquisition methods, data processing procedures, and various techniques and applications. Therefore, it is useful to provide a general overview about several important topics regarding remote sensing of the surface of the earth. This is followed by discussions on the application of remote sensing and GIS in the field of broad environmental issues like climate change, mining environment, urban mapping and landuse change analysis, wetlands and watersheds mapping, groundwater investigation, coastal and marine environment, mapping of invasive species and disaster management, which could be identifiable from aerial photographs and satellite imagery.

2 Applications of Modern Satellites in Environmental Management Study

Remote sensing is the science of obtaining information about the earth using high-flying aircraft and satellites. The data is collected by sensors attached to the aircraft that detect the energy that is reflected from the earth (Fig. 10.1).

Availability of remotely sensed data from different sensors of various platforms with a wide range of spatiotemporal, radiometric and spectral resolutions have perhaps made remote sensing the best source of data for large scale applications and study. Remote sensing (satellite) imagery is available for most of the world since 1972. The multi-date nature of satellite imagery permits monitoring dynamic features of landscape environments and thus provides a means to detect major land-cover changes and quantify the rates of change (Joshi et al., 2004). The interpretation and analysis of Landsat TM image since 1987, provided a comprehensive

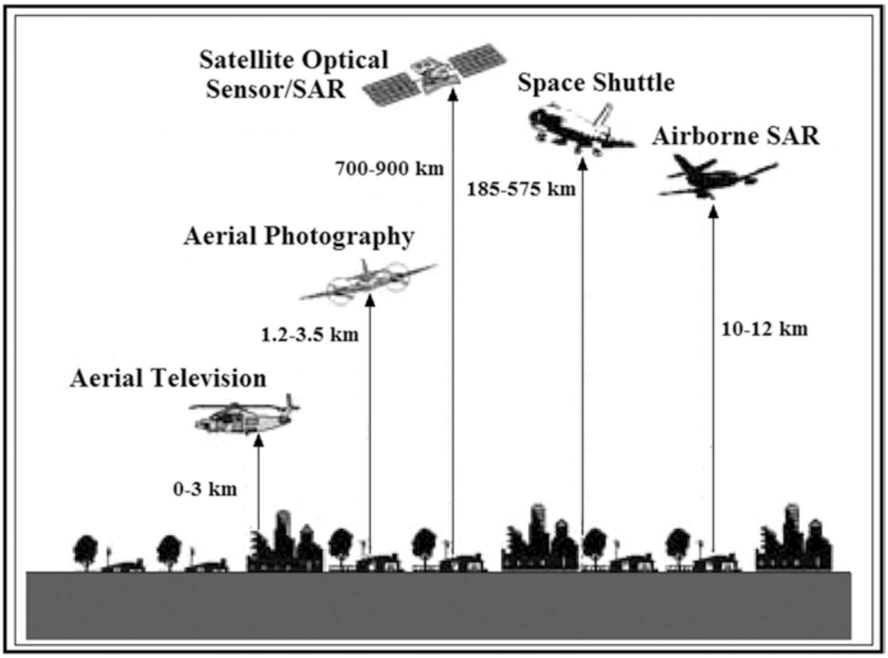

Fig. 10.1 Platforms and sensors of satellite and airborne remote sensing. (*Source:* Yamazaki, 2001)

information of the area especially regarding various landuses and their associated environmental problems. The use of remote sensing is becoming increasingly frequent in environmental studies. In the 1970s and 1980s, satellite images were mostly used in simple interpretations or as a map background (Merified and Lamar, 1975; Rib and Liang, 1978).

2.1 Evolution and Advances in Remote Sensing Satellites and Sensors for the Study of Environment

2.1.1 Optical Sensors

Optical sensors are those that detect electromagnetic radiation emitted or reflected from the earth, the main source of light being the sun. Among the passive sensors are photographic and optical-electronic sensors that combine similar photographic optics and electronic detection system (detectors and push scanning) and image spectrometers (Franklin, 2001; Jensen, 2006). Optical remote-sensing systems are classified into different types, depending on the number of spectral bands used in the imaging process:

1. *Panchromatic imaging system:* The sensor is a single-channel detector sensitive to radiation within a broad wavelength range. If the wavelength range coincides with the visible range, then the resulting image resembles a 'black and white' image.
2. *Multispectral imaging system:* The sensor is a multichannel detector with a few spectral bands. Each channel is sensitive to radiation within a narrow wavelength band. The resulting image is a multilayer image, which contains both brightness and spectral information of the targets.

NASA's Landsat, one of the more common multispectral image, is widely used for monitoring a wide range of landscape scale properties. Prior to the Hyperion and other airborne hyperspectral data, mostly multispectral remote sensing data were used to map the feasibility of environmental impacts in the world. Multispectral satellite data are highly useful for monitoring temporal changes and continuous monitoring of environmental impacts due to mining activities. Similarly, Synthetic Aperture Radar (SAR) images are useful in detecting landuse morphological changes due to mining activities.

3. *Hyperspectral imaging systems:* The sensor acquires images in several (typically hundred or more) contiguous spectral bands. The precise spectral information contained in a hyperspectral image enables better characterisation and identification of targets. Hyperspectral images have a great potential in applications regarding coastal management, vegetation monitoring, biomass estimation etc. It allows measurements of materials spectra, making it possible to identify an area specific mineral, rocks, soils and vegetation of the changes over time with high resolution

2.1.2 Active Sensors

Active sensors are those that provide its own energy source in order to control the double operation of signal emission and reception of known characteristics. These sensors have the advantage of an operational capacity to produce information both at night and in the day, in addition to working in a region of the electromagnetic spectrum that makes them less sensitive to atmospheric conditions. Of these, radar and LiDAR systems (Franklin, 2001; Jensen, 2006) are the most known.

3 Geographic Information System

GIS is used to collect, store, analyse, disseminate and manipulate information that can be referenced to a geographical location. GIS can be used in representative application areas to foster effective short- and long-term decision making in socio-economic and environmental problems, transportation, local government and business. Burrough and McDonnell (1998) have defined GIS as a powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data from the real world for a particular set of purposes. Application of GIS is revolutionising planning and management in the field of environment. The technology that has given vast scope to the applicability of remote sensing and field-based analysis is GIS.

4 Satellites and Sensors for Environmental Applications

Satellite remote sensing has a number of potential applications across a broad range of environmental disciplines. Each application itself has specific demands for spectral resolution, spatial resolution and temporal resolution of the satellite sensor. Remotely sensed information can be used in many environmental applications (Table 10.1).

A state-of-the-art satellite sensors widely used in environmental applications and natural resources management are given in Table 10.2. These sensors provide data in a wide range of scales (or pixel resolutions), radiometry, band numbers and band widths, and provides distinct advantage of consistency of data, synoptic coverage, global reach, cost per unit area, repeatability, precision and accuracy. Added to this is the long-time series of archives and pathfinder datasets (e.g., Tucker et al. 2005; Agbu and James, 1994) that have global coverage. Much of this data is also free and accessible online. Many applications (e.g., Thenkabail et al., 2006) in environmental monitoring require frequent coverage of the same area. This can be maximised by using data from multiple sensors (Table 10.1). However, since data from these sensors are acquired in multiple resolution (spatial, spectral, radiometric), multiple bandwidth, and in varying conditions, they need to be harmonised and synthesised

Table 10.1 Application of remote sensing in environmental studies

Atmospheric parameters	*Hydrological parameters*	*Natural and manmade hazards*	*Landuse planning*	*Environmental protection*	*Climate and coastal and inland waters*
– Aerosol – Fog – Blackcarbon – Dust storm – Ozone and other trace gases	– Water quality – Soil moisture – Sea surface temperature – Clouds optical properties – Snow cover	– Floods, tsunami, earthquakes, landslides mapping and risk assessment – Droughts – Epidemic mapping – Forest fires	– Landuse/ landcover changes – Urban planning – Urban heat islands – Agriculture – Forests (land & coastal) – Coastal zone monitoring – Wetlands and watersheds – Biomass estimation	– Environmental impact assessment	– Shoreline change detection – Coastal colour – Glacier retreat, changes in polar ice cover – Timberline change and coral bleaching

before being used (Thenkabail et al., 2004). This will help to normalise sensor characteristics such as pixel sizes, radiometry, spectral domain, and time of acquisitions, as well as for scales. Also, inter-sensor relationships (Thenkabail, 2004) will help to establish the seamless monitoring of phenomenon across landscape.

5 Indian Earth Observation System (EOS)

The Indian EOS has emerged as a strong constellation of geostationary and polar orbiting satellites (Table 10.3) to provide data for mapping and monitoring of ecosystems, detecting changes in various temporal and spatial scales and retrieval of land, oceanic and atmospheric parameters for calibrating and validating the circulation models (Navalgund and Singh, 2011; Navalgund et al., 2007; Navalgund, 2006). The current remote sensing satellites consist of theme-specific polar orbiting satellites, with a constellation of satellites in operation (IRS-1C, IRS-1D, IRS-P3, OCEANSAT-1/2,Technology Experiment Satellite (TES), RESOURCESAT-1 and CARTOSAT-1 and 2/2A/2B).

The polar orbiting satellite RESOURCESAT-1 provides multispectral data at 5.8 m (LISS-4), 23.5 m (LISS-3) and 56 m (AWiFS) spatial resolution with a few days to a few weeks revisiting capability, thereby offering a better scope for resource management. CARTOSAT-1 provides high resolution (2.5 m spatial resolution) panchromatic data in the stereo mode, making it possible to generate Digital Terrain

Table 10.2 Characteristics of some optical systems used in environmental applications

Sensor	*Spectral range (nm)*	*No. of bands*	*Spatial resolution*	*Temporal resolution*	*Orbit type*
Landsat 4,5 TM	450–900	4 VNIR	30 m	16 days	Sun synchronous
	1550–2350	2 SWIR	30 m		
	10410–12500	1 TIR	120 m		
Landsat 7 ETM+	450–900	4 VNIR	30 m	16 days	Sun synchronous
	1550–2350	2 SWIR	30 m		
	10410–12500	1 TIR	60 m		
	520–900	1 PAN	15 m		
SPOT 4-5 HRVIR	500–890	3 VNIR	20 m	26 days	Sun synchronous
	1580–1750	1 SWIR	20 m		
	610–680	1 PAN	10 m		
SPOT 5 HRS	500–890	3 VNIR	10 m	26 days	Sun synchronous
	1580–1750	1 SWIR	20 m		
	510–730	1 PAN	5 m		
ASTER	520–860	3 VNIR	15 m	16 days	Sun synchronous
	1600–2430	6 SWIR	30 m		
	8125–11650	5 TIR	90 m		
MODIS	620–14385	16 VNIR	250 m–1 km	1 day	Sun synchronous
		4 SWIR			
		16 TIR			
SeaWIFS	402–885	8 VNIR	1.1 km	1 day	Sun synchronous
MERIS	290–1040	15 VNIR	300 m	<3 days	Sun synchronous
Hyperion EO-1	400–2500	220	30 m	16 days	Sun synchronous
IKONOS-2	455–850	4 VNIR	4 m	1–3 days	Sun synchronous
	760–850	1 PAN	1 m		
Quick Bird	430–918	4 VNIR	2.44 m	<3 days	Sun synchronous
	405–1053	1 PAN	0.61 m		
Orbview-3	450–900	4 VNIR	4m	<3 days	Sun synchronous
	450–900	1 PAN	1m		
GeoEye-1	450–920 450–800	4 VNIR 1 PAN	1.65 m 0.41 m	2.1–8.3 days	Sun synchronous
WorldView-2	400–1040 450–800	8 VNIR 1 PAN	1.85 m 0.46 m	1.1–2.7 days	Sun synchronous
Pleiades 1A/1B	430–950 480–830	4 VNIR 1 PAN	2.0 m 0.5 m	1 day	Sun synchronous
Sentinel-2	420–2370	VNIR-SWIR	10, 20, 60 m	<3 days	Sun synchronous
RAPID EYE	440–850	5 VNIR	6.5 m	5 days	Sun synchronous
KOMPSAT-2	500–900 450–900	1 PAN 4 VNIR	1 m 4 m	14 days	Sun synchronous

Table 10.3 Planned and present Indian earth observation satellites used for environmental application

Satellite	*Sensors*
IRS-1A	LISS-I, LISS-II
IRS-1B	LISS-I, LISS-II
IRS P2	LISS
IRS1 C	LISS
IRS-P3	MOS A,B,C, WiFS
IRS-1D	LISS-III,PAN,WiFS
INSAT-2E	CCD, VHRR
IRS-P4 (Oceansat-1)	OCM, MSMR
IRS-P6	LISS-III, LISS-IV, AWiFS
IRS-P5 (Cartosat-1)	PAN (Fore, Aft)
Cartosat-2	PAN
Cartosat-2A	PAN
IMS-1	Hysi, Mx
Oceansat-2	Scatterometer, OCM, ROSA
Cartosat-2B	PAN
RISAT*	SAR
MeghaTropiques*	MADRAS, SAPHIR, ScaRaB, GPS Occ.
INSAT-3D*	Imager, sounder
SARAL*	Altika. ARGOS

*Planned for launching.

Model (DTM) for various applications. The latest remote sensing satellite CARTOSAT-2/2A/2B is designed to provide much higher resolution data (0.8 m spatial resolution) for cartographic mapping. Oceansat-1 and Oceansat-2 both carry eight band Ocean Colour Monitor (OCM). Passive microwave radiometer (MSMR) was flown on Oceansat-1 satellite, which provided important information on polar ice cover.

6 Applications

6.1 Climate Change

Satellite remote sensing has provided major advances in understanding the climate system and its changes, by quantifying processes and spatiotemporal states of the atmosphere, land and oceans.

The Global Climate Observing System (GCOS) has listed 26 out of 50 essential climate variables (ECVs) as significantly dependent on satellite observations (WMO, 2011). Data from satellite remote sensing is also widely used for developing prevention, mitigation and adaptation measures to cope with the impact of climate change (Joyce et al., 2009).

In the past decade, various ozone-monitoring sensors had been launched to study global climate cycles. These include the Total Ozone Mapping Spectrometer (TOMS) sensor and many of the sensors on Terra, Aqua and future EOS satellites. Advanced very-high-resolution radiometer (AVHRR) data from National Oceanic and Atmospheric Administration's (NOAA) Polar Operational Environmental Satellite (POES) is used in conjunction with RADARSAT to monitor the polar ice sheets and iceberg movements. The Earth Observation Satellites (EOS), beginning with the Terra, were designed specifically for monitoring climate conditions, including the observation of aerosols, cloud cover, fires, ocean productivity, pollution, solar radiation, sea ice and snow cover (Michael and David, 2000).

India's Earth Observation Programme addresses various aspects of land, ocean and atmospheric applications. The present and planned missions such as Resourcesat-1, Oceansat-2, RISAT, Megha-Tropiques, INSAT-3D, SARAL, Resourcesat-2, Geo-HR Imager and series of environmental satellites (I-STAG) would help in understanding the issues related to climate changes. Navalgund and Singh (2011) have thoroughly mentioned various experiments and studies carried out at ISRO (Indian Space Research Organisation) on mapping/detecting the indicators of climate change, monitoring the agents of climate change and understanding the impact of climate change, in national perspectives. Studies to assess glacier retreat, changes in polar ice cover, timberline change and coral bleaching are being carried out to monitor indicators of climate change.

India has also launched geostationary satellites, i.e., INSAT series (viz., INSAT 1, 2 and 3) and METSAT (Kalpana-1) for meteorological applications. INSAT series deployed in orbit comprises Very High Resolution Radiometer (VHRR) with imaging capability in visible (0.55–0.75 μm), thermal infrared (10.5–12.5 μm) and water vapour channel (5.7–7.1 μm) and provides 2×2, 8×8 and 8×8 km ground resolution, respectively. The satellite METSAT (Kalpana-1), which carries VHRR and Data Relay Transponder (DRT) payload, provides meteorological services.

6.1.1 Earth Observation Systems for Monitoring Climate Variables

The Earth System Science Pathfinder (ESSP) of NASA addresses unique, specific, highly focused mission requirements in earth science research. The ESSP program is an innovative approach for addressing Global Change Research by providing periodic 'Windows of Opportunity' to accommodate new scientific priorities. ESSP missions are capable of supporting a variety of scientific objectives related to earth science, including the atmosphere, oceans, land surface, polar ice regions and solid earth. The ESSP mission comprises analysis/retrieval of parameters from the host of satellites viz., Gravity Recovery and Climate Experiment (GRACE), Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), CloudSat and Aquarius. NASA has developed a strategy for long-term monitoring of some key parameters needed to bring us closer to the answers we need regarding climate change and its relation to social systems. This technology consists of a group of satellites that can make a suite of earth observations referred to as the ‘A-Train’. CloudSat and CALIPSO, Aqua, PARASOL and Aura are important satellites in A-Train formation.

6.1.2 Space-based Climate Change Studies

Many studies have been carried out towards mapping and monitoring of climate change indicators, which include glacier retreat (Kulkarni et al., 2005, 2006, 2007), changes in polar ice cover (Vyas et al., 2003), timberline change (Panigrahy et al., 2007) and coral bleaching (Bahuguna, 2008). There have been some pioneering efforts to map the global change forcing agents. Spatial methane inventories from paddy rice (Manjunath et al., 2009), livestock (Chhabra et al., 2009) and wetlands (Garg et al., 2005) have been prepared. Trends and seasonal pattern of aerosols (Singh et al., 2004; Prasad et al., 2004), CO (Singh et al., 2008a), CO_2 (Singh et al., 2008b) and NO_2 (Ghude et al., 2008) have been analysed. All these information along with land surface parameters may help in improving the accuracy of regional climate models and their projections for India.

6.1.3 Glacial Retreat in Himalaya

Satellite remote sensing data has been used to map and monitor the Himalayan glaciers. Glacier inventory of Indian Himalaya has been completed at 1:250,000 scale using IRS-1A (LISS-II) data. 1702 glaciers covering an area of 23,300 km^2 has been mapped. Initial studies on monitoring of glacial retreat and estimation of loss in glacial area carried out for two glaciers viz., SamudraTapu (Kulkarni et al., 2006) and Parbati glaciers (Kulkarni et al., 2005) in Himachal Pradesh using satellite images show that these glaciers are presently retreating at the rate of 26 m and 38 m per year, respectively (from base year 1962) (Navalgund and Singh, 2011).

6.1.4 Change in Polar Ice Cover

Polar sea ice has been monitored quasi-continuously over the last 30 years using Passive Microwave Radiometers (PMR), namely SSMR (Nimbus-7) and SSM/I (DMSP). Space Applications Centre (SAC), in collaboration with National Centre for Antarctic and Ocean Research, Goa, India, has also contributed significantly in the use of MSMR data for monitoring the Antarctic region. Vyas et al. (2003) have assessed the potential of Multifrequency Scanning Microwave Radiometer (MSMR) observations for analysing the sea ice extent. Bhandari et al. (2005) have carried out relative calibration of MSMR using independent SSM/I measurements for Sea Ice Concentration (SIC). These studies have developed the confidence on use of MSMR data for polar ice studies.

6.2 Mining Environment

The application of remote sensing techniques in the mining environmental study has unique advantages, because of its multispectral mode, synoptic view and repetitive coverage. The advancement of high-resolution imaging spectrometry is an excellent tool to study the environmental impacts due to mining activities. To monitor the landuse changes due to opencast strip mining, subsidence, dumping of mine wastes, deforestation and erosion due to mining activities satellite based remote sensing techniques have been applied successfully (Gupta, 2005). Mularz (1998) mapped the landuse/land cover changes in and around the open-cast lignite mine in the central part of Poland using airborne remote photography along with Landsat TM and SPOT images to discriminate, assess and even to measure the impact on the environment due to mining. The degradation of land due to coal mining using remote sensing techniques at Jharia coal field has been studied by Prakash and Gupta (1998). Das and Nizamuddin (2002) have successfully utilised the hyperspectral sensor ('Hyperion') data to map the mineral abundance in iron and manganese mines in parts of Singhbhum district, Orissa. They also utilised spectral signature and spectral mixture modelling techniques for targeting laterite and bauxite ore deposits. Levesque et al. (2001) used the hyperspectral remote sensing data to monitor and assess the rehabilitation of mine tailing sites. Multi-date infra-red Landsat images were utilised to study the environmental changes in Sierra Leone, West Africa, especially to understand the impact on hydrogeomorphology (Akiwumil and Butler, 2007). An attempt has been made to delineate the magnesite ore deposits in Salem using hyperspectral remote sensing data, which reveals the potential of using narrow band hyperspectral data for mapping the impact of mining on environment (Sathish Kumar et al., 2011).

6.3 Wetland and Watershed Mapping

Mapping and monitoring of wetlands have gained importance with the development of the remote sensing techniques. Wetlands as a transition between terrestrial and open-water aquatic ecosystems (Mitsch and Gosselink, 2015) contain open water bodies, vegetation and mixture and mixture of both.

Wetland monitoring may employ a combination of land-observation and ocean-observation satellites. ETM+ data can be used to delineate wetland areas, make topographical observations, and to detect illegal development. Active systems can provide consistent and accurate observations of dynamic wetland parameters such as tidal and seasonal patterns, climate, hydrology, topography, vegetation and soil type (Elijah, 1997). Satellite data and images can also be used to delineate the flow of water through watersheds, and can even be used to track pollutants. Furthermore, using algal productivity as an indicator, scientists are able to monitor whether high levels of nutrients pollute areas of a watershed (David, 2000).

The most commonly used multispectral satellite sensors for wetland mapping include Landsat MSS/TM/ETM/OLI, MODIS, AVHRR, SPOT-4/5/6/7, IKONOS, QuickBird, GeoEye-1, RapidEye, Sentinel-2 and WorldView-1/2/3/4, among others. Comprehensive reviews of these commonly used satellite sensors for wetland mapping can be found in Ozesmi and Bauer (2002), Klemas (2011) and Lang et al. (2015). Compared to aerial photography, satellite sensors can provide multispectral imagery with finer spectral and better temporal resolutions, which are essential for classifying wetland vegetation types and analysing wetland water dynamics (Wu, 2018).

New image analysis techniques using hyperspectral imagery and narrow-band vegetation indices have been able to discriminate some wetland species and estimate biochemical and biophysical parameters of wetland vegetation, such as water content, biomass, and leaf area index (Adam et al., 2010; Gilmore et al., 2010; Ozesmi and Bauer, 2002; Wang, 2010).

The integration of hyperspectral imagery and light detection and ranging (LIDAR)-derived elevation data has significantly improved the accuracy of mapping salt marsh vegetation (Yang and Artigas, 2009; Yang et al., 2009). LIDAR techniques, combined with GPS, can provide accurate topographical and bathymetric maps, including shoreline positions (Ackermann, 1999; Lillycrop et al., 2002). SAR technology provides the increased spatial resolution that is necessary in regional wetland mapping, and SAR data have been used extensively for this purpose (Bourgeau-Chavez et al., 2005; Lang and McCarty, 2008; Novo et al., 2002).

The mapping of submerged aquatic vegetation (SAV), coral reefs, intertidal habitats and general bottom characteristics has benefited from the newly available high-resolution (0.6–4 m) satellite and aerial hyperspectral imagery (Mishra et al., 2006; Mumby and Edwards, 2002; Trembanis et al., 2008). High-resolution multispectral data provided by satellites, such as IKONOS and QuickBird, have been used to map SAV with accuracies of about 75% for classes including high-density seagrass, low-density seagrass and unvegetated bottom.

Landsat data from 1985 to 2009 have been used for mapping changes in wetland ecosystems in northern Virginia using the NDVI (Normalised Difference Vegetation Index) (Kayastha et al., 2012). Another study (Dong et al., 2014) uses both NDVI and LSWI (Land Surface Water Index) for mapping wetlands in Northwest China. Other indices such as ARVI (Atmospherically Resistant Vegetation Index) (Kaufman and Tanre, 1992), SARVI (Soil and Atmosphere Resistant Vegetation Index) (Huete et al., 1997), NDWI (Normalised Difference Water Index) (Dvorett et al., 2016) etc. have been also used for mapping wetlands. GIS have also been widely used aside with remote sensed data in monitoring wetlands (Feyisa et al., 2014). Czajkowski et al.(2007) used GIS rule-based decision tree algorithm to classify four different wetland types. Kaplan and Avdan (2017) presented the capabilities of Sentinel-2 for mapping and monitoring wetlands. For this purpose, three different approaches were used: pixel-based, object-based and index-based classification. Additionally, for more successful extraction of wetlands, a combination of object-based and index-based method was proposed.

Table 10.4 Imagery acquisition costs (approximate)

	Resolution (m)	*Swathwidth (km)*	*Cost ($/km²)*
Digital camera imagery (ADS40)	0.3[a]		330
Aerial hyperspectral (AISA)[b]	2.3	0.6	175
High resolution satellite (IKONOS)	1–4	13	30
Medium resolution satellite (Landsat TM)	30	180	0.02[c]

[a]Cell area ¼ 2.3 3 2.3 km.
[b]35 spectral channels (0.44–0.87 µm).
[c]$600 per scene (now free of charge).

Therefore when remote sensing techniques are used wisely with complementary combinations of different satellite and airborne sensors, they can provide data that can enhance the research, management and restoration of coastal ecosystems. Remote sensors used in wetland restoration projects can monitor and assess long-term trends and short-term changes of vegetation and hydrology faster, more completely, and at lower cost per unit area than field surveys. However, as shown in Table 10.4, cost becomes excessive if the site is larger than a few hundred square kilometres, and in that case, medium-resolution sensors, such as Landsat Thematic Mapper (TM) (30 m) and SPOT (20 m), become more cost effective than the high-resolution systems (Klemas, 2011).

6.4 Urban Mapping and Landuse Change Analysis

Timely and accurate information on the existing landuse/landcover pattern and its spatial distribution and changes is a prerequisite for planning, utilisation and formulation of policies and programmes for making any micro- and macro-level developmental plans. Remote sensing technology along with GIS is an ideal tool to identify, locate and map various types of lands associated with different landform units (Dhinwa et al., 1992; Palaniyandi and Nagarathinam, 1997; Murthy and Venkateswara, 1997; Khan et al., 1999). Passive sensors, including those on the NOAA, IKONOS, Landsat, Terra and SPOT satellites are used in a broad range of forest and landuse applications. These applications include estimations of primary production, biomass, crop yields and to delineate vegetation type, deforestation, desertification, forest boundaries, forest harvest, soil erosion and bush or forest fires. Landsat 7's EMT+ sensor is especially useful in studying landuse change because its data have been archived since the first Landsat mission in 1972. Passive sensors have also been used to observe and monitor changes associated with storm, flood and fire damage.

In India, the complexity of urban development is so dramatic that it demands immediate attention and perspective physical planning of the cities and towns (Sokhi, 1999). The dynamic nature of urban environmental necessitates both macro- and micro-level analysis. Therefore, it is necessary and fundamental for policy makers to integrate remote sensing into urban planning and management. Traditional approaches and technique designed for towns and cities may prove to be inadequate tools when dealing with metropolis. New approaches are required, and new methods must be incorporated into current practice. Until recently, maps and land survey records from the 1960s and 1970s were used for urban studies, but now the trend has shifted to using digital, multispectral images acquired by EOS and other sensors. The trend towards using remotely sensed data in urban studies began with first-generation satellite sensors such as Landsat MSS and was given impetus by a number of second-generation satellites: Landsat TM, ETM+ and SPOT. The recent advent of a third generation very high spatial resolution (5 m/pixel) satellite sensors is stimulating. The high-resolution PAN and LISS III merged data may be used together effectively for urban applications. Data from IRS P-6 satellites with sensors on board especially LISS IV Mono and Multispectral (MX) with 5.8 m/pixel spatial resolution is very useful for intensive urban studies (Rai and Kumra, 2011). IRS-1D Pan image with 5.8 m resolution, Cartosat-I imagery of 2.5 m resolution with stereo capabilities, Cartosat-II with 1 m, IKONOS imageries of Space Imaging with 4 m in multispectral mode and 1 m in panchromatic mode, Quickbird imagery of Digital Globe with 61 cm resolution in panchromatic mode provide a new methodology in the urban mapping application (NRSA, 2005).

Application of remote sensing technology can lead to innovation in the planning process in various ways:

(a) Digitisation of base maps.
(b) Development of various layers of information with the help of image processing software like ERDAS Imagine, ENVI and PCI Geomatica, ILWIS etc. Such superimposed maps in GIS software like Map info, Geomedia, Arc View, Auto CAD Map and Arc GIS provide valuable information for planning, implementing and management in urban areas.
(c) Selection of sites for specific facilities such as hospital, restaurants, solid waste disposal and industry.

The potentials of remote sensing techniques in urban application includes study of urban growth and sprawl analysis, landuse and landcover mapping, urban change detection and mapping, urban infrastructure and utilities mapping, urban land surface temperature mapping, urban population estimation and management. Some of the salient features of different satellite sensors and the extractable levels of urban information are summarised in Table 10.5.

Remote sensing literature review suggests that major approaches for urban environmental management include pixel-based image classification (Schneider et al., 2009), spectral index (Deng and Wu, 2012), object-oriented algorithms (Bhaskaran et al., 2010), machine learning like artificial neural networks (Zhang and Foody, 2001) and decision tree classification algorithm (Schneider et al., 2010). Techniques, such as data/image fusion, have also been explored (Byun et al., 2013). Recent research has used high and very high spatial resolution remote sensing imagery to quantitatively describe the spatial structure of urban environments and characterise

Table 10.5 Remote sensing platforms and sensor application in urban studies

Platform and sensor system	*Spatial resolute (m, pixel)*	*Year of operation*	*Mapping scale*	*Extractable information*
Landsat (MSS) IRS-1A & 1B- (LISS-I)	80 72	1972 1988 & 1991	1: 1,000,000 1: 250,000	Broad landuse/landcover and urban sprawl
Landsat TM IRS-1A & 1B- (LISS-II) IRS-1C & 1D- (LISS-III) SPOT HRV-I(MLA) IRS-1D(LISS-IV)	30 36 23 20 5.8	1982 1988 & 1991 1995 & 1997 1998 2003	1: 50,0000 1: 5000	Thematic data for broad structural plans and spatial strategies
ASTER VNIR(0.52–0.86 μm) SWIR(1.60–2.43 μm) TIR(8.125–11.65 μm)	15 30 90	1999	1: 250,000 1: 50,000	Landuse/landcover, urban sprawl, ecological monitoring data
SPOT HRV-II(MLA) IRS-1C &1-D(PAN)	10 5.8	1998 1995 & 1997	1:25,000 1:10,000	Data for landuse/landcover for urban area
MOMS-II	4	1983	1:8000	Landuse/landcover details
IKONOS Quickbird	1.0 0.61	1999 2001	1:4000 1:2000	Cadastral map, detailed information extraction for urban planning and infrastructure mapping
CARTOSAT-1 CARTOSAT-2	2.5 1.0	2005 2007	1:4,000 1:1000 1:2000	Large scale cartographic work and DM generation cartographic applications at cadastral level, urban and rural infrastructure development and management
ALMAZ	1.0		1: 4000 1: 2500	Ground plans and urban design
RESOURCESAT-I(LISS-IV)	5.8	2003	1:10,000/ 1:4000	Monitoring the urban growth, inventory of landuse/landcover

Source: Modified after Rahman (2006).

patterns of urban morphology (Puissant et al., 2012). Additionally, the methods based on the artificial neural networks (ANN) are also widely used for the classification of urban areas (Mas and Flores, 2008). Other supervised classification methods such as decision tree (DT), regression model (RM) and maximum likelihood (ML) can also provide plausible results in the mapping of urban areas (Bhatta, 2010).

6.4.1 Urban Growth and Sprawl Analysis

Although a chronological history of urban geographic research in India can be found in Thakur and Parai (1993), researches on urban growth, especially by using remote sensing data, have not been well documented. The first appearance of urban growth and sprawl analysis using remote sensing data in a publicly published form can be found in 1989 in the *Journal of the Indian Society of Remote Sensing*. Two papers, Sokhi et al. (1989) and Uttarwar and Sokhi (1989), were published; both focusing on the city of Delhi. Research of Uttarwar and Sokhi (1989) was aimed to study the urban fringe from aerial remote sensing data. The other paper, Sokhi et al. (1989), was focused on mapping and monitoring of sprawl. Satellite imageries of 1975, 1981, 1985 and 1987 were visually interpreted to prepare landuse/landcover maps via manual mapping. Sudhira et al. (2003) focused on the analysis of urban growth pattern in the form of either radial or linear sprawl along the Bangalore–Mysore highway over a period of 1972–1998. They used classified remote sensing image for 1998 and Survey of India topographical maps for the year 1972. Kumar et al. (2007) considered Indore city for a similar analysis. They analysed the city using three temporal satellite remote sensing data for a period of 1990–2000. A paper by Jat et al. (2008) is another example which analysed the Ajmer city (Rajasthan) for the time span of 1977–2005 using eight temporal satellite remote sensing data. They classified the images using supervised maximum likelihood classifier to extract 10 information classes. Bhatta (2008) analysed the urban growth pattern of Kolkata using Landsat Multispectral Scanner (MSS), Landsat Thematic Mapper (TM) image, Landsat Enhanced Thematic Mapper Plus (ETM+). Several statistical methods were applied to recognise and analyse the pattern, which shows increasing dispersed development of the city with the declining population growth rate.

6.4.2 Urban Land Surface Temperature Mapping

Rise in urban population, rapid industrialisation, destruction of tree cover, filling of wetlands and waterbodies are the principal cause of climate change in recent times. Vegetated areas are been converted to concrete land surfaces resulting in the rise in land surface temperature (LST). Various studies have investigated the trend of landuse change with relative rise in LST of urban areas (Weng et al., 2004; Pal and Ziaul, 2017). The availability of thermal remote sensing (TRS) data and high-resolution satellite images has made quantification and estimation of LST more accurate through assessment of land surface emissivity (Nicloś et al., 2004; Humes et al., 1994). The increase in urbanisation has deteriorated the environmental quality in respect of rise in particulate levels and other pollutants in the atmosphere, change in LU/LC, increase in LST and formation of urban heat island (UHI) (Kant et al., 2009; Rahman et al., 2009; Mallick et al., 2013). Dhar et al. (2019) carried out surface heating problem for the newly developed satellite city of Rajarhat New Town located east of Kolkata city with the help of high-resolution satellite images. This study discusses the impact of landuse/landcover (LULC) change on LST of the area in and around Rajarhat block, North 24-Parganas District, West Bengal, covering an area of 165 km^2. Multispectral and multitemporal satellite data from Landsat 5 TM (1990), Landsat 8 OLI (2016) and Sentinel 2A (2016) are used for the LU/LC mapping, and thermal infrared data from Landsat 5 TM and Landsat 8 TIRS (2016) are used for estimating the LST of 1990 and 2016. Results show that landuse pattern in November has changed in Rajarhat from 1990 to 2016. Loss of vegetation (scrubland and tree) cover resulted in LST rise by about 1.5°C.

6.4.3 Urban Hydrology

The urban agglomerations in India are facing at least four hydrological problems, i.e., the mobilisation of sufficient volume of water for domestic and industrial consumption, urban water pollution and quality, flood control and urban storm water runoff disposal. The role of remote sensing in runoff calculation is generally to provide a source of input data or as an aid for estimating equation coefficient and model parameters. Remote sensing techniques can also be applied to obtain information pertaining to surface water quality, soil, drainage, landuse, groundwater and slope of the catchment. For example, remote sensing technology was used to manage the metro water supply problems of Madras city (NRSA, 1994). Chakraborti (1989) discussed an approach for urban stormwater runoff modelling, water supply assessment, and water quality surveillance of Delhi, Najafgarh, Patna and Hyderabad. The operational utility of remote sensing techniques in water resources assessment of Hyderabad city has been dealt with using Landsat TM and IRS LISS-I and II data (Satyanarayana, 1991). Pandey et al. (2014) carried out a study using Landsat TM FCC (False Colour Composite) image to identify and delineate different hydrogeomorphological units in and around Jhansi city and correlated these units with the well yields. Remote sensing can be applied to drainage studies using proxies or surrogates. Satellite data have been successfully used to map surface drainage pattern (Campbell, 1987).

The GIS technology has the ability to capture, store, manipulate, analyse and visualise hydrological data. GIS was utilised to apply a modified DRASTIC method to assess the aquifer vulnerability to arsenic pollution of English Bazar Block of Malda District, West Bengal, India (Chakraborty et al., 2007). The DRASTIC model considered seven groundwater parameters: depth of water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity. The analysis indicated that in 62% of the area the vulnerability classes matched with the arsenic concentration in groundwater. Another study was carried out by Singh et al. (2015) to characterise the human settlement pattern using satellite observation of night-lights and landuse/landcover distribution of Lucknow city. Miller et al. (2007) have developed automated geospatial watershed assessment (AGWA) tool in GIS for analysing water resources. The key components of AGWA are the commonly available GIS data layers to parameterize, execute, and visualize results from two hydrological models – the Soil and Water Assessment Tool (SWAT) and Kinematic Runoff and Erosion model (KINEROS2).

6.5 Groundwater Investigation

Modern technologies such as remote sensing and GIS have proved to be useful for studying geological, structural and geomorphological features together with conventional surveys. Integration of the two technologies has proven to be an efficient tool in groundwater studies (Krishnamurthy et al., 2000; Sander et al. 1996; Saraf and Chowdhury, 1998). Satellite images are increasingly used in groundwater exploration because of their utility in identifying various ground features, which may serve as either direct or indirect indicators of presence of groundwater (Bahuguna et al., 2003). A few studies have attempted to establish relationships between remotely sensed data and data related to groundwater in hard rocks. In certain cases, the imagery proved to contain features, which have a direct link to groundwater discharges. Shahid and Nath (2002), Goyal et al. (1999) and Saraf and Chowdhury (1998) have used remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. Jaiswal et al. (2003) have used GIS technique for generation of groundwater prospect for rural development. Sikdar et al. (2004), Madrucci et al. (2008) and Machiwal et al. (2011) have used a standard methodology to delineate groundwater potential zones using integrated RS, GIS and multi-criteria decision making (MCDM) techniques. Rao and Jugran (2003) have applied GIS for processing and interpretation of groundwater quality data.

6.6 Coastal and Marine Environment

Coastal zones in India are constantly undergoing wide-ranging changes in shape and environment due to natural as well as human development activities. It is, therefore, necessary to monitor coastal zone changes with time using space-borne satellites. The sensitivity of the coastal zone to sea-level rise and its obvious impacts on the societal, economic and ecological aspects of the coastal areas demand constant monitoring and appraisal of prospective impacts and probable responses of this phenomenon (Costanza et al., 1997; Agardy et al., 2005).

Remote sensing technology in recent years has proved to be of great importance in environmental monitoring programmes where the objective is to monitor changes in shoreline position and surface area over time (Goodchild, 2001; Durduran, 2010). Coastal areas have been regularly monitored using satellite imagery from time to time (Balopoulos et al., 1986; Dekker et al., 1992; Lemmens, 2001; Saha et al., 2014).

A list of the most relevant optical sensors used in the last decade to assess coastal zone environment is shown in Table 10.2. A number of sensors have been launched since the Coastal Zone Color Scanner (CZCS) in 1978, including the Sea-viewing

Wide Field-of-view Sensor (SeaWiFS), the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Medium Resolution Imaging Spectrometer (MERIS). Traditionally, the Landsat (TM and ETM+), the French Système Pour l' Observation de la Terre (SPOT) and Terra/ASTER have been reliable data sources for large coastal watersheds' landcover (Davranche et al., 2010; Santillan et al., 2011), water turbidity quantification (Hellweger et al., 2004), suspended sediments' concentration estimation (Ouillon et al., 2008), vegetation cover (Ruelland et al., 2008), among others. However, the 30 m, 20 m and 15 m spatial resolutions in the visible and Near Infra-Red (NIR) bands were initially designed for landcover studies. The availability of high spatial and spectral resolution satellite data has significantly improved the capacity for mapping coastal ecosystems. High-resolution imagery obtained from satellites, such as IKONOS-2, Quick Bird-2, GeoEye-1 and Orbview-3 can be used for different purposes regarding coastal applications. WorldView-2 has a spatial resolution of 2 m for eight multispectral (MS) bands (four standard colours: red, blue, green, NIR, and four new colours: red edge, coastal, yellow, NIR2) and 0.5 m spatial resolution for the panchromatic (PAN) band (450–800 nm). The Pleiades 1A/1B satellites were designed with urgent tasking option, and images can be requested less than six hours before they are acquired. This functionality will prove invaluable in situations where the expedited collection of new image data is crucial, such as coastal crisis monitoring. This sensor is comparable to the other high-resolution sensors (e.g., GeoEye-1, Orbview-3). The Hyperion provides a high-resolution hyperspectral image capable of resolving 220 spectral bands with a 30 m resolution. Through these spectral bands, complex coastal ecosystems can be imaged and accurately classified.

Some application fields related to coastal environments, where optical remote sensing plays an important role are discussed below.

6.6.1 Shoreline Mapping

The shoreline is the boundary between land and waterbody. The shoreline is defined as the line contacting between the mean high-water line and the shore. Various methods for shoreline extraction from optical imagery have been developed.

Guariglia et al. (2006) used a multisource approach for coastline mapping in Basilicata region (Italy). They stated that satellite images are affected by tidal variations depending on their spatial resolution and concluded that the coastline can be extracted from Landsat TM images, without the interference of the tidal factor.

Maiti and Bhattacharya (2009) used multi-date satellite images from Landsat MSS, TM, ETM+ and ASTER to demarcate shoreline positions from which shoreline change rates have been estimated using linear regression along the coast of Bay of Bengal (India) between 1973 and 2003. The shorelines have been identified through the NIR bands, and included grey level thresholding and segmentation by edge enhancement technique. The result shows that 39% of transects have uncertainties in shoreline change rate estimations. On the other hand, 69% of transects exhibit lower root mean square error (RMSE) values for the short-term period indicating better agreement between the estimated and satellite-based shoreline positions.

Chatterjee et al. (2015) analysed the shoreline patterns of 14 selected islands from the Indian Sundarbans delta since 1979 using LANDSAT-TM and IRS 1D LISS III satellite images. They found that all the islands, except Nayachar, are under stress from erosion, sea level rise, inundation or subsidence, resulting in a loss of land area of more than 80 km^2. It was observed that erosion in the eastern part of the delta was more rapid than in the western part. Similar works on shoreline change detection had been carried out on the Mississippi delta by Coleman et al. (2008) and Blum and Roberts (2009).

Thakur et al. (2017) used Landsat 5 TM and Landsat 8 OLI images of the years 1990 and 2016 to detect and analyse the shoreline changes in the Namkhana-Bakkhali-Frasergunj Island of the Sundarban region. The result shows some significant changes in the shoreline position. The eastern and western flanks of the island show both erosion and accretion depending on the flow velocity of the river waters. The southern coast shows increased subaqueous deposition due to lateral shifting of river sediment load by tidal and long-shore currents. Despite of increased deposition, the emerged coastline shows a general retreating trend with decreased beach area by 29.34% during the period 1990–2016.

In conclusion, several techniques for coastline extraction and change detection from optical satellite imagery have been developed in recent years. Regular assessment of changing coastline and LU/LC features of the area is, thus, essential for coastal zone management, environmental mitigation and best landuse practices in the overall interest of mankind.

6.6.2 Ocean Colour

The need for more effective environmental monitoring of the open and coastal ocean has recently led to notable advances in satellite ocean colour technology and algorithm research. Satellite ocean colour sensors' data are widely used for the detection, mapping and monitoring of phytoplankton blooms because earth observation provides a synoptic view of the ocean, both spatially and temporally. Algal blooms are indicators of marine ecosystem health; thus, their monitoring is a key component of effective management of coastal and oceanic resources.

Ody et al. (2016) studied the potential of various satellite sensors including Landsat-8 OLI, MODIS Terra and Aqua, and SEVIRI MSG-3 to monitor and map suspended particulate matter (SPM) in the micro-tidal Rhône River plume. They developed regional algorithms using in situ SPM and satellite derived Remote sensing reflectance (Rrs) data, which were applied to the satellite data sets to monitor the spatio-temporal variations in SPM. Despite being a micro-tidal environment, they found a significant short-term (hourly) variations in SPM mainly controlled by wind and regional circulation. Ody et al. (2016) also discussed the advantages and drawbacks of these satellite sensors in mapping SPM for the study site.

Cheng et al. (2016) assessed diurnal and seasonal variations in the spatial distribution of total suspended particulate matter (TSM) using high frequency Geostationary Ocean Colour Imager (GOCI) data. They found that the diurnal variations of TSM in the macro-tidal Yalu River estuary, China is strongly linked to the tidal cycle induced re-suspension, producing two peaks corresponding to maximum flood and ebb events. The seasonal variability of TSM in the estuary which was highest in winter and lowest in summer was also clearly identified. This study showed the potential of GOCI data in high frequency spatio-temporal monitoring of water quality.

Han et al. (2016) developed a generic semi-analytical algorithm to estimate suspended particulate matter from coastal waters using an extensive data set acquired from coastal areas of Europe, French Guiana, North Canada, Vietnam and China as part of the GlobCoast project. These algorithms were designed to work on various satellite sensors such as MERIS, MODIS, VIIRS, SeaWiFS, Landsat-8OLI and Sentinel 2 and 3. They demonstrated an improved performance by the generic semi-analytical algorithms which used a switching criterion based on the remote sensing reflectance value in red band (at 670 nm).

6.7 Mapping and Spatial Modelling of Invasive Species

Invasive species are a current focus of interest of ecologists, biological conservationists and natural resources managers due to their rapid spread, threat to biodiversity and damage to ecosystems. The global extent and rapid increase in invasive species is homogenising the world's flora and fauna (Mooney and Hobbs, 2000) and is recognised as a primary cause of global biodiversity loss (Czech and Krausman, 1997; Wilcove and Chen, 1998). Bio-invasion may be considered as a significant component of global change and one of the major causes of species extinction (Drake et al., 1989).

Remote sensing technology has received considerable interest in the field of biological invasion in the recent years. It is a tool offering well-documented advantages including a synoptic view, multispectral data, multi-temporal coverage and cost effectiveness (Van der Meer et al., 2002). Integrated GIS and remote sensing have been successfully applied to map the distribution of several plant and animal species, their ecosystems, landscapes, bio-climatic conditions and factors facilitating invasions (Stow et al., 2000; Los et al., 2002; Haltuch et al., 2000).

Based on remotely sensed canopy reflectance response species has been classified into four types as follows:

(a) *Canopy Dominating Species:* Several invasive species dominate the canopy of the earth surface forming homogeneous single species stand that extends over larger areas. Detection of invasive *Prosopis glandulosa* var. *torreyana* and *P. velutina* using TM images (Harding and Bate, 1991), *Gutierrezia sarothrae* with NOAA-10 low resolution spectral image (Peters et al., 1992), *Kalmia angustifolia* (Franklin et al., 1994), *Imperata cylindrical* with multispectral high-resolution visible (HRV) images (Thenkabail, 1999), *Carpobrotus edulis*, *Cordateria jubata*, *Foeniculum vulgare* and *Arundo donax* using high spatial resolution (~4 m) Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data (Ustin et al., 2002) are some of the examples of mapping canopy dominating species. Everitt et al. (2001), who used aerial photographs to discriminate *Acacia smallii, Tamarix chinensis*, *Gutierrezia sarothrae* and *Astragalus wootonii*, noted the importance of differences in canopy architecture, vegetative density and leaf pubescence for the mapping of invasive species. Venugopal (1998) used SPOT multitemporal data to monitor the infestation of *Eichhornia crassipes* (water hyacinth) using NDVI. Shepherd and Dymond (2000) presented a method for correcting AVHRR visible and near-infrared imagery which can be used in detecting indigenous forest, exotic forest, scrub, pasture and grassland. Budd et al. (2001) used AVHRR remote sensing reflectance imagery and found a significant relationship between reflectance before and after *Dreissena polymorpha* invasion.

(b) *Mixed Canopy Dominant Species:* These species include members of a multi-species canopy and directly reflects electro-magnetic radiation. Plant characteristics such as life form, leaves, flowers etc. determine reflectance. Everitt et al. (2001) detected *Helianthus argophyllus*, and *Astragalus mollissimus* var. *earlei* using aerial photography. Allen and Kupfer (2000) discriminated areas with predominance of *Salvinia auriculata* and *Scirpus cubensis* using Landsat TM and HRV-SPOT digital images.

(c) *Invaders Influencing Canopy Dominant Species:* This class includes species not reflecting, but influencing the reflective properties of canopy members belonging to classes a and b above. Numerous investigators have worked on developing techniques for using multispectral data in invasive species mapping and detection (Vrindts et al., 2002). Analysis of hyperspectral data has produced encouraging results in the discrimination of healthy and infected canopy dominant species infected by various fungus such as *Batrachochytrium dendrobatidis*, *Cryphonectria parasitica*, *Ophiostoma ulmi*, *Phyto phthora cinnamomi* and *Pentalonia nigronervosa* (Banana bunchy top virus).

(d) *Understory Species:* This type includes all species that neither reflect light nor influence the reflective properties of other species in classes a and b. Few researchers have pointed out the possibilities of application of remote sensing in studying understory invasive. Plant species such as *Chromolaena odorata*, *Ulex europaeus*, *Clidemia hirta, Lantana camara*, *Mimosa pigra*, *Psidium cattleianum*, *Rubus ellipticus*, *Schinus terebinthifolius* and most of the invasive animal species are examples of this category. May et al. (2000) quantified remotely sensed airborne data into physical and ecological variables, obtaining an improved spatial and temporal representation of the dynamics of native and exotic plant communities. Most of the invasive animals, lower flora, herbs, shrubs and fauna are found to be understory vegetation, making detection using direct remote sensing techniques almost impossible. Nevertheless, a combination of remote sensing techniques, GIS and expert knowledge still offer potential to detect understory invasion through development of models and risk maps.

6.8 Disaster Management

Remote sensing technologies can provide the government with the ability to avoid much of the damage caused by unforeseen natural disasters. While weather satellites have monitored hurricanes and tornados since the 1960s, other satellite sensors, such as ETM+ and MODIS, have potential applications for disaster management and response. Scientists have used ETM+ data to monitor patterns in floods, droughts, beach erosion and volcanic activity over time. The use of optical sensors for flood mapping is seriously limited by the extensive cloud cover that is mostly present during a flood event. SAR data from ERS and RADARSAT have proven very useful for mapping flood inundated areas due to their bad weather capability. In India, ERS-SAR has been used successfully in flood monitoring since 1993, and Radarsat since 1998 (Chakraborti, 1999). MODIS and ASTER data can forecast severe weather with a great degree of reliability, potentially saving states millions of dollars in unnecessary evacuation and emergency response (Kaku and Held 2013). For forest fire emergencies, TOMS data can identify and monitor the occurrence of forest fires, especially in remote areas (Sentinel Asia, 2015) while AVHRR data can create maps denoting fire-susceptible areas. NOAA-POES and NOAA-GOES (Geostationary Operational Environmental Satellite) are used to make weather observations including predicting local weather, tracking weather in real time globally and locally, understanding and predicting hurricanes and other severe weather, studying phenomena such as El Niño, La Niña, the Gulf Stream and other global current patterns, and observing the dynamics between the land temperature, ocean processes and the atmosphere.

The earth observation satellites have their own special systems of imaging sensors, which make use of the visible, infrared, microwave and other parts of the electromagnetic spectrum (Campbell and Wynne, 2011). The characteristics of some sensors that are commonly used to support disaster management are listed in Table 10.6.

'Optical data' are of great importance for disaster management support, because they can be used nearly for all disaster types and for all phases of disaster management. For example, for mapping an earthquake in an urban area optical data with a spatial resolution of <0.5 m are most valuable. The most crucial point for the use of optical images is their availability.

The 'thermal imagery' offers excellent possibilities for automated extraction of anomalous high temperature or hot spots caused by wild fires or information about volcanic eruptions. Microwave sensors' are of great value for the fast response mapping and analysis tasks, as they allow imaging at wavelengths almost unaffected by atmospheric disturbances such as rain or cloud. Most modern SAR sensors are designed to acquire data from various ground resolution elements. In general, the availability of appropriate data with respect to acquisition time, image extent, spatial as well as temporal and spectral resolution is an important consideration for most applications in the disaster context.

Table 10.6 Examples of sensors and their characteristics to support disaster management and image processing techniques for information extraction about natural disasters (modified after Joyce et al., 2011)

Data type	*Sensor*	*Nadir spatial resolution (m)*	*Bands*	*Technique*	*Application*
Optical (multispectral) Thermal	Worldview-3	0.31 1.24 3.7 30	Panchromatic 8 Multispectral 8 SWIR 12 CAVIS (Corrects for Clouds, Aerosols, Vapours, Ice & Snow)	Manual interpretation, Spectral classification, Semi-variogram analysis and other textural classifiers, Image thresholding (including band ratios), Image differencing, Post classification change detection, DEM generation, split window	Infrastructure and property damage due to flooding, earthquakes, landslides, etc., location and extent of flooding, landslides, volcanic debris, fire scars, damage due to earthquakes; location of landslides, location and extent of flooding, landslides, volcanic debris, fire scars, DEM is used as a supplementary information in variety of studies, crater lake temperatures, lava flow, precursor to earthquake activity, temperature and size of fire hotspots
	Worldview-2	0.46 1.84	Panchromatic 8 Multispectral		
	Pleiades-1A / 1-B	0.70 2.00	Panchromatic 4 Multispectral		
	SPOT-6 / -7	1.50 6.00	Panchromatic 4 Multispectral		
	RapidEye ASTER	6.5 15 30 90	5 Multispectral 4 Multispectral 6 SWIR 5TIR		
	MODIS	250 500 1,000	36 bands (VIS, NIR, SWIR/MWIR, LWIR		

Synthetic Aperture Radar (SAR)	TerraSAR-X/ TanDEM-X	1 3 18	Spotlight Stripmap ScanSAR	Coherence, interferometry/ DEM Generation, polarimetry	Change detection due to landslide, flooding, fire, etc., landcover classification and change detection
	Cosmo-SkyMed	<1 3-15 30-100	Spotlight Stripmap ScanSAR		
	Radarsat-2	3 25 8 8 25 25 50 100	Ultra-fine Fine Quad-pol fine Standard Quad-pol standard ScanSAR narrow ScanSAR wide Extended high		
	ALOS	10 100	PALSAR (Fine) PALSAR (ScanSAR)		

Table 10.7 EMR wavelengths and sensors

Wavelength	*Waveband*	*Applicable for*	*Sensors example*
Visible (VIS)	0.4–0.7mm	Vegetation mapping	SPOT; Landsat TM
		Building stock assessment	AVHRR; MODIS; IKONOS
		Population density	IKONOS; MODIS
		Digital elevation model	ASTER; PRISM
Near infrared (NIR)	0.7–1.0mm	Vegetation mapping	SPOT; Landsat TM; AVHRR; MODIS
		Flood mapping	MODIS
Shortwave infrared (SWIR)	0.7–3.0mm	Water vapour	AIRS
Thermal infrared (TIR)	3.0–14mm	Active fire detection	MODIS
		Burn scar mapping	MODIS
		Hotspots	MODIS; AVHRR
		Volcanic activity	Hyperion
Microwave (radar)	0.1–100cm	Earth deformation and ground movement	Radarsat SAR; PALSAR
		Rainfall	Meteosat; microwave imager (aboard TRMM)
		River discharge and volume	AMSR-E
		Flood mapping and forecasting	AMSR-E
		Surface winds	QuikScat radar
		3D storm structure	Precipitation radar (aboard TRMM)

Earth observation satellites are also used extensively in the phases of preparedness/warning and response/monitoring. Table 10.7 gives some examples of more sensors and application for various disaster information and data requirements during the reduction/mitigation phase-based wavelength range.

Remotely sensed data helps in identifying hardest-hit areas, manipulates population density in disaster-prone areas, and monitors rehabilitation or reconstruction after a major havoc. During a crisis, it facilitates plan for timely evacuation and recovery operations. Remote sensing is the only way to overview the disaster events happening on the earth's crust ranging from risk modelling to vulnerability analysis (Krishnamoorthi, 2016).

7 Future Directions of Remote Sensing for Environmental Studies

The advances made in spaceborne remote sensing in the last 50 years, from Sputnik 1 to Worldview-3, have been phenomenal. The present trends point to several innovations. First, availability of data from multiple sensors with wide array of spatial, spectral and radiometric characteristics. These data will be available from multiple sources. Second, significant advances have been made in harmonising and synthesising data from multiple sources that facilitates the use of data from these sensors of widely differing characteristics and sources. Third, availability of data from a constellation such as from RapidEye at very high resolution of 6.5 m, in five bands including a red edge band, and with ability to cover the entire world in 13-day frequency is a likely attractive form of data collection. This will certainly require innovations in data handling, storage, and backup. But for applications, a combination of very high spatial resolution and frequent coverage is very attractive. Fourth, the micro satellites that specialise in gathering data for specific geographic location and/or for particular applications are likely to become more attractive. Fifth, for many environmental and natural resource applications global wall-to-wall coverage is essential and satellites like Landsat will continue to play important role. Sixth, data availability in hyperspectral and hyperspatial sensors brings in new challenges in data mining, processing, backup, and retrieval. Seventh, the advances made in data synthesis, presentation, and accessibility through systems such as Google Earth will bring in new users and multiply applications of remote sensing in environmental and natural resources management.

8 Conclusion

This chapter presents a general review on utilisation of remote sensing and GIS for environmental studies. Remote sensing technology has developed from balloon photography to aerial photography to multispectral satellite imaging. Radiation interaction characteristics of earth and atmosphere in different regions of electromagnetic spectrum are very useful for identifying and characterising environmental and geological features. Remote sensing techniques with an emphasis on climate, geology, geomorphology, physiography, geohydrology, mining, coastal, urban landuse/landcover help in identification of the potential zones for developmental planning and predicting limitations to their implementation with reasonable accuracy. Remote sensing can be potentially employed to address various aspects of disaster management cycle. The visual interpretation of the FCC images supplemented with sufficient ground truth is found to be most efficient and effective way of delineating, demarcating, characterising and classification of the landscape units. The capabilities of remote sensing make it a valuable tool in providing decision makers with large-area maps of target features in a quick manner, and over consistent time intervals. Environmental practitioners seeking to use remote sensing techniques have the availability of extensive data, methods and tools at their disposal. Understandably, this choice can seem overwhelming for practitioners due to the number of publications advocating new techniques and arguing ‘best’ approaches to utilising remote sensing tools and capabilities. Continuing the uncontested usefulness of satellite remote sensing in the environmental monitoring, a new era has already started through the use of modern satellite sensors which provide multispectral and hyperspectral images of continuously increasing spatial accuracy and radiometric quality as well as synchronous microwave and Lidar instrumentation. This could guide to identify the thrust areas and pave necessary ways for future research.

References

Ackermann, F. (1999). Airborne laser scanning—Present status and future expectations. *ISPRS J. Photogramm. Remote Sens.*, **54:** 64–67.

Adam, E., Mutanga, O. and Rugege, D. (2010). Multispectral and hyperspectral remote sensing for identification and mapping of wetland vegetation: A review. *Wetlands Ecol. Manag.*, **18:** 281–296.

Agardy, T., Alder, J., Dayton, P., Curran, S., Kitchingman, A., Wilson, M., Catenazzi, A., Restrepo, J., Birkeland, C., Bla-Ber, S., Saifullah, S., Branch, G., Boersma, D., Nixon, S., Dugan, P., Davidson, N. and Vorosmarty, C. (eds.) (2005). Ecosystems and human well-being: Current state and trends. Millennium Assessment Report Series. Global Assessment Reports. Island Press, Washington, DC, pp. 513–549.

Agbu, P.A. and James, M.E. (1994). *NOAA/NASA Pathfinder AVHRR Land Data Set User's Manual*. Goddard Distributed Active Archive Center, NASA Goddard Space Flight Center, Greenbelt.

Akiwumi, F.A. and Butler, D.R. (2007). Mining and environmental change in Sierra Leone, West Africa: A remote sensing and hydrogeomorphological study. *J. Environ. Monit. Assess*. Springer Netherlands. ISSN: 0167-6369.

Allen, T.R. and Kupfer, J.A. (2000). Application of spherical statistics to change vector analysis of landsat data: Southern Appalachian Spruce – Fir forests. *RS Environ*, **74(3):** 482–493.

Bahuguna, I.M., Nayak, S., Tamilarsan, V. and Moses, J. (2003). Groundwater prospective zones in Basaltic terrain using remote sensing. *J. Indian Soc. Remote Sens.*, **31(2):** 101–105.

Bahuguna, A. (2008). Impact of climate change on coral reefs. *Indian Soc. Geomatics (ISG) Newlett.*, **14(1–4):** 44-48.

Balopoulos, E.Th., Collins, M.B. and James, A.E. (1986). Satellite images and their use in the numerical modelling of coastal processes. *Int. J. Remote Sens.*, **7(7):** 905–919.

Bhandari, S.M., Vyas, N.K., Dash, M.K., Khanolkar, A., Sharma, N. and Khare, N. (2005). Simultaneous MSMR and SSM/I observations and analysis of Sea Ice characteristics over the Antarctic region. *Int. J. Remote Sens.*, **26:** 3123–3136.

Bhaskaran, S., Paramananda, S. and Ramnarayan, M. (2010). Per-pixel and object oriented classification methods for mapping urban features using Ikonos satellite data. *Appl. Geogr.*, **30(4):** 650–665.

Bhatta, B. (2008). Analysis of urban growth pattern using remote sensing and GIS: A case study of Kolkata, India. *Int. J. Remote Sens.*, **30(18):** 4733–4746.

Bhatta, B. (2010). Analysis of Urban Growth and Sprawl from Remote Sensing Data.Springer-Verlag, Berlin, Heidelberg, New York. 170 pp.

Blum, M.D. and Roberts, H.H. (2009). Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. *Nat. Geosci.*, **2:** 488–491.

Bourgeau-Chavez, L.L., Smith, K.B., Brunzell, S.M., Kasischke, E.S., Romanowicz, E.A. and Richardson, C.J. (2005). Remote monitoring of regional inundation patterns and hydroperiod in the Greater Everglades using Synthetic Aperture Radar. *Wetlands*, **25:** 176–191.

Budd, J.W., Drummer, T.D., Nalepa, T.F. and Fahnenstiel, G.L. (2001). Remote sensing of biotic effects: Zebra mussels (*Dreissena polymorpha*) influence on water clarity in Saginaw Bay, Lake Huron. *Limnol. Oceanogr.*, **46(2):** 213–223.

Burrough, P.A. and McDonnell, R.A. (1998). Principles of Geographic Information Systems. Oxford University Press, Oxford, UK, pp. 10–16.

Byun, Y., Choi, J. and Han, Y. (2013). An area based image fusion scheme for the integration of SAR and optical satellite imagery. *IEEE J. Sel. Top. Appl. Earth Observ. Remote Sensing*, **6(5):** 2212–2220.

Campbell, J.B. (1987). Introduction to Remote Sensing. Guilford Press, New York.

Campbell, J.B. and Wynne R.H. (2011). Introduction to Remote Sensing, 5th edition. The Guilford Press, New York, 662 pp.

Chakraborti, A.K. (1989). Role of water management in urban settlement in India: A remote sensing based assessment. National Remote Sensing Agency, Hyderabad Technical Report, **40:** 1–12.

Chakraborti, A.K. (1999). Satellite remote sensing for near-real-time flood and drought impact assessment – India experience. Workshop on Natural Disasters and their Mitigation—A Remote Sensing and GIS Perspective, 11–15 October 1999, Dehradun, India.

Chakraborty, S., Paul, P.K. and Sikdar, P.K. (2007). Assessing aquifer vulnerability to arsenic pollution using DRASTIC and GIS of North Bengal Plain: A case study of English Bazar Block, Malda District, West Bengal, India. *J. Spat. Hydrol.*, **7(1):** 101–121.

Chatterjee, N., Mukhopadhyay, R. and Mitra, D. (2015). Decadal changes in shoreline patterns in Sundarbans, India. *J. Coastal Sci.*, **2(2):** 54−64.

Cheng, Z., Wang, X., Paull, D. and Gao, J. (2016). Application of the geostationary ocean color imager to mapping the diurnal and seasonal variability of surface suspended matter in a macro-tidal estuary. *Remote Sens.,* 8: 244; doi:https://doi.org/10.3390/rs8030244.

Chhabra, A., Manjunath, K.R., Panigrahy, S. and Parihar, J.S. (2009). Spatial pattern of methane emissions from Indian livestock. *Curr. Sci.*, **96(5):** 683–689.

Coleman, J.M., Huh, O.K. and Braud, D.W. Jr. (2008). Wetland loss in world deltas. *J. Coastal Res.*, **24(1A):** 1–14.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and Van Den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, **387:** 253–260.

Czajkowski, K., Torbick, N. and Lawrence, P. (2007). Application and Assessment of a Giscience Model for Jurisdictional Wetlands Identification in Northwestern Ohio Wetland and Water Resource Modeling and Assessment: A Watershed Perspective, pp. 2−12. CRC Press.

Czech, B. and Krausman, P.R. (1997). Distribution and causation of species endangerment in the United States. *Science*, **277:** 116−117.

Das, I.C. and Nizamuddin, M. (2002). Spectral signatures and spectral mixture modeling as a tool for targeting laterite and bauxite ore deposits, Koraput, Orissa. Presented in Map Asia-Bangkok.

David, S. (2000). Symposium on Viewing the Earth: The Role of Satellite Earth Observations and Global Monitoring in International Affairs. George Washington University Washington, DC.

Davranche, A., Lefebvre, G. and Poulin, B. (2010). Wetland monitoring using classification trees and SPOT-5 seasonal time series. *Remote Sens. Environ.*, **114(3):** 552–562.

Dekker, A.G., Malthus, T.J., Wijnen, M.M. and Seyhan, E. (1992). Remote sensing as a tool for assessing water quality in Loosdrecht Lakes. *Hydrobiologia*, **233(1–3):** 137–159.

Deng, C. and Wu, C. (2012). BCI: A biophysical composition index for remote sensing of urban environments. *Remote Sens. Environ.*, **127:** 247**–**259.

Dhar, R.B., Chakraborty, S., Chattopadhyay, R. and Sikdar, P.K. (2019). Impact of land-use/land-cover change on land surface temperature using satellite data: A case study of Rajarhat Block, North 24-Parganas District, West Bengal. *J. Indian Soc. Remote Sens.,* 47(2): 331-348. doi:https://doi.org/10.1007/s12524-019-00939.

Dhinwa, P.S., Pathan, S.K., Sastry, S.V.C., Rao, Mukund, Majumder, K.L., Chotani, M.L., Singh, P.J. and Sinha, R.L.P. (1992). Land-use change analysis of Bharatpur district using GIS. *J. Indian Soc. Remote Sens.*, **20(4):** 237–250.

Dong, Z.Y., Wang, Z.M., Liu, D.W., Song, K.S., Li, L. and Jia, M.M. (2014). Mapping wetland areas using landsat-derived NDVI and LSWI: A case study of West Songnen Plain, Northeast China. *J. Indian Soc. Remote Sens.*, **42(3):** 569**–**576.

Drake, J.A., Mooney, H.A., Castri, F.D., Groves, R.H., Kruger, F.J., Aejmamek, M. and Williamson, M. (1989). Biological Invasions: A Global Perspective. John Wiley & Sons, Chichester.

Durduran, S.S. (2010). Coastline change assessment on water reservoirs located in the Konya Basin area, Turkey, using multitemporal landsat imagery. *Environ. Monit. Assessm.*, **164(1–4):** 453–461.

Dvorett, D., Davis, C. and Papes, M. (2016). Mapping and hydrologic attribution of temporary wetlands using recurrent Landsat imagery. *Wetlands*, **36(3):** 431–443.

Elijah, R. (1997). *Using Remote Sensing to Monitor Global Change.* National Wetlands Research Center Fact Sheet 096–97.

Everitt, J.H., Escobar, D.E. and Davis, M.R. (2001). Reflectance and image characteristics of selected noxious rangeland species. RS *GIS Symp.*, **54(2):** A106–A120 (special electronic section).

Feyisa, G.L., Meilby, H., Fensholt, R. and Proud, S.R. (2014). Automated water extraction index: A new technique for surface water mapping using Landsat imagery. *Remote Sens. Environ.*, **140:** 23–35.

Franklin, S. (2001). Remote Sensing for Sustainable Forest Management. CRC Press LLC, USA,409 pp.

Franklin, S.E., Titus, B.D. and Gillespie, R.T. (1994). RS of vegetation cover at forest regeneration sites. *Global Ecol. Biogeogr. Lett.*, **4(2):** 40–46.

Garg, J.K., Patel, J.G. and Singh, T.S. (2005). Methane emission from wetlands in India. Scientific Report, Space Applications Centre, Ahmedabad. SAC/RESIPA/FLPG/ SR/03/2005, p. 131.

Ghude, S.D., Fadnavis, S., Beig, G., Polade, S.D. and Vander, A.R.J. (2008). Detection of surface emission hot spots, trends and seasonal cycle for satellite retrieved NO_2 over India. *J. Geophys. Res.*, **13:** D20305. doi:https://doi.org/10.1029/2007JD009615.

Gilmore, M.S., Civco, D.L., Wilson, E.H., Barrett, N., Prisloe, S., Hurd, J.D. and Chadwick, C. (2010). Remote sensing and in situ measurements for delineation and assessment of coastal marshes and their constituent species. *In:* Wang, J. (ed.), Remote Sensing of Coastal Environment. CRC, Boca Raton, Florida, 423 pp.

Goodchild, M.F. (2001). Metrics of scale in remote sensing and GIS. *Int. J. Appl. Earth Observ. Geoinform.*, **3(2):** 114–120.

Goyal, S., Bharawadaj, R.S. and Jugran, D.K. (1999). Multicriteria analysis using GIS for groundwater resource evaluation in Rawasen and Pilli watershed, U.P. http://wwwGISdevelopment.net. Accessed on 04 May 2020.

Guariglia, A., Buonamassa, A., Losurdo, A., Saladino, R., Trivigno, M.L., Zaccagnino, A. and Colangelo, A. (2006). A multisource approach for coastline mapping and identification of shoreline changes. *Ann. Geophys*., **49:** 295–304.

Gupta, R.P. (2005). Remote Sensing Geology, Second Edition. Springer Publications, pp. 537.

Haltuch, M.A., Berkman, P.A. and Garton, D.W. (2000). Geographic information system (GIS) analysis of ecosystem invasion: Exotic mussels in Lake Erie. *Limnol. Oceanogr.*, **45(8):** 1778–1787.

Han, B., Loisel, H., Vantrepotte, V., Mériaux, X., Bryère, P., Ouillon, S., Dessailly, D., Xing, Q. and Zhu, J. (2016). Development of a semi-analytical algorithm for the retrieval of suspended particulate matter from remote sensing over clear to very turbid waters. *Remote Sens.*, **8(3):** 211. doi:https://doi.org/10.3390/rs8030211

Harding, G.B. and Bate, G.C. (1991). The occurrence of invasive Prosopis species in the northwestern Cape, South Africa. *South Afr. J. Sci.*, **87(5):** 188–192.

Hellweger, F.L., Schlosser, P., Lall, U. and Weissel, J.K. (2004). Use of satellite imagery for water quality studies in New York Harbor. *Estuar Coast Shelf Sci.*, **61(3):** 437–448.

Huete, A., Liu, H., Batchily, K.V. and Van Leeuwen, W. (1997). A comparison of vegetation indices over a global set of TM images for EOS-MODIS. *Remote Sens. Environ.*, **59(3):** 440–451.

Humes, K., Kustas, W., Moran, M., Nichols, W. and Weltz, M. (1994). Variability of emissivity and surface temperature over a sparsely vegetated surface. *Water Resources Res.*, **30(5):** 1299–1310.

Jafari, R. and Bakhshandehmehr, L. (2013). Quantitative mapping and assessment of environmentally sensitive areas to desertification in central Iran. *Land Degrad. Dev.*, **27(2):** 108**–**119.

Jaiswal, R.K., Mukherjee, S., Krishnamurthy, J. and Saxena, R. (2003). Role of remote sensing and GIS techniques for generation of groundwater prospect zones towards rural development – An approach. *Int. J. Remote Sens.*, **24(5):** 993–1008.

Jat, M.K., Garg, P.K. and Khare, D. (2008). Modeling urban growth using spatial analysis techniques: A case study of Ajmer city (India). *Int. J. Remote Sens.*, **29(2):** 543–567.

Jensen, J. (2006). Remote Sensing of the Environment: An Earth Resource Perspective. 2nd ed. Prentice Hall, New Jersey, 608 pp.

Joshi, C., Leeuwa, J. and Duren, I.C. (2004). Remote sensing and GIS applications for mapping and spatial modelling of invasive species. Proceedings of XXXV ISPRS congress. www.isprs.org.comm7/papers/132.pdf.

Joyce, K.E., Belliss, S.E., Samonsov, S.V., McNeill, S.J. and Glassey, P.J. (2009). A review of the status of satellite remote sensing and image processing techniques for mapping natural hazards and disasters. *Prog. Phys. Geog.*, **33:** 183–207.

Joyce, K.E., Wright, K.C., Samonsov, S.V. and Ambrosia, V.G. (2011). Remote sensing and the disaster management cycle. *In:* Geoscience and Remote Sensing. 317–346. DOI: 10.5772/8341. Vienna: In-Tech Publishing.

Kaku, K. and Held, A. (2013). Sentinel Asia: A space-based disaster management support system in the Asia-Pacific region. *Int. J. Disaster Risk Reduction*, **6:** 1–17. DOI: 10.1016/j.ijdrr.2013.08.004.

Kant, Y., Bharath, B., Mallick, J., Atzberger, C. and Kerle, N. (2009). Satellite-based analysis of the role of land use/land cover and vegetation density on surface temperature regime of Delhi, India. *J. Indian Soc. Remote Sens.*, **37(2):** 201–214.

Kaplan, G. and Avdan, U. (2017). ISPRS Annals of the photogrammetry, remote sensing and spatial information sciences, volume IV-4/W4, 4th International GeoAdvances Workshop, 14–15 October 2017, Safranbolu, Karabuk, Turkey.

Kaufman, Y.J. and Tanre, D. (1992). Atmospherically resistant vegetation index (ARVI) for EOS-MODIS. *IEEE Trans. Geosci. Remote Sens.*, **30(2):** 261–270.

Kayastha, N., Thomas, V., Galbraith, J. and Banskota, A. (2012). Monitoring wetland change using inter-annual landsat time-series data. *Wetlands*, **32(6):** 1149**–**1162.

Khan, S., Bhuvneswari, B. and Quereshi, M. (1999). Land use/land cover mapping and change detection using remote sensing and GIS: A case study of Jamuna and its environments. *Socio-econ. Dev. Rec.*, **6:** 32**–**33.

Klemas, V. (2011). Remote sensing of wetlands: Case studies comparing practical techniques. *J. Coastal Res.*, **27:** 418–427.

Kolios, S. (2018). Contribution of Satellite Remote Sensing in Environmental Monitoring at Regional Scales: A Short Review. *Environmental Analysis & Ecology Studies*, **1(3):** 66–67.

Krishnamoorthi, N. (2016). Role of remote sensing and GIS in natural-disaster management cycle. *Imperial J. Interdiscip. Res. (IJIR)*, **2(3):** 144–154.

Krishnamurthy, J., Mani, A.N., Jayaram, V. and Manivel, M. (2000). Groundwater resources development in hard rock terrain: An approach using remote sensing and GIS techniques. *Int. J. Appl. Earth Observ. Geoinform.*, **2(3/4):** 204–215.

Kulkarni, A.V., Bahuguna, I.M., Rathore, B.P., Singh, S.K., Randhawa, S.S., Sood, R.K. et al. (2007). Glacial retreat in Himalaya using Indian Remote Sensing Satellite data. *Curr. Sci.*, **92(1):** 69–74.

Kulkarni, A.V., Dhar, S., Rathore, B.P., Govindharaj, K.B. and Kalia, R. (2006). Recession of Samudra Tapu glacier, Chandra river basin, Himachal Pradesh. *J. Indian Soc. Remote Sens.*, **34(1):** 39–46.

Kulkarni, A.V., Rathore, B.P., Mahajan, S. and Mathur, P. (2005). Alarming retreat of Parbati Glacier, Beas basin, Himachal Pradesh. *Curr. Sci.*, **88(11):** 1844–1850.

Kumar, J.A.V., Pathan, S.K. and Bhanderi, R.J. (2007). Spatio-temporal analysis for monitoring urban growth—A case study of Indore city. *J. Indian Soc. Remote Sens.*, **35(1):** 11–20.

Lang, M.W. and McCarty, G.W. (2008). Remote sensing data for regional wetland mapping in the United States: Trends and future prospects. *In:* Russo, R.E. (ed.), Wetlands: Ecology, Conservation and Restoration. pp. 1–40. Nova, Hauppauge, New York.

Lang, W.M., Chavez, L.B., Tiner, R.W. and Klemas, V.V. (2015). Advances in Remotely Sensed Data and Techniques for Wetland Mapping and Monitoring. *In:* Remote Sensing of Wetlands. pp. 79–116. Taylor and Francis.

Lemmens, M.J.P.M. (2001). Structure-based Edge Detection: Delineation of Boundaries in Aerial and Space Images. Doctoral thesis. Delft University Press, Delft.

Levesque, J., Neville, R.A., Staenz, K. and Truong, Q.S. (2001) Preliminary results on the investigation of hyperspectral remote sensing for the identification of uranium mine tailings. *In:* Proceedings of the ISSSR: June 10–15, 2001, Quebec City, Canada.

Lillycrop, W.J., Pope, R.W. and Wozencraft, J.M. (2002). Airborne lidar hydrography: A vision for tomorrow. *Sea Technol.*, **43:** 27–34.

Los, S.O., Tucker, C.J., Anyamba, A., Cherlet, M., Collatz, G.J., Giglio, L., Hall, F.G. and Kendall, J.A. (2002). Environmental Modelling with GIS and RS. Taylor & Francis, London.

Machiwal, D., Jha, K.M. and Mal, C.B. (2011). Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. *Water Resour. Manage.*, **25:** 1359–1386.

Madrucci, V., Taioli, F. and de Araújo, C.C. (2008). Groundwater favorability map using GIS multicriteria data analysis on crystalline terrain, São Paulo State, Brazil. *J. Hydrol.*, **357:** 153–173.

Maiti, S. and Bhattacharya, A.K. (2009). Shoreline change analysis and its application to prediction: A remote sensing and statistics based approach. *Mar. Geol.*, **257:** 11–23.

Mallick, J., Rahman, A. and Singh, C.K. (2013). Modeling urban heat islands in heterogeneous land surface and its correlation with impervious surface area by using night-time ASTER satellite data in highly urbanizing city, Delhi, India. *Advances in Space Research*, **52(4):** 639–655.

Manjunath, K.R., Panigrahy, S., Addhya, T.K., Beri, V., Rao, K.V. and Parihar, J.S. (2009). Methane emission inventory from Indian Rice ecosystem using remote sensing, GIS and field observations. Scientific Report, Space Applications Centre, Ahmedabad, SAC/AFEG/AMD/EIAA/SN/03/08, p. 131.

Mas, J.F. and Flores, J.J. (2008). The application of artificial neural networks to the analysis of remotely sensed data. *Int. J. Remote Sens.*, **29(3):** 617–663.

May, C.J., Neale, C.M.U. and Henderson, N. (2000). Mapping riparian resources in semiarid watersheds using airborne multispectral imagery. *IAHS AISH Publ.*, **267:** 539–541.

MEC (Ministerio da Educacao e Cultura) (1999). Secretaria de Educacao Media e Tecnologica. Parametros Curriculares Nacionais: Ensino Medio. Brasilia, pp. 188.

Merified, P.M. and Lamar, D.L. (1975). Active and inactive faults in southern California viewed from Skylab, TM X-58168, vol. 1. NASA, 779–797.

Michael, D.K. and David, D.H. (2000). Monitoring the Earth's vital signs. *Sci. Am.*, **282(4):** 92–97.

Miller, S.N., Semmens, D.J., Goodrich, D.C., Hernandez, M., Miller, R.C., Kepner, W.G. and Guertin, D.P. (2007). The automated geospatial watershed assessment tool. *J. Environmental Modeling and Software*, **22:** 365–377.

Mishra, D., Narumalani, S., Rundquist, D. and Lawson, M. (2006). Benthic habitat mapping in tropical marine environments using Quick Bird multispectral data. *Photogramm. Eng. Remote Sens.*, **72:** 1037–1048.

Mitsch, W.J. and Gosselink, J.G. (2015). Wetlands, 5th ed. John Wiley & Sons, Inc. New York, pp. 155-204.

Mooney, H.A. and Hobbs, R.J. (2000). Invasive Species in a Changing World. Island Press, Washington, DC.

Mularz (1998). Satellite and airborne remote sensing data for monitoring of an open-cast mine, ISPRS, Vol. 32. *In:* Fritsch, D., Englich, M. and Sester, M. (eds), 'IAPRS' Vol. 32/4, ISPRS Commission IV Symposium on IS - Between Visions and Applications, Stuttgart, Germany, pp. 395–402.

Mumby, P.J. and Edwards, A.J. (2002). Mapping marine environments with IKONOS imagery: Enhanced spatial resolution can deliver greater thematic accuracy. *Remote Sens. Environ.*, **82:** 248–257.

Murthy, K.S.R. and Venkateswar, R.V. (1997). Temporal studies of land use/land cover in Varah river basin, Andhra Pradesh. *J. Indian Soc. Remote Sens.*, **25:** 153–154.

Navalgund, R.R. and Singh, P.R. (2011). Climate change studies using space based observation. *J. Indian Soc. Remote Sens.*, 39(3): 21-295. doi. 10.1007/s12524-011-0092-4.

Navalgund, R.R. (2006). Indian Earth observation system: An overview. *Asian J. Geoinformatics*, **6:** 17–25.

Navalgund, R.R., Jayaraman, V. and Roy, P.S. (2007). Remote sensing applications: An overview. *Curr. Sci.*, **93(12):** 1747–1766.

Nicloś, R., Caselles, V., Coll, C., Valor, E. and Rubio, E. (2004). Autonomous measurements of sea surface temperature using in situ thermal infrared data. *J. Atmos. Oceanic Technol.*, **21(4):** 683–692.

Novo, E.M.L.M., Costa, M.P.F., Mantovani, J.E. and Lima, I.B.T. (2002). Relationship between macrophyte stand variables and radar backscatter at L and C band, Tucurui reservoir, Brasil. *Int. J. Remote Sens.*, **23:** 1241–1260.

NRSA (1994). Mapping and monitoring urban sprawl of Hyderabad. Project report. National Remote Sensing Agency, Balanagar, Hyderabad, pp. 1–85.

NRSA (2005). National Remote Sensing Agency Quarterly Newsletter. 2(2), Balanagar, Hyderabad.

Ody, A., Doxaran, D., Vanhellemont, Q., Nechad, B., Novoa, S., Many, G., Bourrin, F., Verney, R., Pairaud, I. and Gentili, B. (2016). Potential of high spatial and temporal ocean color satellite data to study the dynamics of suspended particles in a Micro-Tidal River Plume. *Remote Sens.*, 8.

Ouillon, S., Douillet, P. and Petrenko, A. (2008). Optical algorithms at satellite wavelengths for total suspended matter in tropical coastal waters. *Sensors*, **8:** 4165–4185.

Ozesmi, S.L. and Bauer, M.E. (2002). Satellite remote sensing of wetlands. *Wetland Ecol. Manage.*, **10:** 381–402.

Pal, S. and Ziaul, S. (2017). Detection of land use and land cover change and land surface temperature in English Bazar urban centre. *Egypt. J. Remote Sens. Space Sci.*, **20(1):** 125–145.

Palaniyandi, M. and Nagarathinam, V. (1997). Land use/land cover mapping and change detection using space born data. *J. Soc. Remote Sens.*, **25:** 27–33.

Pandey, N.K., Shukla, A.K., Shukla, S. and Pandey, M. (2014). Assessment of underground water potential zones using modern geomatics technologies in Jhansi district, Uttar Pradesh, India. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Volume XL-8. 2014 ISPRS Technical Commission VIII Symposium, 09–12 December 2014, Hyderabad, India, 337–381.

Panigrahy, S., Anitha, D., Kimothi, M.M. and Singh, S.P. (2007). Climate change indicators in alpine ecology of central Himalaya: An analysis using satellite remote sensing data. Tropical Ecology Congress 2007, 2–5 December 2007, Dehradun, India.

Papagiannopoulos, N., Mona, L., Alados-Arboledas, L., Amiridis, V. and Baars, H. (2016). CALIPSO climatological products: Evaluation and suggestions from EARLINET. *Atmos. Chem. Phys.*, **16(4):** 2341–2357.

Peters, A.J., Reed, B.C., Eve, M.D. and McDaniel, K.C. (1992). RS of brome snakeweed (*Gutierrezia sarothrae*) with NOAA-10 spectral image processing. *Weed Technol.*, **6(4):** 1015–1020.

Popescu, S.C., Zhao, K., Neuenschwander, A. and Lin, C. (2011). Satellite lidar vs. small footprint airborne lidar: Comparing the accuracy of aboveground biomass estimates and forest structure metrics at footprint level. *Remote Sens. Environ.*, **115(11):** 2786–2797.

Prakash, A. and Gupta, R.K. (1998). Land-use mapping and change detection in a coal mining area – A case study in the Jharia coal field, India. *Int. Rem. Sen.*, **19(3):** 391–410.

Prasad, A.K., Singh, R.P. and Singh, A. (2004). Variability of aerosol optical depth over Indian subcontinent using MODIS data. *J. Indian Soc. Remote Sens.*, **32:** 313–316.

Puissant, A., Zhang, W. and Skupinski, G. (eds) (2012). Urban morphology analysis by high and very high spatial resolution remote sensing. *In:* International Conference on Geographic Object-Based Image Analysis.

Rahman, A. (2006). Application of remote sensing and GIS technique for urban environment management and development of Delhi, India. Applied Remote Sensing for Urban Planning Governance and Sustainability. http://www.springerlink.com/index/x5w74277j3I13959pdf.

Rahman, A., Netzband, M., Singh, A. and Mallick, J. (2009). An assessment of urban environmental issues using remote sensing and GIS techniques: An integrated approach. A case study, Delhi, India. Urban Population-Environment Dynamics in the Developing World: Case Studies and Lessons Learned, International Cooperation in National Research in Demography (CICRED), Paris, pp. 181–211.

Rai, P.K. and Kumra, V.K. (2011). Role of Geoinformatics in urban planning. *J. Sci. Res.*, **55:** 11–24.

Rao, Y.S. and Jugran, D.K. (2003). Delineation of groundwater potential zones and zones of groundwater quality suitable for domestic purposes using remote sensing and GIS. *Hydrol. Sci. J.*, **48(5):** 821–833.

Rib, H.T. and Liang, T. (1978). Recognition and identification, in landslides – Analyses and control. *In:* Schuster, R.L. and Krizek, R.J. (eds), National Academy of Sciences, Washington, DC, pp. 34–69.

Ruelland, D., Dezetter, A., Puech, C. and Ardoin-Bardin, S. (2008). Long-term monitoring of land cover changes based on Landsat imagery to improve hydrological modelling in West Africa. *Int. J. Remote Sens.*, **29(12):** 3533–3551.

Saha, P., Saha, B.K. and Hazra, S. (2014). Recent changes in coastal configuration of Henry's Island. *Curr. Sci.*, **107(4):** 679–688.

Sander, P., Chesley, M.M. and Minor, T.B. (1996). Groundwater assessment using remote sensing and GIS in a rural groundwater project in Ghana: Lessons learned. *Hydrogeol. J.*, **4(3):** 40–49.

Santillan, J., Makinano, M. and Paringit, E. (2011). Integrated Landsat image analysis and hydrologic modeling to detect impacts of 25-year land-cover change on surface runoff in a Philippine watershed. *Remote Sens*., **3(6):** 1067–1087.

Saraf, A.K. and Chowdhury, P.R. (1998). Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. *Int. J. Remote Sens.*, **19(10):** 1825–1841.

Sathish Kumar, J., Sanjeevi, S. and Govindan, S. (2011). Hyperspectral radiometry to characterize dunite alteration and magnesite deposits of Salem, South India. *Ind. J. Remote Sens.*, **39(4):** 497–505.

Satyanarayana, R. (1991). Remote sensing studies of the land and water resources of Hyderabad city and its environs. PhD thesis. Sri Venkateswara University.

Schneider, A., Friedl, M.A. and Potere, D. (2009). A new map of global urban extent from MODIS satellite data. *Environ. Res. Lett*., **4(4):** 11.

Schneider, A., Friedl, M.A. and Potere, D. (2010). Mapping global urban areas using MODIS 500-m data: New methods and datasets based on 'urban ecoregions'. *Remote Sens. Environ.*, **114(8):** 1733–1746.

Schutz, B.E., Zwally, H.J., Shuman, C.A., Hancock, D. and DiMarzio, J.P. (2005). Overview of the ICE Sat mission. *Geophys. Res. Lett.*, **32(21):** 01.

Sentinel Asia. [Internet] (2015). Available from: https://sentinel.tksc.jaxa.jp/sentinel2/top Control.jsp. Accessed 24 April 2019.

Sepehr, A., Zucca, C. and Nowjavan, M.R. (2014). Desertification status using factors representing ecological resilience. *British Journal of Environment and Climate Change*, **4(3):** 279–291.

Shahid, S. and Nath, S.K. (2002). GIS integration of remote sensing and electrical sounding data for hydrogeological exploration. *J. Spatial Hydrol.*, **2(1):** 1–12.

Shepherd, J.D. and Dymond, J.R. (2000). BRDF correction of vegetation in AVHRR imagery. *Remote Sens., Environ.*, **74(3):** 397–408.

Sikdar, P.K., Chakraborty, S., Adhya, E. and Paul, P.K. (2004). Land use/land cover changes and groundwater potential zoning in and around Raniganj coal mining area, Bardhaman District, West Bengal: A GIS and remote sensing approach. *J. Spat. Hydrol.*, **4(2):** 1–24.

Singh, A., Srivastav, S.K., Kumar, S. and Chakrapani, J.G. (2015). A modified-DRASTIC model (DRASTICA) for assessment of groundwater vulnerability to pollution in an urbanized environment in Lucknow, India. *Environ. Earth Sci.*, **74:** 5475–5490.

Singh, R.P., Dey, S., Tripathi, S.N., Tare, V. and Holben, B. (2004). Variability of aerosol parameters over Kanpur, Northern India. *J. Geophys. Res.*, **109:** D23206. doi:https://doi.org/10.1029/2004JD004966.

Singh, R.P., Sobhan, K.K., Panigrahy, S. and Parihar, J.S. (2008a). Study of carbon monoxide using remote sensing data. Proceedings of Technical Hindi Seminar on January 29, 2008. Space Applications Centre, Ahmedabad.

Singh, R.P., Sobhan, K.K., Panigrahy, S., Buchwitz, M. and Parihar, J.S. (2008b). Variability of atmospheric carbon dioxide concentration over India derived using ENVISATSCIAMACHY measurements. Presented at National Seminar on Advances in Remote Sensing Technology and Applications with Special Emphasis on Microwave Remote Sensing. Annual Conference of Indian Society of Remote Sensing. December 18–20, 2008. Nirma University, Ahmedabad, India.

Sokhi, B.S. (1999). Remote sensing in urban land use structure-transportation system relationship: A case study of Delhi. *In:* Sokhi, B.S. and Rashid, S.M. (eds), Remote Sensing of Urban Environment. Manak Publications Ltd., Delhi, pp. 174–195.

Sokhi, B.S., Sharma, N.D. and Uttarwar, P.S. (1989). Satellite remote sensing in urban sprawl mapping and monitoring: A case study of Delhi. *J. Indian Soc. Remote Sens.*, **17(3):** 57–69.

Stavros, K., Chrysostomos, D. and Stylios (2013). Identification of land cover/land use changes in the greater area of the Preveza peninsula in Greece using lands at satellite data. *Appl. Geogr.*, **40:** 150–160.

Stow, D., Hope, A., Richardson, D., Chen, D., Garrison, C. and Service D. (2000). Potential of colour-infrared digital camera imagery for inventory and mapping of alien plant invasions in South African shrublands. *Int. J. Remote Sens.,* **21(15):** 2965–2970.

Sudhira, H.S., Ramachandra, T.V., Raj, K.S. and Jagadish, K.S. (2003). Urban growth analysis using spatial and temporal data. *J. Indian Soc. Remote Sens.*, **31(4):** 299–311.

Thakur, S., Dey, D., Das, P., Ghosh, P.B. and De, T.K. (2017). Shoreline change detection using remote sensing in the Bakkhali Coastal Region, West Bengal, India *Indian J. Geosci.*, **71(4):** 611–626.

Thakur, B. and Parai, A. (1993). A review of recent urban geographic studies in India. *GeoJournal*, **29(2):** 187–196.

Thenkabail, P.S. (1999). Characterization of the alternative to slash-and-burn benchmark research area representing the Congolese rainforests of Africa using near-real-time SPOT HRV data. *Int. J. Remote Sens.,*, **20(5):** 839–877.

Thenkabail, P.S. (2004). Inter-sensor relationships between IKONOS and Landsat-7 ETM+ NDVI data in three ecoregions of Africa. *Int. J. Remote Sens.*, **25(2):** 389–408.

Thenkabail, P.S., Biradar, C.M., Turral, H., Noojipady, P., Li, Y.J., Vithanage, J., Dheeravath, V., Velpuri, M., Schull, M., Cai, X.L. and Dutta, R. (2006). An Irrigated Area Map of the World (1999) derived from remote sensing. Research Report # 105; International Water Management Institute, pp. 74.

Thenkabail, P.S., Enclona, E.A., Ashton, M.S., Legg, C. and Jean De Dieu, M. (2004). Hyperion, IKONOS, ALI, and ETM+ sensors in the study of African rainforests. *Remote Sens. Environ.*, **90:** 23–43.

Tim, U.S. and Mallavaram, S. (2003). Application of GIS Technology in Watershed-based Management and Decision Making, Watershed Update, 1(5): 1-6.

Trembanis, A.C., Hiller, T. and Patterson, M. (2008). Exploring coral reef sustainability. *Hydro Int.*, **12:** 10–15.

Tucker, C.J., Grant, D.M. and Dykstra, J.D. (2005). NASA's global orthorectified Landsat dataset. *Photogramm. Eng. Remote Sens.*, **70(3):** 313–322.

Ustin, S.L., DiPietro, D., Olmstead, K., Underwood, E. and Scheer, G. (2002). Hyperspectral RS for invasive species detection and mapping. International Geoscience and RS Symposium, 24th Canadian Symposium on RS, Toronto, Canada.

Uttarwar, P.S. and Sokhi, B.S. (1989). Remote sensing application in urban fringe study: A case study – Delhi. *J. Indian Soc. Remote Sens.*, **17(3):** 43–56.

Van der Meer, F., Schmidt, K.S., Bakker, A. and Bijker, W. (2002). New environmental RS systems. *In:* Skidmore, A.K. (ed.), Environmental Modelling with GIS and RS. Taylor & Francis, London, pp. 26**–**51.

Venugopal, G. (1998). Monitoring the effects of biological control of water hyacinths using remotely sensed data: A case study of Bangalore, India. *Singapore J. Trop. Geogr*, **19(1):** 92**–**105.

Vrindts, E., De Baerdemaeker, J. and Ramon, H. (2002). Weed detection using canopy reflection. *Precis. Agric.*, **3(1):** 63**–**80.

Vyas, N.K., Dash, M.K., Bhandari, S.M., Khare, N., Mitra, A. and Pandey, P.C. (2003). On the secular trend in sea ice extent over the Antarctic region based on OCEANSAT-1 MSMR observations. *Int. J. Remote Sens.*, **24:** 2277–2287.

Wang, Y. (2010). Remote sensing of coastal environments: An overview. *In:* Wang, J. (ed.), Remote Sensing of Coastal Environments. CRC, Boca Raton, Florida, 423 pp.

Weng, Q., Lu, D. and Schubring, J. (2004). Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies. *Remote Sens. Environ.*, **89(4):** 467–483.

Wilcove, D.S. and Chen, L.Y. (1998). Management costs for endangered species. *Conserv. Biol.*, **12:** 1405**–**1407.

WMO (World Meteorological Organization) (2011). Global Climate Observing System Systematic Observation Requirements for Satellite-based Data Products for Climate: 2011 Update GCOS-154.

Wu, Q. (2018). GIS and Remote Sensing Application in Wetland Mapping and Monitoring. *In:* Huang, B. (ed.), Geographic Information System. Elseiver, Netherlands, **203:** 139-157.

Yamazaki F. (2001). Applications of remote sensing and GIS for damage assessment. *In:* Corotis et al. (eds), Structural Safety and Reliability. Swets & Zeitlinger, ISBN 90 5809 197 X.

Yang, C., Everitt, J.H., Fletcher, R.S., Jensen, J.R. and Mausel, P.W. (2009). Mapping black mangrove along the south Texas gulf coast using AISA+ hyperspectral imagery. *Photogramm. Eng. Remote Sens.*, **75:** 425–436.

Yang, J. and Artigas, F.J. (2009). Mapping salt marsh vegetation by integrating hyperspectral and LiDAR remote sensing. *In:* Wang, J. (ed.), Remote Sensing of Coastal Environment. CRC, Boca Raton, Florida, 423 pp.

Zhang, J. and Foody, G.M. (2001). Fully-fuzzy supervised classification of sub-urban land cover from remotely sensed imagery: Statistical and artificial neural network approaches. *Int. J. Remote Sens.*, **22(4):** 615**–**628.

Chapter 11
Environmental Disaster Management and Risk Reduction

Subham Mukherjee, Surajit Kar, and Sukdeb Pal

1 Introduction

The environment can be well-defined as all forms that surround both living elements (such as humans or animals, fishes and birds) as well as non-living elements, itself classified as both moving (such as air and water) and non-moving (such as mountains and forests). Human activities do interact with the bio-physical environment in a multifaceted manner connecting different geographical levels. The existence of all living forms on this planet gradually evolved to build a healthy and well-balanced environment throughout the space and time. The new economic demand should operate in a way that shields the biophysical environment to maintain the balanced and sustainable growth both at present and in the future. We must not merely consider the natural resources, such as forests, as carbon sinks. Rather, it is the time to reconsider them as vital resources that provide vital elements such as fresh air for our crucial survival. Human beings inhale oxygen from the environment and release carbon dioxide back while plants simultaneously absorb carbon dioxide and give out oxygen, thus maintaining a balance between the two. Another significant contributor to the GHGs is the livestock emission (mostly Methane) which many of us often ignore. Radical changes in

S. Mukherjee (✉)
Institute of Geographical Sciences, Physical Geography, Freie Universität Berlin, Berlin, Germany
e-mail: subham.m@fu-berlin.de

S. Kar
Department of Geography, University of Calcutta, Kolkata, India

S. Pal (✉)
Wastewater Technology Division, CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India

Academy of Science and Innovative Research (AcSIR), Ghaziabad, India
e-mail: subham.m@fu-berlin.de; s_pal@neeri.res.in

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_11

either of the consumption-release patterns can lead to an unmanageable environmental balance. Presently the world is facing enormous population growth and pressure. Capitalism has fuelled it by exploiting natural resources at a faster pace than ever. Formerly, nature itself used to check ecological balance through extreme events such as natural disasters as well as hazardous epidemics. The arrival of modern health care systems and advancements in the field of science and technology can control epidemics and diminish the effects of natural disasters today. At the same time, we are becoming increasingly susceptible to diseases and the rate is rapidly increasing. The complexity of the man-nature relationship has significantly altered in today's world. In the past, nature was seen as necessary and beneficial on which amplification of human need in today's world has left its footprint. Therefore, a minor environmental change nowadays puts significant impacts on human life. However, the perception of what constitutes a 'hazard' and 'disaster' changes over time (Paton and Johnston, 2001; Furedi, 2007). A hazard is a dangerous incident that brings a menace to humans, while a disaster is a stern disturbance striking over a shorter or longer duration that grounds extensive material and/or ecological loss for both human and natural enevironments that surpasses the capacity of the impacted community to survive back using its immediate own resources again. Hazards will be considered disasters once they affect humans, but if they occur in an unpopulated area, they will remain hazardous. Since the man-nature relationship is not identical over different periods of time and at different places, the intensity of disasters or natural outbreaks are different accordingly (Zhao et al., 2006). Developing countries pay the most once a disaster hits. These fatalities in developing countries due to natural hazards are over 20 times bigger in terms of GDP than the industrialised countries (Peduzzi et al., 2002).

Therefore, the question remains whether development and environmental protection can be achieved together or whether there is a kind of dichotomy between the two. This is, however, not a simple question to answer. For example, urban areas are highly modified to suit human needs which results in the destruction of green spaces and formation of urban heat islands (Doick et al., 2014). However, in rural areas, although the natural environment is quite intact, unskilled agriculture and pressure on farmland causes serious land degradation, thereby leading to ecological and economic stress (Sudhishrf and Dass, 2012). A disaster or any natural outbreak has a cause and effect inter-relationship between nature and human societies. A disaster can be defined as a serious disturbance of the functioning of both biophysical and human societies, causing extensive environmental, human and material losses which surpass the ability of the affected communities to deal with using only its own resources (Asian Disaster Reduction Center, 2003). The impact of anthropogenic impact on the natural environment is directly co-related to population growth (Donner and Rodríguez, 2008), particularly in urban areas with a population density of around 30%, which may reach up to 60% by 2050 (Patel and Burke, 2009). Related factors include consumption patterns of populations as well as their innovative technology-intensive lifestyles. Humans consume resources from the healthy ecosystem, but in return they transform it into an unhealthy form of ecosystem.

From the prehistoric to the modern age, the idea of disaster has been influenced by such diverse factors as religious belief and scientific considerations. Disasters were often characterised as 'acts of God,' thereby implying that 'nothing could be done about their occurrence' (Quarantelli, 2000). Nevertheless, with the advent of Enlightenment thinking and the augmentation of scientific knowledge, the idea was shifted from 'acts of God' to 'acts of Nature' and consequently to 'acts of Men and Women' (Quarantelli, 2000). Post-1980, the perception of disaster has been considered through a sociological and ecological lens. Instead of focusing on natural phenomena such as tornadoes and tsunamis, research focus has now shifted towards the new acts of man-made toxic and technical disaster (Shaluf, 2007). With this anthropological turn in scientific research, such events have come to be related to human activities and their causes have accordingly been perceived as the consequences of human irresponsibility or malevolence (Park, 2016).

2 Disaster Vulnerability

The concept of 'vulnerability' emerged after the environmental movement of the 1970s (Kroll-Smith et al., 1997) which brought the central ecological perspective of disaster to the forefront (Trickett, 1995). The intensity of damage brought about by any disaster indicates to what extent the communities are vulnerable (Kelman et al., 2016) and what preventive measures should be taken to tackle future risks (Kunz et al., 2014). Besides the practical nature of vulnerability, Heijmans, noted that the concept of vulnerability is also a matter of perception (Heijmans and Victoria, 2001). One of the principal claims of this study is that the number of occurrences of disasters are dramatically increasing and thus communities are becoming gradually more exposed to their impact. Vulnerability or exposure to the disaster is here conceptualised as the natural state of being (Ewald, 2002). The terms 'vulnerability' and 'risk' are often interchangeably used where 'risk' denotes anticipated losses from a particular hazard to certain element(s) at a particular point of time in the future (Cardona, 2005). Increase in population is generally regarded as the core of the problem which increases vulnerability, and potential damage of biophysical environmental stability encompasses *exponential growth in numbers.*

The rising intensity of financial activities, exclusively its meditation in sporadic urban agglomerations, adds to this above mentioned issue. However, it is uncertain whether the correlation between the loss in ecosystem and growth in financial sectors is simple or direct. For instance, studies revealed that only 11% of the people vulnerable to natural hazards living in low human development countries comprise more than 53% of recorded losses. This implies that development rank and risks associated with disasters are meticulously linked (UNDP, 2004). Further, the intensity of any catastrophe may not be the same in different places, even catastrophic events usually differ from place to place, though the same event will inflict different degrees of damage in different places (Hewitt, 2007). These findings seem to indicate that historical, socio-cultural, and recent eco-political developments set some groups of people at greater risk compared to others (Enarson and Morrow, 1998). While, the specific contexts are examined, the largest losses not only tend to accrue to relatively disadvantaged and powerless communities, but also reveal certain growths in human settlement, most visibly those in and around the rapidly increasing urban centres (Maskrey, 1989; Fernandez, 1999; Pelling, 2003a; Pelling 2003b). However, it should be pointed out that the incident of losses may not be an accurate assessment of how far communities are vulnerable to disaster, for such vulnerability is also affected by such factors as proper site selection for residential areas, carrying capacity, and, most importantly, level of modern safety standards (World Bank, 2001; Ozerdem and Jacoby, 2006).

Water has been the lifeline for all the civilisations existing on earth and today water pollution is one of the major sources of vulnerability. For example, aquifer contamination is the artificially induced deterioration of natural groundwater quality. It is mainly caused by anthropogenic (mainly, industrial and/or agricultural) activities. These potential sources of contamination (pollutants) are responsible for the degradation of groundwater quality, consequently increasing vulnerability. The aquifer vulnerability is demarcated as the relative incident when a pollutant injected on or near the land-surface can migrate to the aquifer due to the certain land use management practices, the characteristics of the pollutants and conditions of the aquifer sensitivity (Aller et al., 1987).

Details of total fatalities accentuate the exposure of not only certain communities, sectors, and/or areas, but also of confusing and undesirable incidents. The special apprehension is looming for proficient responses such as official reports of modern safety standards that are sometimes, if not mostly, either ignored or unenforced. For instance, although there is fairly convincing evidence that the 2012 Kedarnath disaster in northern India was the consequence of flash flooding and cloud blast (Dobhal et al., 2013), the intensity of damage was mainly due to improper site selection for build-up area (Ray et al., 2016). The disaster could have been explained as a natural phenomenon only if the mountain valley was to be free from human residency (Rao et al., 2014). Therefore, it is evident that in both wealthy and developing countries disregard, catastrophes and public trusts are extensively stated in official regulatory systems (McClean and Johnes, 2000; Oliver-Smith and Hoffman 2001).

3 Types and Effects of Environmental Disasters

Disasters constitute one of the major reasons of inequitable and unsustainable growth in today's world. Disasters can primarily be broadly classified into three specific categories, i.e., natural, anthropogenic, and mixed or hybrid. The natural disasters are those which are beyond anthropogenic control and therefore, necessitate our adaptation to them. Anthropogenic disasters, mainly, are caused by human themselves and are primarily the result of human greed, inefficient governance, and the poor civic sense among the different classes of society. The question of how society makes sense of the associative link between an unexpected calamity and the resultant impact is related to disaster vulnerability (Fischer, 2002). Following the attacks on the World Trade Centre on 9/11 incident in the USA, there has been a new or emerging awareness and appreciation in the field of research on the impact of disasters on human societies. Disaster categories and definitions have been discussed in details by Turner and Pedgeon (1997), Richardson (1994), the World Health Organization (2003), the Federal Emergency Management Agency (2003a, b), and the Mid-Florida Area Agency on Aging (2003).

3.1 Natural Disasters

Natural disasters are hazards that are triggered by natural reasons and may be of hydrometeorological, atmospheric, geological, or even biological causes (World Health Organization, 2006). Common examples of these natural hazards include cyclones, earthquakes, tsunamis, and volcanic eruptions which are exclusively of natural origin. Together with climate change, natural disasters present considerable challenges to socio-economic attainment and sustainable development as they disturb a wide array of both social and ecological systems (IPCC, 2001). Even today, many societies are ill-prepared to cope with extreme events and climate change threatens to undermine many decades of effort in the spheres of development assistance, poverty reduction, and disaster risk management (Thomalla et al., 2006). The observations of the *International Federation of the Red Cross and Red Crescent Societies in the World Disasters Report* (IFRC, 2002, 2003, 2004a, b) reveal that the number of people killed by natural disasters continues to be elevated, as well as that the number of people or communities altogether affected and, most certainly, associated financial losses have augmented significantly since the 1970s (IPCC, 2001).

3.2 Anthropogenic Disasters

Anthropogenic disasters are hazards which can be caused due to direct human negligence or faults. These man-made disasters are linked with industries, agriculture or energy generation facilities and include pollution, leakage of toxic waste, bigger impacts such as dam failure and explosions, wars or civil unrest to name a few (Pidgeon and O'Leary, 2000). Man-made disasters are also labelled as *socio-technical disasters* (Richardson, 1994) that are caused by failures in different organisational sectors like transport, industrial as well as public places or fora. Although access to safe and enough water and air are indispensable for both health and overall development of human beings, which are currently *at risk* if we continue to deteriorate both of them. The food and health care industries are extinguishing natural bio-physical elements and destroying the environments for both human and other living beings across the world. Sporadic urbanisation, population explosion, improper agricultural practices and unrestrained sewage discharge into rivers and wetlands are the main reasons behind the heavy increase in surface water pollution. Although groundwater is being used extensively, recent research which explores the fundamental structures that reveals current forms of human exposure to rapid and anthropogenic environmental transformation is not being considered (Kasperson and Kasperson, 2001; Turner et al., 2003; Pelling, 2003b). Studies also have improved our perception of how human influences and social constructions interact with physical environmental systems in creating hazardous conditions. Heavy industries, mining activities, and transport systems based on fossil fuels have been the major contributors to groundwater pollution. Across the globe, human civilisation developed on the banks of the rivers since water is necessary to sustain life. However, since the industrial revolution, with industrialisation concentrated mostly around urban centres, a major chunk of population from the rural-agricultural setup began to migrate to urban centres in search of better opportunities. This rise in migration together with improper agricultural practices contributed to the growth of pollution, thereby affecting not only the environment but also all existing living creatures on earth. Both, younger groups of people today convey a certain amount of more than 100 chemical residues that were absent in the bodies of their older generations. These harmful chemical substances accumulate slowly in their systems and are being transmitted to the next generation in very high concentrations. Waterborne diseases caused by the intake of chemicals and contaminated water affect around 3.4 million people globally.

Environment Institute (SEI) and Clark University in the US have illustrated both *the complexity of, and interactions involved in, vulnerability analysis*, *drawing attention to how multiple socio-political and physical processes operating at different spatial and temporal scales produce vulnerability within the coupled human-environment system* (Turner et al., 2003).

Industrial pollution can either be sourced from point sources or non-point sources of pollutants. Industrial pollution can be controlled either by legislative measures (such as the Water Act of 1974, the Air Act of 1981, the Environmental Act of 1986, the EIA Notification of 2006, and so on) or by the establishment of Pollution Control Boards. However, there are systemic weaknesses which complicate matters. The Bhopal gas tragedy serves as the perfect example to illustrate this point. The disaster could have been deterred if governmental departments had followed the specified norms as an alternative. However, residential or non-commercial houses were allowed everywhere in the factory, thereby resulting in the magnitude of the disaster. Further, urban water pollution has considerably reduced the availability of drinking water.

Agricultural pollution is mainly a non-point source of pollution and hence there are no fixed and universally accepted rules and regulations to control it. The only possible remedy can be inviting a change of technological methods applied or innovated. Although some farmers have made some effective attempts in this direction, most government authorities have not shown much interest. The Gulf of Mexico, for instance, has turned into a dead zone spreading over a considerably huge area with runoffs that contain residues of highly toxic (for marine aquatic organisms) chemical fertilisers and sprays from agricultural farms carried through the waters of the Mississippi river in the USA.

3.3 Hybrid Disasters

Since the relationship between human beings and nature is dynamic and complex, a new subset of anthropocentric disasters has been defined on the basis of the role played by both elements. This is called 'hybrid disaster' (Song and Park, 2017) and is based on the premise that both human error and natural forces collude to cause disaster. One of the examples of this type of disasters was Latur earthquake which happened on September 30, 1993. This early morning earthquake incident was one of the deadliest earthquakes the state of Maharashtra (India) has seen till date. In this intraplate-earthquake, about 52 villages were devastated and over 30,000 people were injured whereas nearly 10,000 people were dead. The earthquake left a massive hollow in Killari village, the epicentre of the earthquake, remains the same till date. The earthquake's focus was around 12 km deep - relatively shallow causing shock waves to cause more damage. The inexplicable failure of India's seismological network system, the untimely responses from the scientists fail to give necessary warning as well as the traditional building construction practices in the area led to unimaginable death rates and destruction of properties of poor people (Sinha and Goyal, 1994; Ravi, 1994).

4 Environmental Disasters in Social Context

If we overlook meteorologic issues it would be difficult to determine the increasing disaster risk. Even for meteorological hazards, the geophysical aspects of the worst cases of events in recent years had already been equalled or surpassed in the last centuries. With scientific agreement, considering anthropogenic activities as the main drivers of the current rapid climate change issues, the only way to effectively inverse the trend similarly depends upon gradual social transformations. At large, social assessments confirm the potential dangers that come mainly from more human exposure to the threats and, certainly, the lack of safety measures taken into serious account. In the meantime, for the last several decades and in almost everywhere in this world, the production of assests per capita and the obtainability of modern commodities have far surpassed even the growth of population. Accessibility and transformation of wealth could have had better and positive effects on safety measures, although wealthier countries often experience horrific disasters in recent times, such as the Fukushima disaster in Japan, which could have been controlled or even prevented more profoundly (Hewitt, 2013). According to McClean and Johnes (2000), the negligence in responsibility and preventive measures can act as a trigger to the greater exposure of risk, and damage to many selective groups of people or communities that are already standing on the verge of vulnerability due to the absence of a proper regulatory framework of risk reduction or lack of equitable responbilities.

Thus, presence of marginalities and internal power relations within the society(s) affect the vulnerability more selectively. The fatalities and impacts of any disaster are being seen in an inequitable way, more for some particular groups or parts of the population on the basis of their sex, gender or any other intersectional attributes. It is evident in cases of different disasters, such as tsunami of 2004. The countries along the Indian Ocean suffered the most and there was a high number of women fatalities among the deaths. It was also the similar case of the earthquake in Kobe during 1995, where the death toll was major among women residents of the area. According to Enarson and Morrow (1998), these unequal losses can be explained by the cultural history of social practices as it divided the society into groups and put some in greater exposure of danger.

Therefore, it is evident that due to the existing social divisions and selectiveness, differences in power and hegemonic roles, some groups are already in danger, whereas disasters or physical conditions do not discriminate between people, communities and societal practices (Hewitt, 2013). So-called wealthier nations do not avoid such situations, although not too substantial most of the times, but the losses found to be directly associated with inequitable and discriminatory social conditions for certain groups or communities. It can be linked with absence of serious institutional and technical preparedness for all. Detailed scrutiny of the specific concerns of threats could reduce the risk of disasters. Comprehensive reconstruction efforts show that many victims had been living in areas and buildings which violated basic safety rules and regulations. Pre-disaster investigations or surveys reveal the same. A majority of the victims were also reported to have already been suffering from a range of acute stresses and lack of basic support system, even before the disasters occurred.

5 Disaster Mitigation And Risk Reduction

5.1 Pre-Disaster Prediction and Risk Assessment

Preparedness is a shielding procedure that incorporates measures to enable governments, groups or communities, and individuals to respond fast to disaster conditions to deal with them as effectively as possible. It thus embraces the formulation of feasible plans for emergency supplies, the advancement of practical warning systems, the careful preservation of inventories, and the last but not the least, personnel training to cope. Further, it includes necessary investigation and rescue actions and evacuation plans, wherever necessary, to avoid the threat and impact from another surge of the disaster. Preparedness thus involves these important steps well in advance of any possible disaster event to minimise the projected fatalities, trouble in critical services supply and the direct structural damage.

5.2 Disaster Response: Monitoring and Assessment

Forecasting natural disasters is a budding area of research in recent years. However, the measure of human anguish in post-disaster situations is rarely considered prior to the occurrence of any disaster. Generally, this puts an instantaneous burden on the already damaged environmental services for the provision of emergency supplies of shelter, water, or waste management services. Nearly all disasters cause certain environmental impacts, which lay extra adverse effects to the already impacted communities. Considering the degrees of dangers in a disaster and its impacts on both the environment and the society, the immediate requirements of the communities, and the consequences for the early recovery preventive plans is therefore an essential need. Simultaneously, there are a number of philanthropic and relief-based activities which are generally undertaken at the initial preventive stage that may themselves have a serious impact on the state of the situation. Till date, post-disaster preventive measures entail assessments that are being carried out primarily to identify the instant life-saving requirements. From the perspective of humanitarian reforms, attention should be given to the immediate needs of the affected communities after the end of the emergency phase and before full-scale development starts to fill the gap. This initial recovery stage of disaster management should be allocated and provided according to the need of the people.

Efforts and measures taken at the early recovery phase by governments and other intergovernmental actors in case of a larger disaster event ever so often suffer from a combination of isolated initiatives and sporadic strategic leadership. This ultimately takes the whole situation to the deficiency of a holistic strategy and framework, resulting in a replication of efforts, a wastage of resources and, of course, lives as well as a catastrophe to factor in risk reduction deliberations. This condition makes the whole recovery in peril from the sustainable point of view. Therefore, renewed effort is now being considered for supporting the necessary early recovery phase of any post-disaster conditions by addressing the immediate needs and chances across the board, taking an intersectoral consideration, and institutional and community requirements into account, and consolidating necessary data into a common understandable format which can be instantly introduced into the available measures for both immediate and future financial support. Monitoring and Evaluation (M&E) are important as they: a) make operational activities more liable to the affected and the supportive groups, b) validate the risk reduction activities to the responsible authorities to demonstrate the efforts engaged and c) improve the perception of the Disaster Risk Reduction (DRR) procedures in practice by identifying the issues responsible for larger impacts.

The variations of M&E methods and frameworks for relief as well as further recovery have been developed significantly over the past decades. This can partially be determined by wide disparagement and pressure from the responsible donors but also because of the ongoing demand to demonstrate and aggravate the success and improved performance during and after disaster(s). Thus, a growing body of work is delivering governmental and non-governmental agencies the better-informed direction on M&E approaches for further development in disaster risk reduction, and emergency services. This is also supported by different humanitarian initiatives active throughout the world. Assessment of a M&E project should emphasise on the following features:

- *Inputs* which include the financial, technical and human resources arranged. Their critical effectiveness, profitability, and feasibility can also be assessed simultaneously.
- *Activities* include the performance of measures and their responsible factors.
- *Outputs* are the immediate outcomes or deliverables achieved by the project.
- *Impact* refers to significant deviations caused by the action(s) taken.

Monitoring discourses on the above mentioned inputs, activities, and outputs need to meet the timely data requirement of the associated project authorities and supply information related to developmental progress to the donors. Thus, these monitoring discourses must maintain a regularity and commence throughout the duration of the disaster management project. Whereas, evaluations generally focus on outputs, their impact, and degree of involvement of wider stakeholders even beyond the organisational setup. It is more infrequent and implied at any stage of the entire project cycle or, even beyond. Thus, monitoring is having an eloquent nature and evaluation is more investigative. Reviews are supplements for regular monitoring processes, in a less frequent manner and provide opportunities to identify key issues required in the project. They thus form a significant part of an internal managerial procedure, eventually engaging external stakeholders. Audits are important for assessing the project and to follow the compliance of the programme with already considered and existing agreed regulations, and mandates.

The evaluation procedure should be initiated at the design phase of the project where aims and objectives are being established and outcomes-based project frameworks are being developed. An array of evaluations should be there during and after the project ends to allow more profound assessment, although this practice is unlikely in reality. Evaluations should be programmed at those critical points within the project cycle whenever they are needed at the most, especially for the decision-making stages. Quantitative evaluation indicators are generally target oriented like the number of disaster-resistant structures built or disaster preparedness committees involving the community(s) established, sometimes using proxy indicators for this. Whereas, qualitative measurement indicators are more often necessary for the risk assessment, using inputs from the stakeholders through various workshops, interviews, engaging focus groups and semi-structured consultation based interviews. These qualitative measurement indicators can be crucial to provide proper measures of development and outcomes, therefore untangling insights into the processes undertaken. Participatory approaches have been proven to be delivering a decent qualitative information.

5.3 Post-Disaster Mitigation and Recovery

Mitigation holds measures to decrease both the direct impact of the hazard and the after math situations in order to reduce the degree of a future disaster. Mitigation measures can therefore focus on the hazard directly or on the exposure to the future threat. For example, water management can be a hazard specific mitigation measure applicable for drought-prone areas to relocate people from the affected areas, and reinforcement of infrastructures to mitigate damage once a hazard occurs. Apart from these physical mitigation measures, reducing the economic and social threats of the disasters in the future should also be another aim for mitigation. Unfortunately, due to the lack of proper governance system and awareness measures among the societies, socio-economic mitigation measures, generally, cannot show its full potentiality in most of the cases, such as disasters related to flood in most of the developing countries almost every year.

In the aftermath of a disaster, the pressure to rapidly restart the essential services increase the mitigation and rebuilding. In many communities, powerful right-wing alliances mainly, consisting of landowners, industry lobbies, and some governmental sectors attempt to maintain the previous capitalistic practices that results profit for this smaller group of higher powerholders, regardless of the impact on the less powerful groups and interests (Logan and Molotch, 1987). On the contrary, research as well as experiences recommend that proper planning and *the use of public sector dispute resolution techniques* can play a role in addressing the power imbalance and relations, and enduring requirements and concerns of the communities (Forester, 1987, 1989; Godschalk, 1992; Susskind and Cruikshank, 1987). The process of equitable disaster mitigation recovery is not always the best and possible approach. Disaster mitigation and recovery should consider the significant but limited scope of prospect to restructure the damaged services even stronger than their previous condition (before the event) by adjusting landuse pratices and its patterns, and reform the existing social sphere.

Many studies have revealed that disasters incline to variably impact individual persons and groups depending on their pre-disaster levels of existing social vulnerability (Blaikie et al., 1994; Bolin and Bolton, 1986; Bolin and Stanford, 1999; Peacock, Morrow, and Gladwin, 1997). Linking the status quo and captivating benefit of post-disaster prospects towards the positive change, inclusive actions taken in favour of less-powerful groups, it is obligatory for planners and other authoritative agencies to involve all stakeholders and pursue consensual approaches which elicit mutual benefits across the potentially disagreeing groups. Previous researches have also revealed that disaster mitigation and recovery policy are less prominent to local officials and authorities who tend to face disasters less frequently than the state itself and higher personnel, whereas the resistance to change may be overcome through a rapidly developed inclusive recovery measures (Wright and Rossi, 1981; Geipel, 1982). While researching on earthquake recovery strategies in Peru, Oliver-Smith (1990) found that sustainable recovery goals (e.g., tackling issues of existing inequality in the society and the adoption of best practices mitigating hazard) were reached when planning strategies met local needs. In this case, local capabilities were taken into consideration by those responsible for the supply of external aid, and the community, on the other hand, understood the organisational requirements. Some recent studies suggest that individuals and organisations are both, perhaps, more considerable to changes in the status quo following the occurrence of disasters (Birkland, 1997), that include sustainable disaster recovery planning and reconstruction measures taken as an approval of leaders from various levels who advocate for this approach (Smith, 2004).

The efficiency of pre-disaster response planning for post-disaster emergency response not necessarily always complies with the impactful management of disaster response actions (Quarantelli, 1993). Similarly, some groups appeared to react more efficiently to a disaster once they failed to plan or ignored existing planning measures altogether (Clarke, 1999). Equitable recovery planning can be accomplished through an adaptive and methodical approach (Smith, 2004). Mileti (1999) mentioned the following features underlying effective recovery plans at the local level:

i. Impacted stakeholders (by post-disaster measures) should be taken into consideration for input generation and accordingly policy-makers should attain buy-ins from them as a preventive measure. This will not only reduce conflict but also help to aid in the developmental process of a rapid recovery plan reflecting the local needs.
ii. The usefulness of a plan is also driven by the data and information used for making the policy and immediate action. Specific data and information crucial to develop an effective recovery plan incorporates hazard characteristics too (for example, high wind or storm surge) and potentially vulnerable areas, population size, and its composition, and spatial distribution, local economic factors etc. Technology such as Geographic Information System (GIS) can be used to provide a meaningful investigative platform to graphically display and analyse collected data and, thus, is being, even more, used by local governmental agencies and emergency planners and managers in the decision making process to mitigate and recover the impacts of hazards and disasters.
iii. A recovery management strategy should identify the potentially relevant groups and organisations that can offer specific types of support. A recovery group can therefore lead post-disaster management efforts and regularly organise to engage in preventive planning and policy-making decisions. This organisational structure must involve governmental agencies as well as non-profits and emergent organisations which can be the most effective while trying to aid the marginalised and/or those remain heavily excluded following disasters.
iv. Recovery and mitigation plans should be pragmatic and applicable. In the post-disaster conditions, existing policy-making measures must be adapted to account for the requirement to make fast decisions. Thus, measures should include hazard mitigation for the recovery of damaged infrastructural facilities and the future development plans according to the acknowledged hazard-prone areas to be put on the exclusion list.

v. The recovery strategy should also clearly articulate the effective functioning tasks in regard to the mobilisation, distribution, and coordination within the operational groups to conduct impact assessments. The information should be collected in such a manner that it can be quickly integrated and used to weigh local needs and support in the execution of pre and post-disaster reformation planning and policies.
vi. Generally, major disasters can affect in financial loss significantly exceeding local governmental budgets. The ability to bridge the identified needs collected as parts of the impact assessment as mentioned above to existing financial resources and funding sources and properly planned policies is central to the successful execution of identified goals and objectives, where, even if, local needs may not be enough to match the certain eligibility criteria but the presence of alternative implementation strategies in the planning procedure. It helps to plan for the effective contingency budget as a part of the preventive measures.

6 Environmental Disaster Management

6.1 The Role of Geospatial Sciences in Environmental Disaster Management

Geospatial sciences which complies Geographic Information Systems (GIS), Remote Sensing (RS), and Global Positioning Systems (GPS) together have gained much attention in recent years for the practical and on-time applications in disaster mitigation and management planning and are progressively being employed throughout the total cycle of disaster management system as a tool to support decision-making. GISs, are in many cases, recognised as a standard key tool for supporting decision making in disaster management (Mileti, 1999). Policy-makers, disaster managers, and the mass are gradually taking these Geospatial sciences seriously for their visualisation capabilities. Disaster management entails complex coordination within existing resources, necessary and available equipments, required skills, and possible human resources from different agencies. This multidimensional process therefore requires robust decision support systems for fostering cooperation and help *disaster loss reduction* (Assilzadeh and Mansor, 2004; Pourvakhshouri and Mansor, 2003). While spatial queries have long been of core of concern for both the disaster researcher groups and practitioners in the field of policy and decision making similarly, the inclusion of GIS has essentially augmented the capacity of the disaster-research-community for incorporating geographic approaches. The locational knowledge regarding the hazard zones and understanding existing inter-relationship with the distribution of various groups and sub groups of the people is crucial to develop planning and policies for mitigation and strengthen preparedness with proper strategies. Real-time locational information can effectively improve the distribution of essential resources as a part of the mitigation response. Despite the complexity regarding the, geographic approaches and technology oriented functional ability in Geospatial sciences, these modern technology is rapidly and effectively being used in recovery strategies for mitigating disaster risks and hazard management.

The spatial decision support system for disaster management (SDSS) incorporates technical dimensions in organisational issues. A decision support system, thus, meets the requirements of the practitioner simultaneously integrating existing physical and social factors. SDSS supports the inter-operability of emergency services essential during response and relief stages (Zlatanova, van Oosterom, and Verbree, 2004). The SDSS thus has a crucial role in mitigation and recovery planning phases of disaster management strategies. Advanced SDSS must be able to perform sophisticated tasks wherever and whenever needed, which involve right from the defining the problem and selection, identification and evaluation of the potential alternative solutions (De Silva, 2001). At the same time, GIS must be taken into the decision making process in accordance with decision-makers, disaster managers and policymakers as well as the public to create a robust system altogether.

The assessment of aquifer vulnerability (pollution potential of an aquifer) is a study pertaining to a combination of hydrogeologic factors, anthropogenic impacts or influences, and contamination sources in a given area. Mapping of aquifer vulnerability is based primarily on the percolation factors and diffusion of contaminants factors. The contaminants present in the aquifer system may be linked to the naturally absorbed components of the host rock or brought by the human activities during infiltration or percolation process of water from the surface of the ground above. Considering the accuracy, frequency of availability and accessibility of the data, aquifer vulnerability assessment method can be regarded as advantageous or with limited merits while application. Aquifer vulnerability assessment methods can be, therefore, categorised into the following:

- *Statistical analysis methods* measure groundwater quality and its pollution level through the study of statistical correlations and associations between the observed pollution data, circumstantial environmental conditions and land use - land cover patterns on the ground above.
- *Computer simulation method* requires more complexity and prerequisites of the details pertaining to the vulnerability assessment. Thus, the computer simulation method examines both physical and chemical properties and processes with greater distinction.
- Descriptive ranking methods classify or categorise the vulnerability or the intrinsic susceptibility of the groundwater table into different low, medium and high categories of vulnerability to help the managerial decisions.

Among these models, the most comprehensive and commonly used model for assessing groundwater vulnerability is the DRASTIC model (Aller et al., 1987). DRASTIC methodology was originally developed by the United Sates Environmental Protection Agency (USEPA) and is one of the worldwide used standardised systems for evaluation of groundwater vulnerability (Merchant, 1994; Lobo-Ferreira and Oliveira, 1997; Babiker et al., 2005). DRASTIC model is comprehensive in nature, and has the worldwide acceptance and application for assessing aquifer vulnerability.

6.2 Planning and Operational Decision-Making

Strategic geographical planning has always been set and executed under uncertainties. Planners used to deal with the uncertainties by overlooking the complexity. The strategic spatial planning can be regarded as a study of possible potentialities (Balducci, 2008; Hillier, 2005). This spatial planning also involves "encouraging the emergence of particular development trajectories" (Healey, 2008). The *emergent trajectory* proposes a shift from previously set targets to a flexible method which seeks to substitute beneficial change. Many suggest involving people in a debate on alternative futures must be important "through the creation of arenas for transparent, inclusive, democratic debate of foresighted potentialities" (Hillier, 2007). Post-disaster recovery planning has to deal with the complexity that arises over the time. Maximum strategic decisions need not to be presented in convenient ways. At the same time, problems and potential opportunities must be identified from "streams of ambiguous, often conflicting subjective opinion" (Mintzberg et al., 1976). The decision-making procedures of identification, prototypes, and negotiating adaptation strategies for disaster managers are still not very clear and universally accepted. Little attention has been paid to the initial diagnosis step which is a prerequisite for necessary actions to be taken.

Quarantelli (1969) observed that recovery suggests an attempt to take the post-disaster condition to some stages of acceptance which can be similar to the pre-impact stage. Recovery may decipher a form of stability rather than a return to any recognisable pre-event order (Hills, 1998). Right after WWII, planning became progressively rational, following a recognised pattern of consideration of all possible alternatives by decision-makers, the identification and assessment of the costs of each course of action, and the subsequent selection of the one which was the most desirable. One characteristic of this rational model of planning was the incorporation of the evaluation stage into the existing planning process. Recently, this model had been defied. Now, planning can be regarded as a frame of reference and an instrumental strategy for decision-making and at the same time, integration of uncertainty in the system, thus making planning process more flexible (Faludi, 1987).

Decision-making, on the other hand, can be viewed as a problem-solving action concluded by a solution deemed to be satisfactory (Schacter et al., 2011). Thus the decision-making appears as a process of selection which can be rational or irrational and based on explicit assumptions. Rational choice theory represents the notion to maximise benefits while minimising costs. Nevertheless, it should also consider that some, if not the most, decisions are made unconsciously, without thinking much about the decision process (Nightingale, 2008).

Rational theories of reasoning reveals how the reasoning should help to make proper judgments, and take decisions accordingly. These theories such as probability theory or decision theory suggest guidelines to follow. All rational choice models agree with preferences, for example, motivations, affect, desires, values, tastes, and beliefs such as cognition, ideas, knowledge, information, as the systematic driving forces behind the actions taken (Sun-Ki Chai, 1997). Kinicki (2008) suggests that rational decision-making denotes a *structured and stepwise approach* to decision-making which follows a rational four-steps order:

1. Identification of the problem
2. Generation of alternatives
3. Solution selection
4. Implementation and evaluation of the outcome.

The main benefit of this rational choice approach lies in its ability to support in the prediction of the act, either at the individual or the collective level. However, there are crucial limitations associated with this model for disaster decision-making, like unacceptable delays in the pursuit of an ideal solution, inadequate information, and the swiftly-changing nature of the issues. In contrast, the 'irrational' model proposes that decision-making is considered by inadequate information and its processing capacity, using critical heuristics and shortcuts to simplify decision-making, and by picking solutions meeting the minimum requirements to be good enough.

Disaster mitigation planners and managers are needed to take a range of reactive decisions to respond to the crisis events. Many of these operational decisions, in case of well prepared nations, would have been practised in advance and there would be well-established strategic protocols in place for most contingencies. Time is limited after a disaster and there is an imperative need to transport relief and to return to normalcy starting from clearing up the debris, repairing the damage happened, rebuilding livelihoods. Hence we must consider the fact that decision-making process needs to be prompt and under severe pressure than normal.

6.3 Building Capacities through Environmental Training and Awareness Building and Communication

Capacity refers to the total strengths, attributes, and available resources that a society, community or organisation possess in order to cope and decrease the risk from disaster and increase resilience (UNISDR, 2017). It emphasises capacity of the individual more to predict, manage, resist, and improve the loss, impacted from disasters, despite of focusing on the limiting vulnerability. Capacity also depends on other performing assets that economy, political stability or instability, presence of good governance, psychological conditions and, certainly the bio-physical environment offer (DFID, 2004). Capacity can also be designated as the opposite of vulnerability, nevertheless, even vulnerable people have some degrees of capacities too (Wisner et al., 2012; Shepard et al., 2013). Undeniably, the initial stage of capacity development is the composite of traditional or indigenous knowledge, powers, qualities, and other material assets that individuals, organisations, and/or societies altogether already have. Capacity may also incorporate collective infrastructural, institutional, knowledge and skill oriented qualities like social cohesion, leadership, and management capabilities (UNISDR, 2017). Thus, developing capacity can be defined as a concept that extends the ambit of building strength to encompass all the aspects of creating and sustaining growth over time involving learning and training opportunities in order to develop institutional, political, financial and technological awareness and resources as a comprehensive system for enabling environment widely (UNISDR, 2017).

Disaster risk reduction requires empowerment as well as comprehensive, accessible, and equitable participation (UN Report, 2015). Capacities are generally endogenous to communities at the household level, implying that people are more regulatory than communities (Wisner et al., 2012). Instead of making an effort to lessen vulnerability, strengthening capacity may be an easier strategy for the people themselves as most drivers of vulnerability remain unchanged at the household level, although economical, and political conditions can alter them (Wisner 2007). Most of the countries in the Global South, the disasters' impact with wide-ranging risks are commonly absorbed by the low-income groups at the household level, sustaining and increasing poverty intensities and weakening developmental consequences. Augmenting capacity may offer those vulnerable communities the prospect to diminish their risk from the disaster as well as develop and adapt to ongoing threats from the rapidly changing climate. An integrated capacity development always transforms the mindsets and, as a result, attitudes more than simply performing duties or tasks given. Nevertheless, measuring these transformations and consequential effects are no less than a major challenge (UNDP, 2009).

An aiding environment, that is, robust political will and commitment at the maximum levels of authority, all-embracing participation, and transparent public accountability is crucial for deciphering capacity at the performance level. For disaster risk reduction, capacity building offers the foundation of a pragmatic strategy that begins with the development of awareness, evaluation, reduction as well as prevention of potential risk and possible adaptation of mitigation measures (UNISDR, 2008). Organisations offer the comprehensive platform for individuals for working together towards a common set of goals with a shared vision (UNDP, 2008). Organisational capacity may thus be improved and evaluated from the management aspects of financial, administrational, governmental and human resources (USAID, 2012).

Capacities need to be developed through the process of formal education and practical training rather than just depending on the reflexion and performance at the individual level (UNDP, 2009). In addition, networking, leadership development and multi-stakeholder platforms also augment these capacity development processes (Datta et al., 2012). Capacity building should also be established on the essential traditional knowledge of local indigenous communities, which they possess through generations of experiences to deal with the disasters. Capacity-development strategies, hence, at the local level should include:

- Anticipate through raising the awareness, education, participation and implementation of risk assessments;
- Manage by providing essential first aid-training, learning to swim, and so on;
- Resist through preventive measures such as early warning systems, evacuation strategies, storing emergency equipment; and
- Mitigation through providing alternative means of income and social protection etc (Hagelsteen and Becker, 2014).

Capacity building is not just the development of technical measurements but need to be associated with specialised disciplines and precise sectoral requirements and, therefore, required to collectively promote the leadership and other managerial capabilities (UNDP, 2009). These incorporate the capacity to:

- Involve stakeholders
- Evaluate a situation
- Set a goal
- Design policies and related strategies
- Budget, manage and implement
- Assess impact

Cases of applying capacity development process for disaster risk reduction could present various unknown challenges. As of now, there is a considerable degree of uncertainty in the formal terminology used related to disaster risk reduction, capacity building and ownership in both literature and practice. Notions are also different while considering the local context, capacity assessment together with the distinction of roles and responsibilities at different levels of application (Hagelsteen and Becker, 2014). A culture of resilience could develop if we can enhance the disaster risk reduction capacity of individuals as well as organisations.

7 Examples

7.1 Example 1: Brownfield Regeneration and Impact on Human Health: Developed World

Land is a finite resource which is transformed over time with human intervention through production, settlement, and other associated socio-economic activities. Among these economic activities, industry and mining are primarily associated with the depletion of land resources. The term 'Brownfield' refers to the industrial wasteland within an Indian perspective, but this term is also used in parts of Europe, the United Kingdom, and the United States (Bambra et al., 2014). The US Environmental Protection Agency (EPA) defines Brownfield as abandoned, idle, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination. The terms

'Brownfield,' 'Greyfield,' and 'derelict sites' are all related to each other (Maantay, 2013; Litt and Burke, 2002; Shortt et al., 2011) and they are interchangeably used in literature. The primary similarity between these lands is that they are vacant contaminated sites in urban or suburban areas (Bambra et al. 2014) which have the potential to become a health hazard (Catney et al., 2007) and are located within a 5-25 km radius from the centre of each capital city (Newton, 2010).

The Environment Agency estimates that approximately 300,000 Ha of land in England is regarded as land affected by chemical and radiological contamination. Scotland as a whole accounts for a large number of (Hanlon et al., 2005; Mitchell et al., 2005; Taulbut et al., 2009; Walsh et al., 2010) Brownfield and derelict sites that serve as triggers for the inequalities of health (based on the degree of deprivation) as compared to other parts of the UK and Europe, but even within Scotland, Glasgow leads with the highest number of derelict and Brownfield sites, worst overall health, and higher inequalities (Gray, 2008). Nonetheless, it is questionable why Glaswegians tend to have lower health outcomes even when compared with a few developing world cities (Hanlon et al., 2005; Mitchell et al., 2005; Taulbut et al., 2009; Walsh et al., 2010). Even after making allowances for a similar industrial and cultural history, people in Glasgow have poorer health and higher deprivation compared to other cities in the UK (Gray, 2008). In this regard, Fairburn et al. (2004) noted that given the contingencies of industrial pollution and land contamination as well as deteriorating air quality and water quality in rivers, there is a strong interrelationship between environmental degradation and high deprivation in Glasgow as people living in the most-deprived areas are far more likely to be living near the sources of potentially hazardous environment.

With the help of a comprehensive literature review by Brender et al. (2011), it is evident that there is a correlation between environmental pollution and its threat to human health and the disproportionately large magnitude of its effect on poor and minority populations. The concept of Environmental Justice (EJ) refers to the distribution of equal environmental benefits among all population groups (Bullard et al., 2005). However, it should be noted that distribution patterns may be unequal as a consequence of the patterns of human settlement, income levels, racial traits, and cultural differences (Craig, 2010). Although it is evident that lower income groups and immigrant communities suffer significantly as a consequence of problems brought about by environmental pollution (Smyth, 2000), this connection is highly standardised with respect to racial traits, ethnicity, and poor environmental components in the United States (Maantay, 2001; Maantay, 2002). In Glasgow, there are approximately 927 individual sites of Brownfield land which account for about 4% of total land area in the city and 12% of the entirety of Scotland's Brownfield land (Scottish Government, 2012). More importantly, about 60% of Glasgow's city population resides within a 500 metre radius and over 92% live within a 1,000 metre radius (Chakraborty and Armstrong, 1997; Neumann et al., 1998; Sheppard et al., 1999). With the assistance of the base map (Scottish Government, 2012) of Glasgow City, Maantay (2013) noted that zones separated by radii of 100 metres from the contaminated sites are regarded as 'sacrifice zones' where even city planners are not interested in investing money because these zones have already crossed the threshold of re-development. These contaminated sites (mainly coal tar/creosote, phenols, cyanide and sulphur, heavy metals such as cadmium, lead, barium, and chromium, phytotoxic metals, and so on) have high incidences of foetal death, heart disease, various cancers, low birth weight of infants and, more importantly, respiratory disease (Malik et al., 2004; Ding, 2006; Kuehn et al., 2007; Wang, 2011). About 69% of the population in Glasgow is regarded as 'highly deprived' and does not have access to proper hygiene facilities such as drinking water, air, and food (Greenberg et al., 1998).

Glasgow's environmental degradation is not, however, only due to the presence of Brownfield sites but is rather a consequence of a larger complex of associated issues which are responsible for poor health and deprivation in the city. For example, individual behavioural issues such as excessive smoking, drug abuse, alcohol consumption, and poor diet (Craig, 2010) are also responsible for poor health and depression among communities. Moreover, the issues regarding EJ have only recently come under the attention in parts of the UK. Although EJ in Scotland has been discussed in scholarship, inequalities of health among different communities or within a particular community in the city has not hitherto been the major focus (Dunion, 2003; Scandrett, 2010). Therefore, it is imperative to tackle these health-related inequalities and deprivation through proper policy-making. Although planning has usually failed to effect significant change in the face of a continuing downward spiral, this is not so much the result of negligence on their part but rather due to realistic and pragmatic considerations about the limits of available resources.

7.2 *Example 2: Contaminated Site Management*

Improper management of waste, particularly industrial waste, may contaminate environmental components such as soil, surface water, groundwater, and air. Both natural as well as anthropogenic factors influence the physico-chemical properties of soil depending on natural and anthropogenic factors, and acting together across different spatial and temporal scales. Heavy metal content in many soil types is often significantly influenced by the parent material, and sometimes significantly influences the heavy metal content in many soil types, with concentration levels sometimes exceeding the critical values (Palumbo et al., 2000; Salonen and Korkka-Niemi, 2007). Some rock types of volcanic and metamorphic origin contain several heavy metals such as Ni, Cr and Mn. These are trace elements in some rock types of volcanic and metamorphic origin (Alloway, 1995). During the weathering processes of rocks the primary crystalline structure breaks down and consequently the relevant chemical elements are released from the rocks. Furthermore, these either get absorbed into the topsoil or move towards surface water or groundwater. Prolonged excessive use of pesticides in agricultural land results in the concentration of heavy metals such as copper, nickel, zinc, and cadmium accumulating in the topsoil

(Nicholson et al., 2003). In such cases, the presence of different sources of contamination and the widely divergent patterns of distribution of products make soil pollution assessment overly complex in the presence of different sources of contamination and the widely divergent patterns of distribution of products (Parth et al., 2011).

Disposal sites of Hazardous Waste (HW) are one of the major prime sources of elevated levels of metals in the soil environment (Bozkurt et al., 2002). Hazardous waste is typically defined as a solid, semi-solid, or non-aqueous liquid waste which, because of its chemical composition and characteristics, may pose a substantial human health hazard or environmental hazard if not managed properly or released accidentally. A piece of hazardous waste can be defined by one or more of the following properties:

- *Ignitability*: Waste is considered ignitable if its flashpoint is < 60° C, is an oxidiser, and is capable of causing fire through friction, absorption of moisture, or spontaneous chemical changes under normal conditions of temperature and pressure. Examples include waste oils, organic solvents, paint wastes, epoxy adhesives and resins, spent inks, degreasing agents, white phosphorous, and so on.
- *Corrosivity*: Although not every waste material is corrosive in nature, if it has a pH < 2 or >12.5 then it can be corrosive. For example, spent acids, alkalis, and solids that can form strongly acidic or basic solutions when mixed with water (ferric chloride, sodium hydroxide, etc), solutions that are strongly acidic or basic (ferric chloride, sodium hydroxide, etc).
- *Reactivity*: Waste may be considered as reactive if it is unstable or undergoes rapid or violent chemical reaction when exposed to air, water, or other materials at normal conditions and generates toxic gases or vapours when mixed with water or when exposed to pH conditions between 2 and 12.5 (as is the case with cyanide or sulphide-containing materials). Examples include wastes containing white phosphorous, acetyl chloride, chromic acid, cyanides, hypo-chlorides, organic peroxides, perchlorates, permanganates, sulphides, some plating materials, and bleaches.

Currently, India generates about 6.23 Million Metric Tonnes Per Annum (MMTPA) of hazardous waste. Significantly, most of such HW is produced by the industrialised states, of which Gujarat (28.76%), Maharashtra (25.16%), and Telangana (8.93%) constitute the top three. At the same time, environmental components are highly contaminated in a few states, such as in Gujarat where the air quality is severely degraded and is a direct contributor to serious airborne diseases (Basha et al., 2010). More specifically, the coastal marine atmosphere surrounding large industrial centres can be highly affected by pollution emissions, resulting in the high concentration built-up of pollutants in the ambient air (Chester et al., 1994; Ondov et al., 1997; Scudlark et al., 2002). Levels of trace metals in ambient air were also found to be higher than those in industrial areas of Titao Scalo and Ispra in Italy and Daejon in Korea (Rizzio et al., 1999; Ragosta et al., 2006; Kim et al., 2002). The heavy usage of chemicals in agricultural land in Punjab has been found to contaminate groundwater. Levels of F, NO_3, SO_4, Ca, Na, and Mg higher than permissible have been reportedly found in the groundwater in certain villages of the Bhatinda district (Kochhar 2000). There appears to be a correlation between these high values in groundwater and high uranium and radon activity (Kochhar and Dadwal, 2004). To assess the role of certain elements in causing cancer in the Jajjal and Gyana villages of Bhatinda district, the groundwater characteristics and radon activity including levels of F, NO_3, SO_4, U, Pb, Cr, and Ni were monitored in certain parts of southwest Punjab (Kochhar et al., 2007).

7.3 Example 3: Recent COVID Pandemic

The world is currently facing an unprecedented threat from the coronavirus disease 2019 (COVID-19), a respiratory illness, pandemic caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), infection, a novel (new) coronavirus first identified in Wuhan, China in December 2019. COVID-19 is a respiratory illness caused by SARS-CoV-2 infection. The looming crisis in the developed as well as developing countries threatens to devastate economies and further ramps up inequality. According to the latest report and guidelines published by WHO/UNICEF (2020), 'the provision of safe water, sanitation, and hygienic conditions is essential to protect human health during all infectious disease outbreaks, including the COVID-19 outbreak. Ensuring good and consistently applied WaSH and waste management practices in communities, homes, schools, marketplaces, and health care facilities will help prevent human-to-human transmission of the COVID-19 virus'. COVID-19 has crucially induced the deployment of identification and confinement measures, the drawing of boundaries, and exclusionary strategies which have unsurprisingly re-ignited the contested question of intersectionality and social exclusion in terms of water, food, and energy nexus securities. The provision of safe water, sanitation, and hygienic conditions is absolutely necessary to protect human health during any infectious disease outbreaks, including corona virus pandemic (WHO/UNICEF, 2020). According to the UN Report (2020), in least-developed countries up to 75% of people lack access to soap and water. The recently published UN Water Report (2020) mentions that about 4 billion people live in severe conditions of physical water scarcity for at least one month per year. Around 1.6 billion people—almost one fourth of the world's population—face economic water shortage, which means that they lack the necessary infrastructure to access water. According to the FAO (2020), a pandemic has significant impacts on both food supply and demand, and thus, pose a risk of an impending food crisis. Currently, about 820 million people around the world are experiencing chronic hunger, that is, not consuming enough caloric energy to live a normal life. Of these, 113 million are coping with acute and severe insecurities—hunger so severe that it poses an immediate threat to their lives or livelihoods and renders them reliant on external assistance to survive. These people can hardly afford to have any further potential disruptions to their livelihoods or access to food that COVID-19 might bring. If

COVID-19 cases—already present in most regions of the world—proliferate in the 44 countries that need external food assistance or in the 53 countries home to 113 million people experiencing acute and severe food insecurities, many of whose public health and social protection systems face capacity constraints, the consequences could be drastic and catastrophic.

The energy sector has already felt the impact of COVID-19. The outbreak has contributed to a sharply reduced demand for oil, resulting in plummeting prices and declining production, especially in the wake of the Russia-OPEC price war. According to the IEA Oil Market Report (2020), global oil demand is expected to fall by a record 9.3 mb/d year-on-year in 2020. Demand in April is estimated to be 29 mb/d lower than what it was a year ago, down to a level last seen in 1995. COVID-19 has also accelerated the sustained drop in gas prices. A similar trend of falling demand and price reduction can be observed in the electricity sector. At this moment, it is difficult to predict the consequences of these changes in the water, food, and energy sectors. Although these changes depend upon the ultimate trajectory of the virus outbreak itself which cannot be mapped with certainty having the distinct indications that scenarios will worsen much more for poorer nations (UNCTAD, 2020). In addition, according to the recent UN Report (2020), income losses are expected to exceed $220 billion in developing countries. With an estimated 55% of the global population having no access to social protection, these losses will reverberate across societies, impacting education, human rights and, in the most severe cases, basic food securities and nutrition within (intra-urban) and/or on the fringes (peri-urban) of a city or metropolis in the Global South where the density of population is currently the highest in the world.

Since the discovery of SARS-CoV-2 in December 2019, its geographic distribution continues to evolve (World Health Organization, 2020). UNICEF's Water, Sanitation and Hygiene (WaSH) interventions have contributed to the formulation of government strategies designed to control and terminate the transmission of the disease. The WHO has formulated a standard Strategic Preparedness and Response Plan (SPRP) to be used at country level. The SPRP outlines the public health measures that need to be taken in order to support countries to prepare for and respond to COVID-19.

The eight pillars of the COVID-19 strategic plan (WHO/UNICEF, 2020):

1. Country-level coordination, planning, and monitoring
2. Risk communication and community engagement
3. Surveillance, rapid response teams, and case investigation
4. Point of entry
5. National laboratories
6. Infection prevention and control
7. Case management
8. Operational support and logistics

Over the past few days, a series of *stimulus packages*, unique in both scale and scope, have been declared by China and the major developed countries to combat the escalating economic damages and the deteriorating crisis at the health sectors. Even though many developing countries had already registered slow economic growth in the last quarter of previous year with several inflowing recessions, the rapidity at which the pandemic has dealt an economic shock to even the most advanced economies is comparable to the global financial crisis of 2008. The economic effect of the COVID-19 pandemic is ongoing and gradually becoming difficult to predict, although there are straightforward indications that things will deteriorate considerably for developing economies even before any further preventive step is taken. Nonetheless, the full impact of the current health crisis has not yet been felt in many poor and middle income countries, and the 'end of the beginning' of the economic crisis has not yet been reached in advanced economies. The strong recovery in trade between developing countries that happened in 2010 appears less likely to be repeated this time around. Even if the impairment to global supply chains is retrievable, the entire global business model will have a permanent trait of change from top to bottom in order to recover the predicted damage. Moreover, China has gradually reduced its dependence on exports in its supply-chains increasing its domestic production of intermediate goods. Apart from the economic downfall and predicted global health crisis, the socio-cultural status and morphology in the developing world, especially in a country such as India, can be a vital input for further disaster. Although 'social distancing' is the key strategy for preventing further spread of COVID-19, it is questionable how far such a strategy would be possible in countries such as India, Indonesia, Pakistan, and China. In the case of India, for instance, marginalised communities are entirely dependent on daily wages to sustain their livelihood. Given this financial contingency, how would it be possible for them to follow the 'stay-at-home' protocol? Further, factors such as illiteracy, high population density (414 people per square kilometre), together with moderate-to-poor medical infrastructure will further compound the severity of this pandemic.

8 Concluding Remarks

Apart from the natural hydrometeorological hazards, environmental disasters are very likely during the current century as a result of years of exploitation of environmental resources as well as the absence of social securities for vulnerable groups of people especially in the lower and middle income countries. A range of solutions is, therefore, needed, including access to technologies, early warning systems for disaster management, as well as increased stakeholder capacities at every level. The interlinked nature of the risks posed by natural disasters and climate change is well documented. The urgent need to reduce the disaster risks has been recognised and reaffirmed in the 2030 Agenda for Sustainable Development. It was emphasised that thinking and action must be through managing systems to mitigate disaster risks and build resilience. The most effective means of reducing disaster risks include strong actions on climate change mitigation and adaptation. Otherwise, the frequency and intensity of, and the vulnerability to, disasters will only escalate in the future. Last but not the least, the role of good governance and imbibition of lessons learned from traditional knowledge are also necessary.

Acknowledgements We thank the German Academic Exchange Service (DAAD) who provides a fellowship to conduct this study. We would also like to thank Mr. Jaydeep Sinha, India for his kind assistance in proof reading and checking the language. The article is checked for plagiarism using the iThenticate software and recorded in the Knowledge Resource Center, CSIR-NEERI, Nagpur for anti-plagiarism (KRC No.: CSIR-NEERI/KRC/2020/MAY/WWT/1).

References

Aller, L., Bennett, T., Lehr, I.H. and Petty, R.F. (1987). DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings, EPA/600/2-- R.S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, Ada, Oklahoma.

Alloway, B.J. (1995). Heavy Metals in Soils, 2nd edn. Blackie Academic and Professional, London, pp. 368. ISBN 0-7514-0198-6.

Asian Disaster Reduction Center (2003). Glossary on natural disasters. Available at: www.adrc.or.jp accessed on 11.05.2020.

Assilzadeh, H. and Mansor, S.B. (2004). Natural disaster data and information management systems: Geo imagery bridging continents, XXth ISPRS Congress, July 12–23, 2004 Istanbul, Turkey, Commission 7, V11, WG V11/5.

Babiker, I.S., Mohammed, M.A.A., Hiyama, T. and Kato, K. (2005). A GIS-based DRASTIC model for assessing aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture, Central Japan. *Sci Total Environ*, **345:** 127–140.

Balducci, A. (2008), Constructing (spatial) strategies in complex environments. *In*: J. van den Broeck, F. Moulaert and S. Oosterlynck (eds), Empowering the Planning Fields. Leuven, Acco, 79–99.

Bambra, C., Robertson, S., Kasim, A., Smith, J., Cairns-Nagi, J. M., Copeland, A., … and Johnson, K. (2014). Healthy land? An examination of the area-level association between brownfield land and morbidity and mortality in England. *Environ Plann A*, **46(2):** 433–454.

Basha, S., Jhala, J., Thorat, R., Goel, S., Trivedi, R., Shah, K. and Jha, B. (2010). Assessment of heavy metal content in suspended particulate matter of coastal industrial town, Mithapur, Gujarat, India. *Atmos Res*, **97(1–2):** 257–265.

Birkland, T.A. (1997). After disaster: Agenda setting, public policy, and focusing events. Georgetown University Press, Washington, DC.

Blaikie, P., Cannon, T., Davis, I. and Wisner, B. (1994). At Risk: Natural Hazards, People's Vulnerability, and Disasters. Routledge, London.

Bolin, R.C. and Bolton, P. (1986). Race, Religion and Ethnicity in Disaster Recovery. Monograph No. 42.University of Colorado, Boulder, CO.

Bolin, R.C. and Stanford, L. (1999). Constructing vulnerability in the first world: The Northridge earthquake in Southern California, 1994. *In:* Oliver-Smith, A. and Hoffman, S. (eds.), The Angry Earth: Disasters in Anthropological Perspective.Routledge, New York, pp. 89–112

Bozkurt, S., Moreno, L. and Neretnieks, I. (2002). Long-term processes in waste deposits. *Sci Total Environ,* **250:** 101–121.

Brender, J., Maantay, J. and Chakraborty, J. (2011). Residential proximity to environmental hazards and adverse health outcomes. *Am. J. Public Health*, **101(1):** 37–52.
Bullard, R.D., Warren, R.C. and Johnson, G.S. (2005). The quest for environmental justice. Human Rights and the Politics of Pollution. San Francisco.
Cardona, O. (2005). Indicators of disaster risk and risk management: Summary report. Inter-American Development Bank, Available at lib.riskreductionafrica.org accessed on 11.05.2020.
Catney, P., Eiser, D., Henneberry, J. and Stafford, T. (2007). Democracy, trust and risk related to contaminated sites in the UK. Sustainable Brownfield Regeneration: Livable Places from Problem Spaces, pp. 35–66.
Chakraborty, J. and Armstrong, M.P. (1997). Exploring the use of buffer analysis for the identification of impacted areas in environmental equity assessment. *Cartogr Geogr Inform Syst*, **24(3):** 145–157.
Chester, R., Bradshaw, G.F. and Corcoran, P.A. (1994). Trace metal chemistry of the North Sea particulate aerosol: Concentrations, sources and sea water fates. *Atmos Environ,* **28(17):** 2873–2883.
Clarke, L.B. (1999). Mission Improbable: Using Fantasy Documents to Tame Disaster.The University of Chicago Press, Chicago.
Craig, C. (2010). The Tears that Made the Clyde: Well-Being in Glasgow.Argyll Publishing, Argyll.
Datta, A., Shaxson, L. and Pellini, A. (2012). Capacity, complexity and consulting. Lessons from managing capacity development projects, p. 36.
De Silva, F.N. (2001). Providing spatial decision support for evacuation planning: A challenge in integrating technologies. *Disaster Prev Manage*, **(10):** 11–20.
DFID (Department for International Development). (2004). Disaster risk reduction: A development concern.
Ding, E. (2006). Brownfield Remediation for Urban Health: A Systematic Review and Case Assessment of Baltimore, Maryland. *Johns Hopkins Univ J Young Investig*, **14(2)**.
Dobhal, D.P., Gupta, A.K., Manish, M. and Khandelwal, D.D. (2013). Kedarnath disaster: Facts and plausible causes. *Curr Sci*, **105(2):** 171–174.
Doick, K.J., Peace, A. and Hutchings, T.R. (2014). The role of one large greenspace in mitigating London's nocturnal urban heat island. *Sci Total Environ*, **493:** 662–671.
Donner, W. and Rodríguez, H. (2008). Population composition, migration and inequality: The influence of demographic changes on disaster risk and vulnerability. *Social Forces*, **87(2):** 1089–1114.
Dunion, K. (2003). Troublemakers: The Struggle for Environmental Justice in Scotland. Edinburgh University Press, Edinburgh.
Enarson, E. and Morrow, B.H. (1998). Conclusion: Toward gendered disaster policy, practice, and research. The gendered terrain of disaster: Through women's eyes, pp. 225–231.
Ewald, F. (2002). The return of Descartes's malicious demon: An outline of a philosophy of precaution. Embracing risk: The changing culture of insurance and responsibility, pp. 273–301.
Fairburn, J., Walker, G. and Smith, G. (2004). Investigating environmental justice in Scotland: links between measures of environmental quality and social deprivation SNIFFER report UE4(03)01. Edinburgh: SNIFFER (Scotland and Northern Ireland Forum for Environmental Research), Available at www.eprints.staffs.ac.uk accessed on 11.05.2020.
Faludi, A. (1987). A Decision-centred View of Environmental Planning. Pergamon, Oxford.
FAO (2020). Evaluation of certain veterinary drug residues in food: eighty-eighth report of the Joint FAO/WHO Expert Committee on Food Additives. World Health Organization. Food and Agriculture Organization of the United Nations (FAO). Rome, Italy.
Federal Emergency Management Agency. (2003a), Hazards. Available at: www.fema.gov/ hazards/earthquakes, Accessed on 11.05.2020.
Federal Emergency Management Agency. (2003b), Talking about disasters – heat wave, Available at: www.fema.gov/rrr/talkdiz/heat.shtm accessed n11.05.2020.

Fernandez, M.A. (ed.). (1999). Cities at risk: Environmental degradation, urban risks and disaster in Latin America. LA RED, The Network for Social Studies on Disaster, Lima, Peru.

Fischer, H.W. (2002), Terrorism and 11 September 2001: Does the behavioral response to disaster model fit? *Disaster Prev Manage*, **11(2):** 123–127.

Forester, J. (1987). Planning in the face of conflict. *J Am Plann Assoc*, **53(3):** 303–314.

Forester, J. (1989). Planning in the Face of Power. University of California Press, USA, Berkeley, CA.

Furedi, F. (2007). The changing meaning of disaster. *Area*, **39(4):** 482–489.

Geipel, R. (1982). Disaster and reconstruction. The Fruili (Italy) Earthquake of 1976.Allen and Unwin, London.

Godschalk, D.R. (1992). Negotiating intergovernmental development policy conflicts: Practice-based guidelines. *J Am Plann Assoc*, **58(2):** 368–378.

Gray, L. (2008). Comparisons of health-related behaviours and health measures in Greater Glasgow with other regional areas in Europe.Glasgow Centre for Population Health, Glasgow.

Greenberg, M., Lee, C. and Powers, C. (1998). Public health and brownfields: Reviving the past to protect the future. *Am Jf Public Health*, **88(12):** 1759–1760.

Hanlon, P., Lawder, R.S., Buchanan, D., Redpath, A., Walsh, D., Wood, R., Bain, M., Brewster, D.H. and Chalmers, J. (2005). Why is mortality higher in Scotland than in England and Wales? Decreasing influence of socioeconomic deprivation between 1981 and 2001 supports the existence of a 'Scottish Effect'. *J Public Health*, **27(2):** 199–204.

Hagelsteen, M. and Becker, P. (2014). Forwarding a challenging task: Seven elements for capacity development for disaster risk reduction. Planet@ risk, **2(2)**.

Healey, P. (2008). Making choices that matter: The practical art of situated strategic judgement in spatial strategy-making. *In*: van den Broeck, J., Moulaert, F., and Oosterlynck, S. (Eds.), Empowering the Planning Fields, Leuven, Acco, pp. 23–41.

Heijmans, A. and Victoria, L. (2001). Citizenry-based and development-oriented disaster response. Centre for Disaster Preparedness and Citizens' Disaster Response Centre, pp. 1–171. Available at: www.proventionconsortium.org. accessed on 11.05.2020.

Hewitt, K. (2007). Preventable disasters: Addressing social vulnerability, Institutional risk and civil ethics. *Geogr Rundschau, Int Ed*, **3(1):** 43–52.

Hewitt, K. (2013). Environmental disasters in social context: toward a preventive and precautionary approach. *Natural Hazards*, **66(1):** 3–14.

Hillier, J. (2005). Straddling the poststructuralist abyss: between transcendence and immanence?', *Planning Theory*, **4:** 271–299.

Hillier, J. (2007). Stretching Beyond the Horizon: A Multiplanar Theory of Spatial Planning and Governance. Aldershot, Ashgate, Newcastle, UK.

Hills, A. (1998). Seduced by recovery: The consequences of misunderstanding disaster, *J Contin Crisis Manage*, **6:** 161–169.

IEA (2020). The IEA Oil Market Report (OMR). International Energy Agency (IEA), Paris. Available online: https://www.iea.org/reports/oil-market-report-april-2020 accessed on 11.05.2020.

IFRC (2004a). World Disasters Report 2004. IFRC (International Federation of Red Cross Red Crescent Societies): Geneva. Switzerland.

IFRC (2004b). World disasters report: Focus on community resilience. IFRC (International Federation of Red Cross Red Crescent Societies): Geneva. Switzerland.

IFRC (2003). World Disasters Report 2003. IFRC (International Federation of Red Cross Red Crescent Societies): Geneva. Switzerland.

IFRC (2002). World Disasters Report 2002. IFRC (International Federation of Red Cross Red Crescent Societies). Geneva. Switzerland.

IPCC (2001). Climate Change 2001: Intergovernmental Panel on Climate Change (IPCC) Third Assessment. Available online https://www.ipcc.ch/report/ar3/wg1/ accessed on 11.05.2020.

Kasperson, J.X. and Kasperson, R.E. (2001). International Workshop on Vulnerability and Global Environmental Change: A Workshop Summary. Stockholm Environment Institute, Stockholm, Sweden.

Kelman, I., Gaillard, J.C., Lewis, J. and Mercer, J. (2016). Learning from the history of disaster vulnerability and resilience research and practice for climate change. *Nat Hazards*, **82(1):** 129–143.

Kim, K.H., Lee, J.H. and Jang, M.S. (2002). Metals in airborne particulate matters in the Taejon Industrial Complex area of Korea. *Environ Pollut*, **118(1):** 41–51.

Kinicki, A. (2008). Organisational Behaviour, Small Business toolkit, NSW Government, Australia.

Kochhar, N. (2000). Attributes and significance of the A-type Malani magmatism, northwestern peninsular India. In: Deb, M. (ed.), Crustal evolution and Metallogeny in the Northwestern Indian Shield. Narosa, New Delhi, pp. 158–188.

Kochhar, N. and Dadwal, V. (2004). Radon and chemical quality of ground water in part of SW Punjab in relation to the buried Aravalli-Delhi ridge. *In*: Proceedings workshop on medical geology, IGCP-454, special publication, **83:** 293–298.

Kochhar, N., Gill, G.S., Tuli, N., Dadwal, V. and Balaram, V. (2007). Chemical quality of ground water in relation to incidence of cancer in parts of SW Punjab, India. *Asian J Water Environ Pollut*, **4(2):** 107–112.

Kroll-Smith, S., Couch, S.R. and Marshall, B.K. (1997). Sociology, extreme environments, and social change. *Curr Sociol*, **45(3)**: 1–18.

Kuehn, C.M., Mueller, B.A., Checkoway, H. and Williams, M. (2007). Risk of malformations associated with residential proximity to hazardous waste sites in Washington State. *Environ Res*, **103(3):** 405–412.

Kunz, N., Reiner, G. and Gold, S. (2014). Investing in disaster management capabilities versus pre-positioning inventory: A new approach to disaster preparedness. *Int J Prod Econ*, **157:** 261–272.

Litt, J. and Burke, T. (2002). Uncovering the historic environmental hazards of urban brownfields. *J Urban Health*, **79(4):** 464–481.

Lobo-Ferreira, J.P. and Oliveira, M.M. (1997). DRASTIC groundwater vulnerability mapping of Portugal, groundwater: An endangered resource. *In*: Proceedings of the 27th congress of the international association for hydraulic research, San Francisco, USA, August 10–15, 1997 Theme C, pp. 132–137.

Logan, J. and Molotch, H. (1987). Urban Fortunes: The Political Economy of Place.University of California Press, Berkeley, CA, USA.

Maantay, J.A. (2002). Mapping environmental injustices: Pitfalls and potential of geographic information systems (GIS) in assessing environmental health and equity. *Environ Health Perspect*, **110 (Supp. 2):** 161–171.

Maantay, J.A. (2001). Zoning, equity, and public health. *Am J Public Health*, **91(7):** 1033–1041.

Maantay, J.A. (2013). The collapse of place: Derelict land, deprivation, and health inequality in Glasgow, Scotland. *Cities Environ* (CATE), **6(1):** 10.

Malik, S., Schecter, A., Caughy, M. and Fixler, D.E. (2004). Effect of proximity to hazardous waste sites on the development of congenital heart disease. *Archiv Environ Health*, **59(4):** 177–181.

Maskrey, A. (1989) Disaster Mitigation; A Community-based Approach. Oxfam, Oxford, UK.

McClean, I. and Johnes, M. (2000) Aberfan: Disasters and Government. Welsh Academic Press, Cardiff, UK.

Merchant, J.W. (1994). GIS-based groundwater pollution hazard assessment: A critical review of the DRASTIC model. *Photogramm Engineer Remote Sensing*, **60(9):** 1117–1127.

Mid-Florida Area Agency on Aging (2003), Chapter 6: Types of disasters. Available at: www.mfaaa.org/emeregncy/plan/disaster/6.html accessed 02.05.2020.

Mileti, G.S. (1999). Disasters by Design: A Reassessment of Natural Hazards in the United States. Josepg Henry, Washington, DC, USA.

Mintzberg, H., Raisinghani, D. and Théorêt, A. (1976). The structure of "unstructured" decision processes. *Admin Sci Q*, **21(2):** 246–275.
Mitchell, R., Fowkes, G., Blane, D. and Bartley, M. (2005). High rates of ischemic heart disease in Scotland are not explained by conventional risk factors. *J Epidemiol Commun Health*, **59:** 565–567.
Neumann, C.M., Forman, D.L. and Rothlein, J.E. (1998). Hazard screening of chemical releases and environmental equity analysis of populations proximate to toxic release inventory facilities in Oregon. *Environ Health Perspect*, **106(4):** 217–226.
Newton, P.W. (2010). Beyond greenfield and brownfield: The challenge of regenerating Australia's greyfield suburbs. *Built Environ*, **36(1):** 81–104.
Nicholson, F.A., Smith, S.R. and Alloway, B.J. (2003). An inventory of heavy metals inputs to agricultural soils in England and Wales. *Sci Total Environ,* **311:** 205–219.
Nightingale, J. (2008). Think Smart - Act Smart: Avoiding the Business Mistakes That Even Intelligent People Make. John Wiley and Sons.
Oliver-Smith, A. (1990). Post-disaster housing reconstruction and social inequality: A challenge to policy and practice. *Disasters*, **14(1):** 7–19.
Oliver-Smith, A.S. and Hoffman, S.M. (eds). (2001). The Angry Earth. Routledge, New York, USA.
Ondov, J.M., Quinn, T.L. and Battel, G.F. (1997). Influence of temporal changes in relative humidity on size and dry depositional fluxes of aerosol particles bearing trace elements. In: Baker, J.E. (ed.), Atmospheric Deposition of or.jp/ accessed on 10.05.2020.
Ozerdem, A. and Jacoby, T. (2006). Disaster Management and Civil Society: Earthquake Relief in Japan, Turkey and India. I.B. Tuaris: London.
Palumbo, B., Angelone, M. and Bellanca, A. (2000). Influence of inheritance and pedogenesis on heavy metal distribution in soils of Sicily, Italy. *Geoderma*, **95(3–4):** 247–266.
Park, C.L. (2016). Meaning making in the context of disasters. *J Clin Psychol*, **72(12):** 1234–1246.
Parth, V., Murthy, N.N. and Saxena, P.R. (2011). Assessment of heavy metal contamination in soil around hazardous waste disposal sites in Hyderabad city (India): natural and anthropogenic implications. *J Environ Res Manage*, **2(2):** 027–034.
Patel, R.B. and Burke, T.F. (2009). Urbanization—An emerging humanitarian disaster. *N Engl J Med*, **361(8):** 741–743.
Paton, D. and Johnston, D. (2001). Disasters and communities: Vulnerability, resilience and preparedness. *Disaster Prev Manage*.
Peacock, W.G., Morrow, B.H. and Gladwin, H. (eds.). (1997). Hurricane Andrew: Ethnicity, Gender and the Sociology of Disaster.Routledge, London.
Peduzzi, P., Dao, H. and Herold, C. (2002). Global Risk and Vulnerability Index Trends per Year (GRAVITY), Phase II: Development,
Pelling, M. (2003a). The Vulnerability of Cities: Natural Disasters and Social Resilience. Earthscan, London, UK.
Pelling, M. (Ed). (2003b). Natural Disasters and Development in a Globalizing World. Routledge, London, UK.
Pidgeon, N. and O'Leary, M. (2000). Man-made disasters: Why technology and organizations (sometimes) fail. *Saf Sci*, **34(1–3),** 15–30.
Pourvakhshouri, S.Z. and Mansor, S. (2003). Decision support system in oil spill cases. Literature review. *Disaster Prev Manage*, **12(3):** 217–221.
Quarantelli, E.L. (1969). The disaster recovery process: What we know and do not know from research. Preliminary Paper #286. Disaster Research Center, University of Delaware. USA.
Quarantelli, E.L. (2000). Disaster planning, emergency management and civil protection: The historical development of organized efforts to plan for and to respond to disasters. Disaster Research Center, University of Delaware. USA.
Quarantelli, E.L. (1993). Converting disaster scholarship into effective disaster planning and managing: Possibilities and limitations. *Int J Mass Emerg Disasters*, **11(1):** 15–39.
Ragosta, M., Caggiano, R., D'Emilio, M., Sabia, S., Trippetta, S. and Macchiato, M. (2006). PM10 and heavy metal measurements in an industrial area of southern Italy. *Atmos Res*, **81:** 304–319.

Ray, P.K. Champati, Shovan Lal Chattoraj, M.P.S. Bisht, Suresh Kannaujiya, Kamal Pandey and Ajanta Goswami. (2016). Kedarnath disaster 2013: Causes and consequences using remote sensing inputs. *Natural Hazards*, **81(1):** 227–243.

Rao, S., Nithya, G.K. and Rakesh, K. (2014). Development of a wireless sensor network for detecting fire and Gas leaks in a collapsing building. *In*: Fifth International Conference on Computing, Communications and Networking Technologies (ICCCNT), IEEE, pp. 1–7.

Ravi, A. (1994). Maharastra Earthquake. The Hindu Survey of the Environment. Madras, India.

Richardson, B. (1994). Socio-technical disaster: profile and prevalence, *Disaster Prev Manage*.

Rizzio, E., Giaveri, G., Arginelli, D., Gini, L., Profumo, A. and Gallorini, M. (1999). Trace elements total content and particle sizes distribution in the air particulate matter of a rural–residential area in north Italy investigated by instrumental neutron activation analysis. *Sci Total Environ*, **226:** 47–56.

Salonen, V. and Korkka-Niemi, K. (2007). Influence of parent sediments on the concentration of heavy metals in urban and suburban soils in Turku, Finland. *Appl Geochem*, **22:** 906–918.

Scandrett, E. (2010). Environmental justice in Scotland: Incorporation and conflict. *In*: Davidson, N., McCafferty, P. and Miller, D. (eds.), NeoLiberal Scotland: Class and Society in a Stateless Nation. Cambridge Scholars Publishing, Cambridge, Chapter 5, pp. 183–201.

Schacter, D.L., Gilbert, D.T. and Wegner, D.M. (2011). Psychology. Worth, New York.

Scottish Government (2012). Vacant and Derelict Land Survey. Statistical Bulletin Planning Series. Edinburgh: A National Statistics Publication for Scotland.

Scudlark, J.R., Conko, K.M. and Church, T.M. (2002). Atmospheric wet deposition of trace elements to Chesapeake Bay. *Atmos Environ*, **36:** 1077–1086.

Shaluf, I.M. (2007). An overview on disasters. *Disaster Prev Manage*.

Shepard, A., Mitchell, T., Lewis, K., Lenhardt, A., Jones, L., Scott, L., Muir-Wood, R., et al. (2013). The geography of poverty, disasters and climate extremes in 2030.

Sheppard, E., Leitner, H., McMaster, R.B. and Hongguo, T. (1999). GIS based measures of environmental equity: Exploring their sensitivity and significance. *J Exposure Analyt Environ Epidemiol*, **9:** 18–28.

Shortt, N., Richardson, E., Mitchell, R. and Pearce, J. (2011). Re-engaging with the Physical Environment: A Health-Related Environmental Classification of the U.K., Area. *R. Geogr. Soc.*, **43:** 76–87.

Sinha, R. and Goyal, A. (1994). Damage to buildings in the Latur earthquake. *Curr Sci*, **67:** 38.

Smith, G. (2004). Holistic disaster recovery: Creating a sustainable future. Federal Emergency Management Agency. Emergency Management Institute, Higher Education Project. The course is available online at: http:// training.fema.gov/emiweb/edu/completeCourses.asp

Smyth, J.J. (2000). Labour in Glasgow 1896–1936: Socialism, Suffrage, Sectarianism. Tuckwell Press, East Linton.

Song, C.Y. and Park, S.H. (2017). Strategy for improvement of disaster response system of hybrid disaster in Korea. *J Korea Inst Struct Maintenance Inspect*, **21(3):** 45–53.

Sudhishrf, S. and Dass, A. (2012). Study on the impact and adoption of soil and water conservation technologies in Eastern Ghats of India. *J Agric Eng*, **49(1):** 51–59.

Sun-Ki Chai (1997). Rational Choice: Positive, Normative, and Interpretive. Working paper. Department of Sociology, University of Hawaii.

Susskind, L. and Cruikshank, J. (1987). Breaking the Impasse: Consensual Approaches to Resolving Public Disputes. Basic Books, New York.

Taulbut, M., Walsh, D., Parcell, S., Hanlon, P., Hartmann, A., Poirier, G. and Strniskova, D. (2009). The Aftershock of Deindustrialisation – Trends in Mortality in Scotland and Other Parts of Post-industrial Europe. Glasgow Centre for Population Health, Glasgow.

Thomalla, F., Downing, T., Spanger-Siegfried, E., Han, G. and Rockström, J. (2006). Reducing hazard vulnerability: Towards a common approach between disaster risk reduction and climate adaptation. *Disasters*, **30(1):** 39–48.

Trickett, E.J. (1995). The community context of disaster and traumatic stress: An ecological perspective from community psychology. *In*: Extreme Stress and Communities: Impact and Intervention. Springer, Dordrecht, pp. 11–25.

Turner, B.A. and Pedgeon, N.F. (1997). Man-Made Disasters, 2nd ed., Butterworth-Heinemann, Oxford, UK.

Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J J., Corell, R.W., Christensen, L., … & Polsky, C. (2003). A framework for vulnerability analysis in sustainability science. *Proc Natl Acad Sci USA*, **100(14):** 8074–8079.

USAID (US Agency for International Development) (2012). Building Resilience to Recurrent Crisis: USAID Policy and Program Guidance. Available online: http://www.usaid.gov/sites/default/files/documents/1870/USAIDResiliencePolicyGuidanceDocument.pdf. accessed on 11.05.2020.

UN Report (2015). Sendai framework for disaster risk reduction 2015–2030. United Nations. New York, USA. Available online: https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf accessed on 11.05.2020.

UN Report (2020). Coronavirus and human rights: Call for disability-inclusive recovery. Available online: https://news.un.org/en/story/2020/05/1063242 accessed on 11.05.2020.

UNDP (2004). A global report: Reducing disaster risk; a challenge for development. United Nations Development Programme, Bureau of Crisis Prevention and Management, New York, USA.

UNDP (2008). Capacity Assessment: Practice Note. United Nations Development Programme. New York, USA

UNDP (2009). Capacity Development: A UNDP Primer. United Nations Development Programme. New York, USA.

UNISDR (2008). Briefing Note: Climate Change and Disaster Risk Reduction. United Nations International Strategy for Disaster Reduction (UNISDR): Geneva, Switzerland.

UNISDR (2017). United Nations International Strategy for Disaster Reduction (UNISDR): Terminology on Disaster Risk Reduction 2017: Geneva, Switzerland.

UNCTAD (2020). World Economic Situation and Prospects 2020. United Nations. New York. USA. Available online: https://unctad.org/en/PublicationsLibrary/wesp2020_en.pdf. Accessed on 11.05.2020.

UN Water Report (2020). The United Nations world water development report 2020: Water and Climate Change. UN-Water Publication. UNESCO: Paris, France.

Walsh, D., Bendel, N., Jones, R. and Hanlon, P. (2010). It's 'just deprivation': Why do equally deprived UK cities experience different health outcomes? *Public Health*, **124(9):** 487–495.

Wang, J. (2011). The health impacts of brownfields in Charlotte, NC: A spatial approach. *In*: Geospatial Analysis of Environmental Health, Maantay, J.A. and McLafferty, S. (eds.), Springer Verlag, Dordrecht, NL.

Wisner, B. (2007). The societal implications of a comet/asteroid impact on earth: A perspective from international development studies. *In*: Comet/Asteroid Impacts and Human Society. Springer, Berlin, Heidelberg, pp. 437–447.

Wisner, B., Gaillard, J.C. and Kelman, I. (2012). Framing disaster: Theories and stories seeking to understand hazards, vulnerability and risk. *In*: Handbook of Hazards and Disaster Risk Reduction, Routledge, pp. 47–62.

World Bank. (2001). Gujarat earthquake recovery program: Assessment report. Joint World Bank and Asian Development Bank, March 14.

WHO (2003). Emergency and humanitarian action: Natural disaster profile, World Health Organization available at: www.who.int/disasters accessed on 10.05.2020.

WHO (2006). The world health report 2006: Working together for health. World Health Organization, 2006. Geneva, Switzerland.

WHO/UNICEF (2020). WHO/UNICEF joint statement – Maintaining routine immunization services vital during the COVID-19 pandemic. Available online: http://www.euro.who.int/

en/media-centre/sections/statements/2020/whounicef-joint-statement-maintaining-routine-immunization-services-vital-during-the-covid-19-pandemic accessed on 11.05.2020.

Wright, J.D. and Rossi, P.H. (eds.). (1981). Social Science and Natural Hazards. Abt Books, Cambridge, MA, USA.

Zhao, S.J., Xiong, L.Y. and Ren, A.Z. (2006). A spatial–temporal stochastic simulation of fire outbreaks following earthquake based on GIS. *J Fire Sci*, **24(4):** 313–339.

Zlatanova, S., Van Oosterom, P. and Verbree, E. (2004). 3D technology for improving disaster management: Geo-DBMS and positioning. *In*: Proceedings of the XXth ISPRS Congress. Istanbul, Turkey, p. 6.

Chapter 12
Environmental Impact Assessment

Pradip K. Sikdar

1 Introduction

Environmental impact assessment (EIA) is a formal study process used to anticipate the environmental consequences of a proposed major development project. An EIA concentrates on problems, conflicts on natural resource constraints that could affect: (i) the viability of the project and (ii) the people, their homeland or their livelihood. After predicting potential problems, the EIA identifies measures to minimise the problems and outlines ways to improve the project's suitability for its proposed environment. The aim of the EIA is to ensure that potential problems are foreseen and addressed at an early stage in the projects planning and design. To achieve this aim assessment's finding are communicated to all the various groups who will make decisions about the proposed project such as project developers, investors, decision makers, regulators, planners, local community and politicians.

The EIA is an important phase in the process of deciding about the final shape of a proposed project. The EIA helps officials to make decisions about a project and it helps the project proponents to achieve their aims more successfully. A given project should be sustainable, which will continue to yield profit and hence enhance the quality of life. In order to attain sustainability, the project should be designed to suit the local environment, should conserve the natural resource it relies upon, and should yield its benefit without serious problems to the environment.

Barrett and Therivel (1991) described that EIA should: (i) apply to all projects that are expected to have a major impact on the environment and address all impacts that are expected to be significant, (ii) compare alternatives to a proposed project (including the possibility of not developing the site), management techniques, and mitigation measures, (iii) result in a clear environmental impact statement which conveys the importance of the likely impacts and their characteristics to non-experts

P. K. Sikdar (✉)
Department of Environment Management, Indian Institute of Social Welfare and Business Management, Kolkata, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_12

as well as experts in the field, (iv) include broad public participation and strict administrative review process, (v) to be timed so as to provide information for decision making, (vi) be enforceable and (vii) include monitoring and feedback procedures.

The three central elements of an EIA are: (i) the establishment of environmental, socioeconomic, and public health baseline data for the project site before construction, (ii) the prediction and evaluation of potential—direct and indirect—environmental, socioeconomic and public health impacts of the proposed project and (iii) the identification of appropriate alternatives and mitigation measures to avoid, minimise, remediate or compensate for any environmental, socio-economic and public health impacts resulting directly or indirectly from the project.

In 1969, the United States became the first country to make EIA a legal requirement for major development projects through the National Environment Policy Act, 1969. Since then other countries including India have enacted similar laws suited to their own constitutions, economics and social values.

Practitioners associated with the EIA process include governmental agency; engineering, planning and environmental consulting firms and private companies that have developed an in-house staff capability for carrying out EIA studies. Professionals involved in the EIA process include engineers, planners, biologists, geologists, hydrogeologists, hydrologists, seismologists, meteorologists, air quality/pollution analysts, geographers, soil scientists, social anthropologists, sociologists, archaeologists, architects and economists (World Bank, 1991).

The major benefits of the EIA process for project sponsors (ESSA, 1994) are: (i) reduced cost and time of project implementation; (ii) cost-saving modifications in project design; (iii) increased project acceptance; (iv) avoid negative impacts and violations of laws and regulations; (v) improve project performance; (vi) avoid treatment/cleanup costs. The benefits to local communities from taking part in environmental assessments include: (i) a healthy local environment (forests, water sources, agricultural potential, recreational potential, aesthetic values and clean living in urban areas); (ii) improved human health; (iii) maintenance of biodiversity; (iv) less resource use; (v) fewer conflicts over natural resource use and (vi) increased community skills, knowledge and pride.

2 Important Principles in Managing an EIA

There are five principles in managing an EIA. They are:

1. Focus on the main issue
2. Involve the appropriate persons and group
3. Link information to decision about the project
4. Present clear options for the mitigation of impacts and for sound environmental management
5. Provide information in a form useful to the decision-makers.

2.1 Principle 1: Focus on the Main Issue

It is important that an EIA does not try to cover too many topics in too many details. At an early stage, the scope of EIA should be limited to only the most likely and most serious of the possible environmental impacts. Findings of EIA must be readily accessible and immediately useful to the decision makers and project planners. When mitigation measures are being suggested it is important to focus the study only on workable and acceptable solution to the problems. When it is time to communicate the conclusions, the EIA should provide a summary of information relevant to the needs of each group for making its decision. Supporting data should be provided separately.

2.2 Principle 2: Involve the Appropriate Persons and Group

Generally, three categories of participant are needed. They are: (i) those appointed to manage and undertake the EIA process (usually a coordinator and a staff of expert); (ii) those who can contribute facts, ideas or concern to the study—scientists, economists, engineers, policy makers and representatives of interested or affected groups and (iii) those who have direct authority to permit control or alter the project—developers, investors, regulators (decision makers) and politicians.

2.3 Principle 3: Link Information to Decision about the Project

EIA can have a real effect on the projects by designing the process so that it provides useful information to decision makers at just the right time in the project cycle (Fig. 12.1). It should start early enough to provide information to improve basic design, and should progress through the several stages of project planning. When the developer and investor first broach the project concept, they consider the likely environmental issues. When the developer is looking for sites or routes, environmental considerations aid the selection process. When the developers and investors are assessing the project's feasibility, an EIA is in progress helping them to anticipate problems. When engineers are creating the project design, the EIA identifies certain standards for the design to meet. When a permit is requested, a completed EIA is submitted and also published for general comments. When the developer implements the project, monitoring and other measures provided for in the EIA are undertaken.

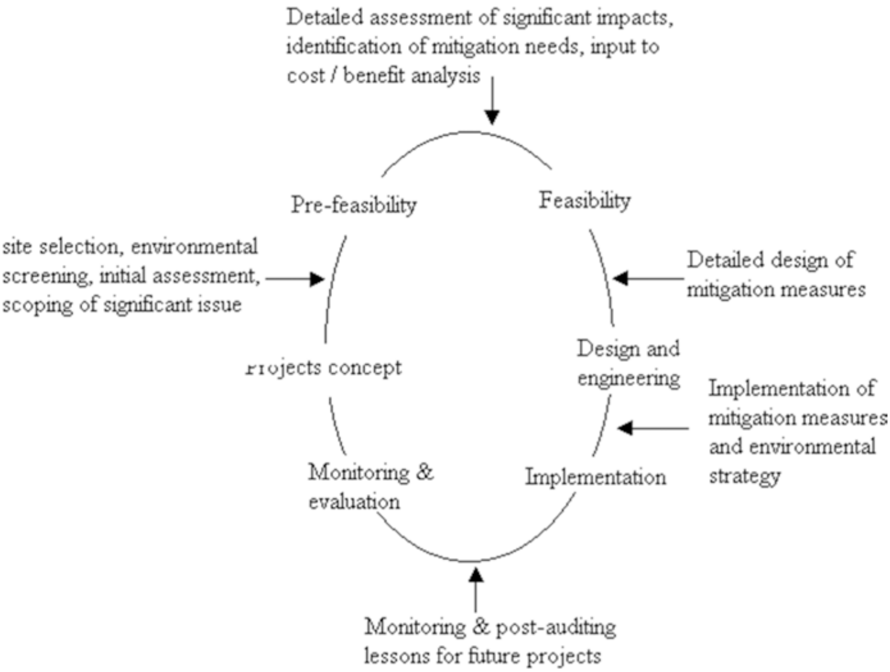

Fig. 12.1 Generalised project cycle showing when and how an EIA can contribute positively to the cycle progress. (*Source*: http://cepassion.blogspot.com/2011/07/environment-impact-assessment-eia.html; accessed on 16.07.2020)

2.4 Principle 4: Present Clear Options for the Mitigation of Impacts and for Sound Environmental Management

To help the decision makers, the EIA must be designed so as to present clear choices on the planning and the implementation of the project and it should make clear the likely result of each option. To mitigate adverse impact, the EIA should propose: (i) pollution control technology or design feature; (ii) reduction, treatment or disposal of waste and (ii) compensations or concessions to affected groups. To enhance environmental compatibility, the EIA should suggest: (i) several alternative sites; (ii) changes to the project design and operation; (iii) limitation to its initial sites or growth and (iv) separate programs, which contribute in a positive way to local resources or to the quality of the environment. To ensure that the implementation of an approved project is environmentally sound, the EIA may prescribe (i) monitoring programs or periodic impact review; (ii) contingency plan for regulatory action and (iii) the involvement of the local community in later decisions

2.5 Principle 5: Provide Information in a Form Useful to the Decision Makers

The hard facts and prediction about impacts should be presented briefly. There should be comments on the reliability of the information. The consequences of each of the project options should be summarised. The essential findings of the assessment should be a concise document supported by separate background material where necessary and make it easy to use providing visuals wherever possible. The terminology and vocabulary to write the EIA report should be easy to read so that the decision makers and the community can understand.

3 Evolution of EIA

Prior to 1970, project reviews were based on engineering and economic studies, e.g., cost–benefit analysis and there was limited consideration of environmental consequences. United States of America was the first country to assign mandatory status to EIA through its National Environmental Protection Act (NEPA) of 1969. During 1970–1985, EIA was introduced in some developed countries namely Canada (1973), Australia (1974), the Netherlands (1981) and Japan (1984); initially (1970–1975) focused on identifying, predicting and mitigating bio-physical effects; less opportunity for public involvement. This phase was followed by the next phase (1975–1980) when multi-dimensional EIA was carried out incorporating social impact assessment (SIA) and risk analysis and public consultation became integral part of development planning and assessment and increased emphasis was given on issues of justification and alternatives in project review. During the period 1980–1985, efforts were undertaken to: (i) integrate project EIA with policy planning and follow up phases; (ii) carry out research and development on effects of monitoring, on EIA audit and process evaluation and on mediation and dispute resolution approach and (iii) adopt EIA by international aid and lending agencies and by some developing countries. In July 1985, the European Community (EC) issued a directive making environmental assessments mandatory for certain categories of projects (Wood, 1994). During 1985–1990, scientific and institutional framework for EIA was rethought in response to sustainability ideas and imperatives, search began for ways to address regional and global environmental changes and cumulative impacts; there was a growing international cooperation on EIA research and training. After 1990 strategic environmental assessment (SEA), a system of incorporating environmental considerations into policies, plans and programmes was introduced in some developed countries; the international convention on transboundary EIA was signed in 1991 at Espoo, Finland, that entered into force in 1997 and UNCED (1992) placed new demands on EIA for expanded concepts, methods and procedures to promote sustainability (e.g., through sustainable development strategies).

Among the developing countries, Columbia was the first Latin American country to institute a system of EIA in 1974. In Asia and the Pacific region, Thailand (1975) and the Philippines (1977) have long established procedures for EIA. EIA was made mandatory in Sri Lanka in 1984 and in India in 1994. Bilateral and multilateral agencies have also recognised the value of EIA as a decision-making tool. The Organisation for Economic Co-Operation and Development (OECD) issued recommendations on EIA to its constituent States in 1974 and 1979, and for development aid projects in 1986. In 1992, OECD issued guidelines for good practices in EIA (OECD, 1992). United Nations Environment Programme (UNEP) in 1980 provided guidance on EIA of the development proposals (UNEP, 1980) and supported research on EIA in developing countries (Ahmad and Swamy, 1985). UNEP, in 1987, set out goals and principles of EIA for the member countries and provided guidance on basic procedures for EIA in 1988. The World Conservation Strategy pinpointed the need to integrate environmental considerations with development in 1980 (IUCN, 1980). EIA became an integral part of World Bank policy in 1987, which states that environmental issues must be addressed as part of overall economic policy. In 1989, the World Bank issued the Operational Directive on Environmental Assessment (O.D. 4.00), which was revised and updated in October 1991 (O.D. 4.01). Asian Development Bank in 1990 published guidelines for EIA (ADB, 1990). Importance of EIA was echoed in the Brundtland Report (WCED, 1987), and at United Nations Earth Summit on environment and development held at Rio de Janeiro in 1992 (UNCED, 1992).

4 EIA in Environmental Laws of Various Developing Countries

4.1 China

EIA was first introduced to China in late 1970s through the 'Environmental Protection Law (pilot-phase)' (1979), which stipulated that all construction related projects must implement EIA. For over three decades, the development of EIA in China has been rapid, fairly effective and has accomplished great achievement to create a unique EIA system. In October 2002, the 'Law of the People's Republic of China on Environmental Impact Assessment' (the EIA Law), was promulgated as standalone piece of legislation. Enactment of the EIA Law in September 2003 marked a milestone of the systematic and legal development of EIA in China (Zhu and Lam, 2009). In February 2004, in order to enhance the quality of EIA professionals and ensure the quality of EIA, the Ministry of Personnel jointly with the State Environmental Protection Administration (SEPA) established the certification system for professional EIA engineers, to put more stringent requirements on professional EIA practitioners. In August 2005, 'Measures for Qualification Management of Environment Impact Assessment for Construction Projects' was promulgated by SEPA to impose higher liability for professional EIA practitioners, and to build an integrated management system of professional EIA units and individuals, along with professional EIA license system. In February 2006, the 'Interim Measures for Public Participation in Environmental Impact Assessment', was introduced by SEPA, which is the first document regulating public participation in environmental protection in China. It clearly defines the rights of public to participate in EIA, and explicitly lays down the specific scope, procedure, way and time limit of public participation, which is beneficial to assure public the 'Right To Know' of the environmental information. The main management agencies of EIA are the competent authorities of environmental protection at central and local government, as well as the competent authorities of marine ecological protection, water and soil conservation etc. The Appraisal Centre for Environmental Engineering '(ACEE) of Ministry of Environmental Protection (MEP) will provide technical support to EIA institutes, and carry out technical evaluations of EIA.

4.2 Philippines

Environmental assessment in the Philippines was first conceived in 1977 with the issuance of the Presidential Decree (PD) 1151, otherwise known as the Philippine Environmental Policy. PD 1151 recognised the right of the people to a healthy environment and stressed on the urgent need to formulate an intensive, integrated program of environmental protection through EIA (Ani, 2016). The responsibility of EIA rests on regional branches of Environmental Management Bureau (EMB), Department of Environment and Natural Resources (DENR). Projects are categorised into A (environmentally critical projects (ECPs) with significant potential to cause negative environmental impacts), B (non-environmentally critical projects in environmentally critical area), C (projects intended to directly enhance environmental quality or address existing environmental problems and D (projects unlikely to cause adverse environmental impacts). Category A and B projects are required to secure Environmental Compliance Certificate (ECC) and those of C and D are not required to secure ECC but may secure Certificate of Non-Coverage (CNC). Projects cannot be implemented unless an environmental compliance approval has been issued by the EMB. A public hearing is conducted if the project is large or located in a particularly sensitive area. After project approval, the compliance with the EIA recommendations are monitored usually by the DENR regional offices (a mixed team including project organizers, the local community and non-government organisations).

4.3 Indonesia

The EIA process in Indonesia is known as AMDAL (Analysis Mengenai Dampak Lingkungan) and its overall management rests with the Environmental Impact Management Agency known as the Badan Pengendalian Dampak Lingkungan (BAPEDAL). The AMDAL process was originally included in law through Government Regulation No. 29 of 1986 (PP29/1986), promulgated under Law No. 4 of 1982, Indonesia's fundamental Environmental Law, which establishes the principle of sustainable development. The 1986 regulation was revoked in 1993 and replaced by PP51/1993. The subsequent guidelines issued by the Minister of State for the Environment were Kep-10/MENLH/3/1994 to Kep-15/MENLH/3/1994 and Keputusan Kepala BAPEDAL Kep-056/1994 (Modak and Biswas, 1999).

The AMDAL process is targeted at those proposed business activities or projects, which have the greatest potential to affect the environment significantly. Essentially, this covers large projects, those using dangerous processes or producing hazardous materials, and those located in or near to areas which require special protection (conservation areas or environmentally sensitive areas). BAPEDAL is authorized to specify the criteria for deciding which proposed businesses or activities require AMDAL. These criteria are specified in KepMen 11/1994. Special provisions have been made in the 1993 revision of the AMDAL process for three types of AMDAL process. They are:

(i) AMDAL Kegiatan Terpadu/Multisektoral is for multi-sectoral projects (several departments or agencies responsible for different aspects, i.e., integrated pulp and paper and forestry plantation). Such projects are handled by an AMDAL commission located within BAPEDAL, rather than in the various responsible government departments.

(ii) AMDAL Kawasan is for projects which are sited together in special areas (including industrial estates, tourism development areas and special bonded import/export areas). All projects in these special areas would be assessed as a group, rather than requiring a separate AMDAL for each one.

(iii) AMDAL Regional is for regional impact assessments. This will cover regional development areas and will address the cumulative impacts of a number of different activities in an area. Guidelines for this type of AMDAL are under development.

The AMDAL commission in the department or agency concerned will review the proposed project and decide on the requirement for AMDAL. Projects requiring AMDAL must first prepare terms of reference, or KA, for the AMDAL study. The KA describes the scope of the study to be carried out, which must focus only on the major issues predicted to arise in the specific project. The KA also describes the data collection and analytical methods to be used. The KA is submitted to the commission, which then has 12 working days to review it and to issue a decision. Usually, the commission will meet with the proponent to discuss the KA and recommend additions or changes. The proponent must then carry out the study as defined in the KA, and prepare the impact assessment in the form of the EIA document (known locally as ANDAL). The ANDAL is an in-depth study of the potential impacts of the proposed project. At the same time, the proponent prepares an environmental management plan (RKL) and an environmental monitoring plan (RPL). The AMDAL regulation also requires the government department or agency concerned to inform the public about businesses or activities which require AMDAL. All AMDAL documents are to be open for public inspection. The public may also provide oral or written comments to the AMDAL commission before it issues a decision on any proposed business or activity. Guidelines for public announcement and public involvement were introduced in 2000 in KepDal 08/2000 (Purnama, 2003).

4.4 Sri Lanka

The first legal framework for EIA was laid down in 1981 by the Coast Conservation Act No. 57 which was limited to a defined strip of the coastal zone of Sri Lanka. In 1988, National Environmental Act (Amendment) Act No. 56 introduced the ElA system to the entire island. The EIA process became fully operative in 1993 with the publication of the required orders and regulations (Zubair, 2001). There are two levels of EIA process in Sri Lanka based on the significance of the environmental impacts: (i) Initial Environmental Examination (IEE), which is carried out when the potential environmental impacts are not significant and (ii) EIA—the more comprehensive study which is carried out when the project is likely to create several significant impacts. The Scoping Committee decides whether a project should be subjected to IEE or EIA.

The overall coordination of the EIA process is the responsibility of the Central Environmental Authority. The approval for projects is granted by government agencies designated as Project Approving Agencies by the Gazette Extraordinary 859/14 of 1995. Accordingly, Ministries with 14 subject areas (e.g., irrigation, energy, forests) and 8 statutory bodies (e.g., Ceylon Tourist Board) have been identified as Project Approving Agencies. The total official time allocated for the EIA process is 116 working days. The developer or project proponent is responsible for the preparation of the EIA report. The EIA report should strictly adhere to Terms of Reference (TOR) although innovations are possible. The EIA report should be submitted in all three languages and made available for public reference and comments through Public Hearing. The EIA report is reviewed by the Project Approving Agency and the final decision is given by the Project Approving Agency with the concurrence of the Central Environmental Authority. Decisions are given with conditions and are time bound. The project proponent can appeal if the project is rejected to the Secretary to the Ministry of Environment whose decision is final. The public has no right of appeal against, if the project is recommended.

4.5 Thailand

The legal framework for EIA in Thailand was first laid down in the Enhancement and Conservation of National Environmental Quality Act (NEQA) in 1975. In 1992, NEQA was revised and the present legal framework of EIA was established with provisions on EIA screening, preparation, review process, timing, mitigation measures and monitoring. At present, there are 35 types and sizes of projects and activities for which EIA is required. Additionally, as per Article 67 of the Constitution of Thailand, 11 projects that cause severe adverse impact on the human health are required to submit Environment and Health Impact Assessment (EHIA). EIA reports have to be prepared by consultants registered with the Office of Natural Resources and Environmental Policy and Planning (ONEP). The EIA has to cover the following aspects, i.e., physical resources, biological resources, human use value and quality of life. The EIA should assess the direct and indirect, short- and long-term environmental impacts from the project, the severity of the impacts and irreversible and irretrievable losses of environmental resources and values. Mitigatory measures to reduce the adverse impacts on the environment and their cost implication should be described. Resettlement issue, if any, should be included in the assessment of impacts and the mitigation measures. Public participation is required at least twice during the preparation of the EIA report. ONEP reviews the EIA report and submits it with its preliminary comments within 30 days to an Expert Review Committee (ERC) appointed by the National Environment Board (NEB). The ERC will have 45 days to review and approve or disapprove the EIA report after receiving the EIA report from ONEP. If the ERC fails to do so, the EIA report is considered approved (Wangwongwatana et al. 2015).

4.6 Pakistan

The Pakistan Environmental Protection Act (PEPA) 1997 is the core legislation for EIA in the country. Under section 12 of PEPA, no proponent can initiate construction or operation of a project, likely to cause adverse environmental effects, prior to submission of an initial environmental examination (IEE) or an EIA whatever is deemed necessary by the concerned EPA, and its approval thereof (GoP, 1997). According to the Act, IEE means a preliminary environmental review is needed to determine whether the proposed project is likely to cause adverse environmental effects and necessitates an EIA. The Act defines EIA as ‘an environmental study comprising collection of data, prediction of qualitative and quantitative impacts, comparison of alternatives, evaluation of preventive, mitigatory and compensatory measures, formulation of environmental management and training plans and monitoring arrangements, and framing of recommendations as such other components as may be prescribed’ (GoP, 1997). EPA is also authorised to impose conditions of approval, require re-submission of EIA or ‘reject the project as being contrary to environmental objectives'. However, if an EPA admits an IEE or EIA as complete, it 'shall communicate its approval or otherwise within four months, failing which it shall be deemed to have been approved to the extent to which it does not contravene the provisions of PEPA or any other relevant rules/regulations' (GoP, 1997). Contravening any provision of the Act shall be considered a punishable offense with a fine of up to one million rupees. If contravention continues, an additional fine of up to one hundred thousand rupees per day shall be taken under Section 17 of this Act.

4.7 Bangladesh

EIA has been practiced in Bangladesh since the late 1980s, but it is through the enactment of the Environment Conservation Act, 1995 and the Environment Conservation Rules, 1997 EIA gained formal status in the country. EIA process in Bangladesh consists of six steps. They are: screening, preparation of initial environmental evaluation (IEE), issuance of site clearance certificate, preparation of the terms of reference, submission of draft EIA report and submission of the final EIA report along with environmental management and monitoring plan. After screening, the developer is required to prepare an Initial Environmental Evaluation (IEE) based on pre-feasibility level of information. This document is similar to a Scoping Document and it identifies the proposed location of the project and the potential environmental and social impacts. The IEE is used by the DoE to issue a Site Clearance and to evaluate whether a full EIA is required or not. At this stage, preliminary cost estimates and alternative locations for the project are also determined (Ministry of Environment and Forest, 1997). Generally, EIA is required prior to issuance of approval to start construction. The decision regarding the need for an EIA is issued as part of the Site Clearance (Mumtaz, 2002). A full EIA is generally required for the projects falling in red category.

4.8 Bhutan

In Bhutan, the Environmental Assessment Act (EAA), 2000 establishes the procedures for assessment of potential effects of projects on the environment and for the determination of measures to reduce adverse effects and to promote environmental benefits. The Act has also established National Environmental Commission (2006) to ensure that environmental concerns are fully taken into account when formulating, renewing, modifying and implementing the project. The first step in the environmental assessment process is to conduct a site survey, followed by preparation of pre-feasibility, engineering, environmental and social investigations, including an EIA study as outlined in the statutes.

4.9 Nepal

The Environmental Protection Act (EPA) of Nepal has established the Ministry of Environment as the administrator of the Act. The Act provides the basis for the establishment of rules for implementation of EIA (Ministry of Environment, 1996). The Ministry of Environment established a series of Rules as the Environmental Protection Rules (EPR) that were initially approved by parliament and later amended in 1999. The rules define the types of projects that require preparation of Initial Environmental Examination (IEE) and those require full scale EIA to be prepared. The rules also outline the basic procedures for EIA approval process (Ministry of Environment, 1996). The stages of EIA in Nepal are screening, scoping, collecting baseline information particularly on bio-physical, social, economical and cultural components of the environment of the proposed project area, preparation of the EIA report and public hearing. Major components of the EIA report include baseline description, impact evaluation and mitigation, monitoring and auditing and compensation plans as the integral part of the EIA report. Draft EIA report is submitted to concerned ministry for comments and after incorporating all the issues raised in the comments, the report becomes final. The final report is submitted to the concerned ministry and forwarded to the Ministry of Environment for final consideration (Khadka and Shrestha, 2011).

4.10 India

The EIA process in India started in 1976–1977 when the Planning Commission asked the Department of Science and Technology to examine the river-valley projects from an environmental angle. This was subsequently extended to cover those projects, which required the approval of the Public Investment Board. Till 1994, environmental clearance from the Central Government was an administrative requirement intended for mega projects undertaken by the Government or PSUs and lacked legislative support. On 27 January 1994, the Union Ministry of Environment and Forests (MoEF), Government of India, under the Environmental (Protection) Act 1986, promulgated an EIA Notification making Environmental Clearance (EC) mandatory for expansion or modernisation of any activity or for setting up new projects listed in Schedule 1 of the Notification. Since then many amendments have been made in the Notification. As a result, MoEF conducted a comprehensive review of the then EC process under the Environmental Management Capacity Building Project in 2001. The Indian Government also set up a committee known as Govindarajan Committee in 2001 for Reforming Investment Approvals and Implementation Procedures. Both the studies recommended that there is a need for reforms in the EIA process. Based on the recommendations the MoEF notified a new EIA legislation in September 2006 (EIA, 2006). The objectives of the EIA Notification 2006 is to formulate a transparent, decentralized and efficient regulatory mechanism to: (i) incorporate necessary environmental safeguards at planning stage; (ii) involve stakeholders in the public consultation process and (iii) identify developmental projects based on impact potential instead of the investment criteria. In the 2006, notification all projects and activities are broadly categorized into two categories—Category A and Category B, based on the spatial extent of potential impacts and potential impacts on human health and natural and manmade resources. All projects or activities included as Category 'A' in the Schedule of the Notification, including expansion and modernisation of existing projects or activities and change in product mix, need to take prior environmental clearance from the Central Government in the Ministry of Environment and Forests and Climate Change (MoEFCC) on the recommendations of an Expert Appraisal Committee (EAC) to be constituted by the Central Government for the purposes of this notification. All projects or activities included as Category 'B' in the Schedule, including expansion and modernisation of existing projects or activities or change in product mix but excluding those which fulfil the General Conditions (GC) stipulated in the schedule, will require prior environmental clearance from the State/Union territory Environment Impact Assessment Authority (SEIAA). The SEIAA shall base its decision on the recommendations of a State or Union territory level Expert Appraisal Committee (SEAC). GC is applied to projects or activities specified in Category 'B' which are located in whole or in part within 10 km from the boundary of: (i) protected areas notified under the Wild Life (Protection) Act, 1972, (ii) critically polluted areas as notified by the Central Pollution Control Board from time to time, (iii) notified eco-sensitive areas and (iv) inter-state boundaries and international boundaries. These projects or activities will then be treated as Category A. There are four stages in prior environmental clearance process. They are: (i) screening which refers to scrutiny of Category 'B' projects seeking prior environmental clearance made in Form-1 into B1 and B2 by the concerned State Level Expert Appraisal Committee for determining whether or not the project requires further environmental studies for preparation of EIA for its appraisal depending upon the nature and location specificity of the project, (ii) scoping which refers to the process by which the EAC in the case of Category 'A' projects or activities, and SEAC in the case of Category 'B1' projects or activities determine detailed and comprehensive TORs addressing all the relevant environmental concerns for the preparation of EIA report, (iii) public consultation refers to the process by which the concerns of local affected persons and others who have plausible stake in the environmental impacts of the project or activity are ascertained and (iv) appraisal, which means the detailed scrutiny by the Expert Appraisal Committee or State Level Expert Appraisal Committee of the application and other documents submitted by the applicant for grant of environmental clearance. The time frame for each of these stages is fixed. The total time for getting the clearance is 210 days for all projects except for building/construction projects/area development projects and townships, which is 90 days. The validity of environmental clearance (the period from which prior EC is granted to the start of production/operations) is maximum 30 years for mining projects, 10 years for river valley projects, 7 years for all other projects and limited period for area development projects till the developer is responsible. The validity can be extended to another 5 years upon submission of application.

5 Problems of EIA in Developing Countries

The problems of EIA in developing countries are: (i) non-availability of adequately trained persons, (ii) EIA is often looked upon as a legal or administrative requirement, (iii) EIA tries to justify a project decision already made, and is concerned mainly with remedial measures, (iv) early consideration of project alternative is rarely attempted, (v) EIA models suitable for temperate climates of many developed countries are often applied without necessary modification in developing countries having tropical or sub-tropical climate often leading to erroneous results and interpretation, (vi) near total absence of environmental database and (vii) lack of political will.

6 The Environmental Impact Assessment Process

Despite its usefulness in finding ways to make projects more successful, the full EIA process is not necessary for every kind of development projects. There are two tiers of assessment, which may be applied to any project before proceeding with a full EIA. They are screening and preliminary assessment.

Screening is appropriate when the project is only a rough concept. Later, when the project is under more general discussion, a preliminary assessment can look deeper into possible sites and potential impacts. This tier approach ensures that impacts are examined at a very early stage in the project planning and not later when the sites or designs are already decided by other factors.

6.1 Screening

Screening is the first and simplest tier of project evaluation. Screening helps to clear types of projects, which in the past experience are not likely to cause serious environmental problems. The exercise may be one of several forms, such as: (i) measuring against simple criteria such as size or location, (ii) comparing the proposal with list of projects types rarely needing an EIA or definitely needing one, (iii) estimating the general impacts and comparing these impacts against set thresholds and (iv) doing complex analysis but using readily available data. Screening serves to determine which projects out of all those proposed at the identification phase of the project cycle need further environmental considerations, and to eliminate those unlikely to have harmful environmental impacts, and indicate the level of environmental appraisal that a project will require. The benefits of screening are highlighting the potential environmental significance of projects at an early stage, and preventing financial and human resources being applied to the environmental analysis of project that are likely to have little environmental significance.

6.2 Preliminary Assessment

If screening does not automatically clear a project, then the step is to undertake preliminary assessment. This involves sufficient research and expertise to identify the project's key impacts on the local environment, describe and predict the extent of the impact, and briefly evaluate their importance to decision makers. The preliminary assessment can be used to assist early project planning—for instance, to narrow the discussion of possible sites—and it can serve as an early warning that the project may have serious environmental difficulties. It is the developer's interest to do a preliminary assessment since this step can clear project of the need for a full EIA.

6.3 Organisation

If after reviewing a preliminary assessment, the competent authority deems a full EIA is needed, the next step is the organisation of EIA study. This entails commissioning and briefing an independent expert study team, identifying the key decision makers who will plan, finance, permit and control the proposed project so as to characterise the audience for the EIA study, researching laws and regulations that will affect these decisions, making contact with each of the various decision makers, and determining how and when the EIA's findings will be communicated

6.4 Scoping

The first task of the EIA study team is scoping the EIA. The aim of the scoping is to ensure that the study addresses all the issues of importance for the decision makers. Job of the study team are to broaden its outlook by discussion with project developers, decision makers, regulatory agencies, scientific institutions and local community, and select primary impacts for the EIA to focus on choosing on the basis of magnitude, geographical extent, significance to decision makers and special local sensitivities such as soil erosion, presence of an endangered species nearby historical sites etc. Scoping establishes the TOR for an EIA by identifying the concerns and issues for consideration, and determining the varying depths of analysis to which alternatives and impacts are to be subjected to. Scoping also helps to save time by focusing the EIA on issues of concern.

Disadvantage of scoping are: (i) early public involvement and inter-agency politics could cause considerable delays to the EIA, (ii) environmentalists rarely agree to eliminate any issue, as a result more issues often come from scoping meetings than were originally included and (iii) when public participation is allowed public concern often gains undue importance in determining issue significance and in complex projects many of the potential impacts may be beyond the understanding of the general public.

6.5 Consideration of Alternatives

This seeks to ensure that the project proponent has considered other feasible approaches, including alternative project locations, scales, processes, layouts, operating condition and the *no-action* option.

6.6 Description of the Project/Development Action

This step seeks to clarify the purpose and rationale of the project and understand its various characteristics, including the stages of development, location and processes.

6.7 Description of the Environmental Baseline

This includes the establishment of both the present and future state of the environment, in the absence of the project, taking into account the changes resulting from natural events and from other human activities.

6.8 Identification of Key Impacts

This brings together the previous steps with a view to ensuring that all potentially significant environmental impacts (adverse and beneficial) are identified and taken into account in the process.

6.9 Prediction of Impacts

This step aims to identify the likely magnitude of the change (i.e., impact) in the environment when the project is implemented in comparison with the situation when the project is not carried out.

6.10 Evaluation and Assessment of Significance

This seeks to assess the relative significance of the predicted impacts to allow a focus on key adverse impacts. Formal definition of significance is the product of consequence and likelihood.

6.11 Mitigation

This involves the introduction of measures to avoid, reduce, remedy or compensate for any significant adverse impacts.

6.12 Public Consultation and Participation

This aims to assure the quality, comprehensiveness and effectiveness of the EIA, as well as to ensure that the public's views are adequately taken into consideration in the decision-making process.

6.13 Environmental Impact Statement (EIS) Presentation

The project proponent prepares the EIS on the finalised draft of the proposed project and submits it in support of the application for authorisation to the competent authority. This is a vital step in the process. If done badly, much good work in the EIA may be negated.

6.14 Review

This involves a systematic appraisal of the quality of the EIS, as a contribution to the decision-making process.

6.15 Decision-making

At this stage, decisions are made by the relevant authority (including consultation responses) together with other material considerations as to whether to accept, defer or reject the project.

6.16 Post-decision Monitoring

This involves the recording of outcomes associated with development impacts, after the decision to proceed with the project. It can contribute to effective project management.

6.17 Auditing

This follows monitoring and involves comparing actual outcomes with predicted outcomes, and can be used to assess the quality of predictions and the effectiveness of mitigation. It provides a vital step in the EIA learning process.

Figure 12.2 illustrates the principle steps involved in the EIA process.

7 EIA Methods

This section describes some of the simplest techniques and methods for EIA, and gives information to help choose the most appropriate method for a given situation. The methods that are discussed are: (i) ad-hoc method, (ii) checklist method, (iii) overlay method, (iv) matrix method, (v) network method and (vi) semi-quantitative method.

7.1 Ad-hoc Method

Ad hoc method is a qualitative assessment of broad areas by a team of experts assembled for a short time to conduct an EIA. Each expert's conclusions are based on a unique combination of experience, training and intuition. These conclusions are assembled into a report. The impact of the project or activities on the environment is classified as: (i) positive/negative/no effect, (ii) beneficial/adverse, (iii) reversible/ irreversible and (iv) short-term/long-term. This method is best applicable for site selection. This method is very easy to use, but does have a few drawbacks

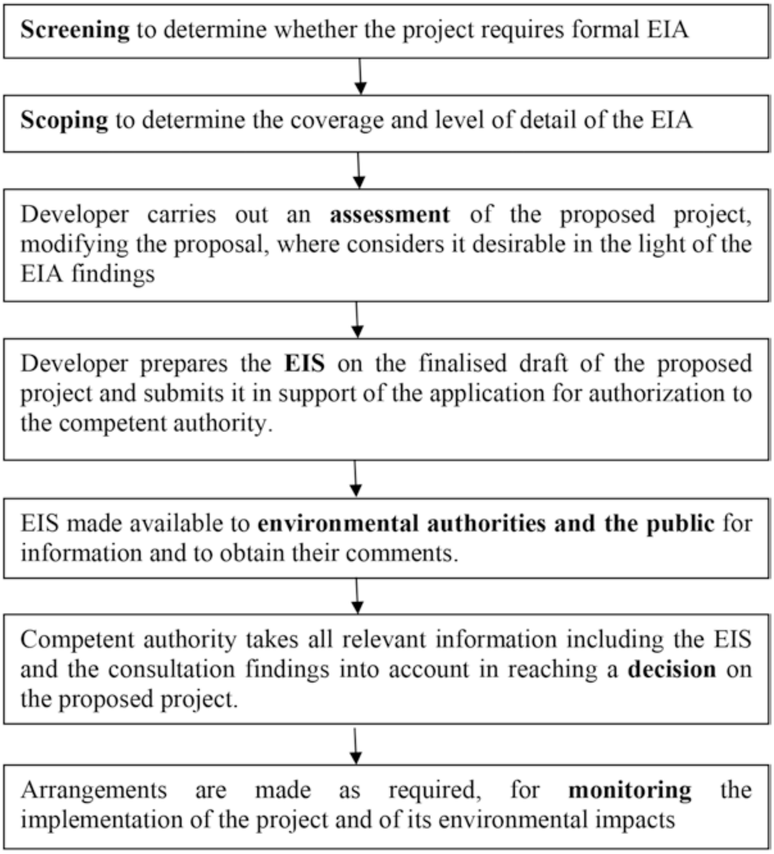

Fig. 12.2 Principle steps involved in the EIA process.

such as: (i) it is subjective in nature, (ii) lacks consistency in analysis, (iii) absence of guidance and lack of assurance regarding identification of all relevant impacts in a comprehensive manner. An example of ad-hoc method is given in Fig. 12.3.

7.2 Checklist Method

Checklists are standard lists of the types of impacts associated with a particular type of project. Checklists methods are primarily for organising information or ensuring that no potential impact is overlooked. They are a more formalised version of ad hoc approach where specific areas of impact are listed and instructions are supplied for impacts identification and evaluation. The character and nature of impact are assessed as: (i) adverse/beneficial, (ii) short term /long term, (iii) no effect/significant effect, etc. The drawbacks of this method are: (i) one general, all-inclusive list

Environmental Impact / Environmental Area	No effect	Positive effect	Negative effect	Beneficial	Adverse	Problematic	Short term	Long term	Reversible	Irreversible
Wild life			√			√	√			
Endangered species	√									
Natural vegetation			√			√			√	
Exotic vegetation	√									
Soil characteristics	√									
Natural drainage	√									
Groundwater		√		√						
Noise			√				√			
Surface paving						√				
Air quality			√		√			√		
Open space			√		√			√		√
Health and Safety	√									
Economic values√		√		√				√		
Public facilities						√	√			
Conformity to regional plans		√		√				√		

Fig. 12.3 Illustrative ad-hoc approach to EIA. (*Source*: Rau and Wooten, 1980)

of impact areas with applicability to all projects, is likely to be very large, cumbersome to use, and may contain information too generalised to adequately describe the nature of impacts, (ii) innumerable checklists are available, applicable to river valley projects, industry, thermal power station etc. and (iii) does not provide for the establishment for the direct cause–effect relationship.

To overcome the drawbacks, Battele Environmental Evaluation System (BEES) a scaling—weighting checklist method was developed by Dee et al. (1972, 1973). This method is one of the most objective and quantitative impact assessment methods. Field test was carried out on the Bear River Project covering Utah, Idaho and Wyoming in the USA. The system is based on a hierarchical assessment of environmental quality indicators consisting of four levels:

- Level I: Categories,
- Level II: Components,
- Level III: Parameters and
- Level IV: Measurements.

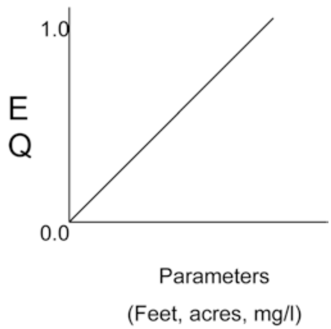

Fig. 12.4 A typical value function curve. (*Source*: Rau and Wooten, 1980)

Each category (Level I) is divided into several components, each component (Level II) into several parameters, and each parameter (Level III) into one or more measurements. The EES identifies a total of four (4) categories, eighteen (18) components and seventy-eight (78) parameters. A total of 1000 weight units are distributed amongst 78 different parameters as per importance assigned by an expert team. These units are known as 'parameter importance units' or PIUs. In the next step, environmental parameters are converted into Environmental Quality (EQ) value using value function curve (Fig. 12.4), which relates the various levels of environmental parameter estimates (X-axis) of functions like DO, % of the total acreage of natural vegetation, community health etc. to the appropriate levels of environmental quality (EQ, Y-axis). Objective measurements are transformed into a subjective interpretation of EQ on a scale of 0–1, where 0 stands for poor EQ and 1 stands for excellent EQ.

BEES assessment of the environmental impacts is based on proportionate 'environmental impact units' (EIU). EIU is obtained by multiplying the EQ values with respective PIU. The EIU for each parameter is added to obtain two EIU scores for 'with' and 'without' the proposed projects using the following equations:

$$\mathrm{EIU}_1 = \sum_{i=1}^{n} (V_i)_1 * W_i$$

where $(V_i)_1$ = value of environmental quality of parameter i with project.
W_i = relative weight of parameter i(PIU_i)
n = total no. of parameters

$$\mathrm{EIU}_2 = \sum_{i=1}^{n} (V_i)_2 * W_i$$

where, $(V_i)_2$ = value of environmental quality of parameter i without the project.
W_i = relative weight of parameter i(PIU_i)
n = total no. of parameters

The difference between the two scores is a measure of the environmental impact (EI).

$$EI = EIU_1 - EIU_2$$

For EI > 0, the situation 'with' the project is better than 'without' the project, indicating that the project has positive environmental benefits. Conversely, for EI < 0, the situation 'with' the project is worse than 'without' the project, indicating that the project has certain negative impacts. A large negative value of EI indicates the existence of substantial negative impacts.

7.3 Overlay Method

Map overlay method to evaluate environmental impacts was originally pioneered by McHarg (1971). This method uses various thematic maps of a project area's environmental (physical, ecological, social and aesthetic) characteristics and then overlay them to produce a composite character of the regional environment. The approach has been employed for screening alternate project site or route. The advantage of this method is that it allows graphical display of impacts in a geographical context. The disadvantages are that to maintain reliability of a composite map the number of parameters in a transparency overlay is limited to about 10 (Munn 1979) and the effectiveness of the method depends largely on cartographic technique and skill. This method has now evolved into sophisticated Geographic Information Systems (GIS), which is more flexible, and has an advantage whenever the reviewer suggests that the system of weights be changed.

7.4 Matrix Method

Matrix method is a technique by which the 'collective' or 'overall' environmental impact (adverse/beneficial) of each impact area (air/water/noise/economic) of the developmental project can be assessed. The simplest technique is the ranking method which can be exemplified with the case of 5 alternative highway (HW) improvement projects vs. one environmental impact area (no. of dwelling units destroyed) as shown in Table 12.1. In this case, HW1 is the best alternative as no dwelling units will be lost.

The situation becomes more complex if there is more environmental impact areas impacted due to the 5 highway improvement projects (Table 12.2).

Table 12.2 indicates that no alternative rank first in all impact areas and therefore there is no clear-cut choice as to which alternative is the best. To understand the best choice the relative importance of the impact areas to the community may determine by a poll conducted by interviewing residents and local business people in the impact area and/or by the team carrying out the EIA on a scale of 1 to 10, where 10 represents the highest importance. The relative importance is then multiplied by the

Table 12.1 A simple situation for ranking method

Alternative	*No. of dwelling units destroyed*	*Rank*
HW1	0	1
HW2	3	2
HW3	22	3
HW4	26	4
HW5	30	5

Table 12.2 Case of five alternative highway improvement projects vs. seven environmental impact areas

Impact areas	*Alternatives*				
	HW1	*HW2*	*HW3*	*HW4*	*HW5*
Market access					
Av. time to civic centre (min)	20	16	12	15	19
Rank	5	3	1	2	4
Level of service					
Av. travel speed (mile/h)	45	40	36	36	42
Rank	1	3	4	4	2
Provision to public service					
Police response time (min)	10	9	6	8	12
Rank	4	3	1	2	5
Disruption of homes					
No. of homes destroyed	12	14	40	20	4
Rank	2	3	5	4	1
User costs					
Annual dollars (millions)	1.0	1.0	0.8	1.6	1.0
Rank	2	2	1	3	2
Noise Pollution					
dB level at 100 ft	75	65	70	50	60
Rank	5	3	4	1	2
Disruption of business					
No. of business lost	2	6	10	4	8
Rank	1	3	5	2	4

rank to arrive at the rating of each impact area of the 5 highway improvement projects. The lowest value of sum total of the product gives the desirable alternative.

Leopold et al. (1971) designed a matrix which consists of a list of 100 project activities on the horizontal axis, and about 88 environmental/social aspects on the vertical axis. The environmental aspects listed on the vertical axis are those that are likely to be affected by any of the project activities. Each cell of the matrix is divided by a diagonal line. The upper half denotes the magnitude of the impact that activity will have on the environmental aspect, and the bottom half describes the significance of that impact (Fig. 12.5). This is subjective to the surveyor and is based on

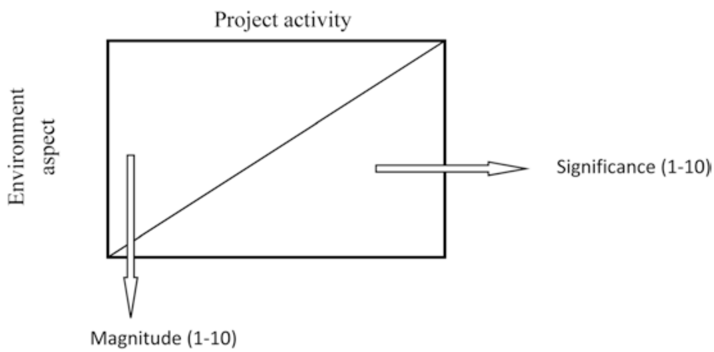

Fig. 12.5 Design of a cell in the Leopold matrix. (Source: Leopold et al., 1971)

the baseline data collected. An arbitrary scale (1 to 10) could be used where, 10 represents greatest magnitude of impact/importance and 1 represents least magnitude of impact/importance. Place '+' in front of magnitude number if the impact is beneficial and '−' if the impact is adverse. If a cell has no division, it means that the activity has no impact on the environmental aspect. The total impact score is calculated as follows:

Total impact on the i^{th} environmental factor from all actions $= \sum_j m_{ij} w_{ij}$

Total impact on the j^{th} action on all environmental f actors $= \sum_i m_{ij} w_{ij}$

Total project impact $= \sum_{ij} m_{ij} w_{ij}$

where, m_{ij} = (+/-) magnitude of the j^{th} action on the i^{th} environmental factor
w_{ij} = weighting of importance of the j^{th} action on the i^{th} environmental factor

The disadvantages of Leopold matrix are: (i) it **does not explicitly describe spatial and temporal effects** of the environmental activity but merely gives us the magnitude and significance of the interaction, (ii) it tends to be **too simplified when a comprehensive analysis** of the impacts on the project area is required and (iii) it cannot explain linkages between two environmental aspects, that is, it **does not describe secondary and tertiary impacts**.

7.5 Network Method

A network diagram is a technique of creation of impact chains and trees, a trait that most environmental systems exhibit when impacted. Impacts of project activity on the environment may be primary, secondary or tertiary. There are four steps in this method. They are:

Step 1: Creation of impact tree (Fig. 12.6).
Step 2: Branch resolution (Fig. 12.7).

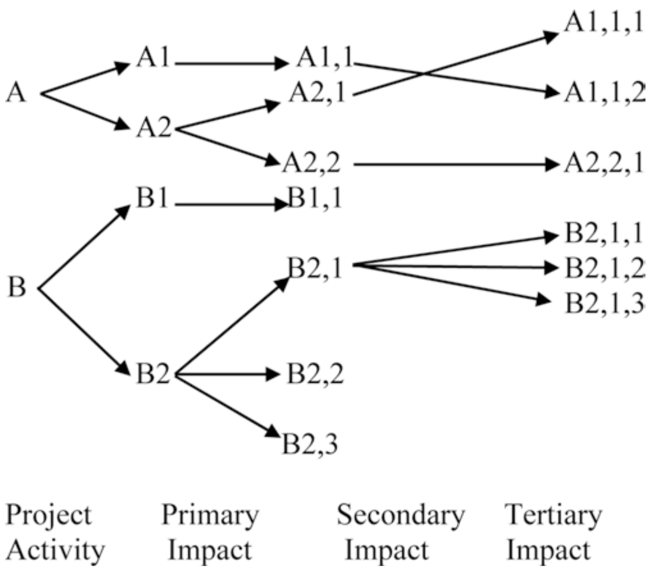

Fig. 12.6 An impact tree. (Source: Sorenson, 1971)

BRANCH 1	A1	→	A1, 1	→	A1, 1, 1
BRANCH 2	A1	→	A1, 1	→	A1, 1, 2
BRANCH 3	A2	→	A2, 1		
BRANCH 4	A2	→	A2, 2	→	A2, 2, 1
BRANCH 5	B1	→	B1, 1		
BRANCH 6	B2	→	B2, 1	→	B2, 1, 1
BRANCH 7	B2	→	B2, 1	→	B2, 1, 2
BRANCH 8	B2	→	B2, 1	→	B2, 1, 3
BRANCH 9	B2	→	B2, 2		
BRANCH 10	B2	→	B2, 3		

Fig. 12.7 Branch resolution. (Source: Sorenson, 1971)

Step 3: Assignment of probability (P_i), magnitude (M_x, +ve or –ve) and importance (I_x) for each activity or impact of these chains.

Step 4: Sum up for total environmental impact score (EIS), where

$$\mathrm{EIS} = \sum_{i=1}^{n} P_i \sum_{x=1}^{k} M_x I_x$$

where k = no. of events of branch i

n = no. of branches

The advantages of network method are that it **helps to follow the chain of events** of developmental projects, and its associated impacts and can **assess multiple impacts at the same time** identifying links that can easily be overlooked in the checklist or matrices forms of impact assessment. The disadvantages are: (i) a lot of impacts tend to be repeated and a great care is required to develop the tree by weeding out repetitions, (ii) the **networks can get very long and messy, (iii)** impact identification is inadequate and subjective **and (iv)** in order to identify all levels of impacts, **considerable knowledge of the environmental conditions of the project area is required.**

7.6 Semi-quantitative Method

This method was developed by Sikdar et al. (2002) for the proposed info-tech complex in East Kolkata Wetlands. In this method, the anticipated project activities during construction, development and operational phases are identified which may affect a number of environmental parameters such as ambient air, surface water, groundwater, soil, land use, noise and socio-economics. The impacts are categorised as direct or indirect; short term or long term; reversible or irreversible; site specific, local or regional and adverse or beneficial. The impact intensity of each activity on each of the environmental parameter can be classified as low, appreciable, moderate, significant, high or permanent. A detailed checklist of project activities, environmental parameters likely to be affected due to such activities and the specific impact areas, nature, intensity and extent of such impacts are prepared (Table 12.3).

In the next step, the nature and frequency of adverse and beneficial impacts on environmental parameter are calculated from Table 12.3 and shown in Table 12.4.

Next, a quantitative assessment of the impacts of the major activities of the proposed project on the different environmental parameters is done through a standard graded matrix system. Taking into consideration the degree of stress that the various activities will impose cumulatively, the seven environmental attributes are ranked on a scale of 1 to 5. The score of each parameter is converted to a probability value and then recalculated by multiplying each value by a factor of 1000 to arrive at the parameter importance value (PIV), so that the values conform to the units of Assessment Value Index Scale generally used for evaluating the degree of impact of a set of activities on environment. The degree of anticipated impact of each activity on each of the environmental parameters has been graded as per the Index Scale below:

Table 12.3 Nature and intensity of impact of environmental parameters

Project activities	*Impact*	*Environmental parameters affected*	*Nature of impact*	*Impact intensity*
Activity1	Arrest of surface runoff	Surface water	Direct, long term, reversible, beneficial, local	High
	Recharge of shallow groundwater	Groundwater	Direct, long term, reversible, beneficial, local	Significant
	Increase in soil productivity	Soil	Direct, long term, reversible, beneficial, local	High
	Generation of dust	Air	Direct, short term, reversible, adverse, local	Low
	Generation of employment	Socio-economic	Direct, short term, reversible, beneficial, local	Low
	Change in land use pattern	Land	Direct, long term, reversible, beneficial, local	Moderate
	Vision	Aesthetics	Direct, long term, reversible, beneficial, local	High
Activity 2	Abstraction of groundwater	Groundwater	Direct, long term, reversible, adverse, local	Low
	Deterioration of groundwater quality	Groundwater	Direct, long term, reversible, adverse, local	Low
	Improvement of public health	Socio-economic	Direct, long term, irreversible, beneficial, local	Significant

Degree of impact		*Impact value*
Low	=	0.5
Appreciable	=	1.0
Moderate	=	2.0
Significant	=	3.0
High	=	4.0
Permanent	=	5.0

A (+)ve or (−)ve sign is assigned to each impact depending on its beneficial or adverse effect respectively.

In the next step, the environmental impact matrix is set up with the major project activities as columns and environmental parameters (attributes) as rows. The PIV for each environmental parameter is placed as first column. An impact value is

Table 12.4 Nature and frequency of impact on environmental parameter

Nature of impact			*Low*	*Appreciable*	*Moderate*	*Significant*	*High*	*Permanent*	*Total*
Adverse									
Direct	Long term	Reversible	2	–	–	–	–	–	2
		Irreversible	–	–	–	–	–	–	–
	Short term	Reversible	1	–	–	–	–	–	1
		Irreversible	–	–	–	–	–	–	–
Indirect	Long term	Reversible	–	–	–	–	–	–	–
		Irreversible	–	–	–	–	–	–	–
	Short term	Reversible	–	–	–	–	–	–	–
		Irreversible	–	–	–	–	–	–	–
Total adverse			3	–	–	–	–	–	3
Beneficial									
Direct	Long term	Reversible	–	–	1	1	3	–	5
		Irreversible	–	–	–	1	–	–	1
	Short term	Reversible	1	–	–	–	–	–	1
		Irreversible	–	–	–	–	–	–	–
Indirect	Long term	Reversible	–	–	–	–	–	–	–
		Irreversible	–	–	–	–	–	–	–
	Short term	Reversible	–	–	–	–	–		–
		Irreversible	–	–	–	–	–	–	–
Total beneficial			1	–	1	2	3	–	7

Table 12.5 Assessment value index scale

Score value	*Extent of impact*
> (−)1000	No appreciable impact
(−) 1000 to (−) 2000	Appreciable impact but not injurious, mitigation measure important
(−) 2000 to (−) 3000	Significant impact, major control measures necessary
(−) 3000 to (−) 5000	Injurious impact, site selection to be reconsidered
< (−)5000	Irreversible damage, alternate site to be considered

assigned to each major activity-environmental parameter impact area on the basis of the summation of the nature and intensity of impact and the Index Scale. The impact score for each environmental parameter (SC_i) has been calculated from the following formula modified after Rau and Wooten (1980):

$$SC_i = (\text{PIV})_i \sum_{j=1}^{n} Iij$$

where ‘*I*’ is the impact value (on the scale of 1 to 5, + or −) due to the effect of the project activity ‘*j*’ on an environmental parameter ‘*i*’ and ‘*n*’ is the total number of project activities.

The total impact score (TIS) is arrived at through the formula:

$$\text{TIS} = \sum_{i=1}^{m} \text{SC}i$$

where m = total number of environmental parameters.

The total impact score is evaluated as per the Assessment Value Index Scale (Table 12.5).

8 Conclusion

In recent years, major projects have encountered serious difficulties because insufficient account has been taken of their relationship with the surrounding environment; of resource depletion; of public opposition; financially encumbered by unforeseen costs; held liable for damages to natural resources; and held responsible for the cause of disastrous accidents. As a result, it is very risky to undertake, finance or approve a major project without first taking into account its environmental consequences—and then siting and designing the project so as to minimise adverse impacts. Thus, EIA has been considered to be a pillar for robust, economically-viable projects apart from economic analysis and engineering feasibility studies.

EIA is an interdisciplinary and multi-step procedure to ensure that environmental considerations are included in decisions regarding projects that may impact the environment. Simply defined, it is a formal process use to predict the environmental consequences of any developmental project, finds way to reduce unacceptable impacts and to shape the projects so that it suits the local environment, and presents these predictions and options to decision makers. In developing countries, the policy frameworks have been developed regarding principles of the EIA which are legally binding and it is mandatory to provide development either without compromising the biophysical and socio-economic environments or with mitigation measures. EIAs mean better, more successful projects. EIAs are good investment for both the developer and the economy as a whole.

References

ADB (1990). Environmental Guidelines for Selected Industrial and Power Development Projects. Office of the Environment, Asian Development Bank, Bangkok.

Ahmad, Y.J. and Swamy, G.K. (1985). Guidelines to Environmental Impact Assessment in Developing Countries. Hodder and Stoughton, London.

Ani, A.B. (2016). The Philippine Environmental Assessment Policies. FFTC Agricultural Policy Articles, Environment and Natural Resources. http://ap.fftc.agnet.org/ap_db.php?id=625&print=1. Assessed 4 March 2019.

Barrett, B.F.D. and Therivel, R. (1991). Environmental Policy and Impact Assessment in Japan. Routledge, Chapman and Hall, New York.

Dee, N., Baker, J., Drobny, N., Duke, K. and Fahringer, D. (1972). Environmental evaluation system for water resource planning (to Bureau of Reclamation, U.S. Department of Interior). Battelle Columbus Laboratory, Columbus, Ohio.

Dee, N., Baker, J., Drobny, N., Duke, K., Whitman, I. and Fahringer, D. (1973). An environmental evaluation system for water resource planning. *Water Resources Res.*, **9(3):** 523–535.

EIA (2006). Environmental Impact Assessment. Gazette of India, Extraordinary, Part-II, and Section 3, Sub-section (ii) Ministry of Environment and Forests, New Delhi.

ESSA (1994). Preliminary Design and Project Charter for ADB RETA 5544: Computerized EIA System. ESSA Technologies Ltd (report prepared for the Asian Development Bank), Manila, Philippines.

GoP (Government of Pakistan) (1997). Pakistan Environmental Protection Act. Gazette of Pakistan, Islamabad.

IUCN (1980). World Conservation Strategy: Living Resource Conservation for Sustainable Development. IUCN-UNEP-WWF.

Khadka, R.B. and Shrestha, U.S. (2011). Process and procedure of environmental impact assessment application in some countries of South Asia: A review study. *J. Environ Sci. Tech.,* **4:** 215–233.

Leopold, L.B., Clarke, F.E., Hanshaw, B.B. and Balsley, J.R. (1971). A Procedure for Evaluating Environmental Impact. Geological Survey Circular 645: Washington, U.S. Geological Survey.

McHarg, I. (1971). *Design with Nature. Doubleday and Compan*y Inc, Garden City, New York.

Ministry of Environment (1996). Environmental Protection Act (EPA). Government of Nepal.

Ministry of Environment and Forest (1997). Environmental Conservation Rules (ECR). Government of People's Republic of Bangladesh.

Modak, P. and Biswas, A.K. (1999). Conducting Environmental Impact Assessment in Developing Countries. United Nations University Press.

Mumtaz, S. (2002). Environmental impact assessment in Bangladesh. *Environ. Impact Assess. Rev.,* **22:** 163–179.

Munn, R.E. (1979). Environmental Impact Assessment: Principles and Procedures (2nd edition). John Wiley, New York.

National Environmental Commission (2006). Reference Manual for Environmental Impact Assessment Training in Bhutan. RGB, Thimpu, Bhutan.

OECD (1992). Good Practices for Environmental Impact Assessment of Development Projects, OECD Development Assistance Committee Guidelines on Aid and Environment **(1):** 1–15.

Purnama, D. (2003). Reform of the EIA process in Indonesia: Improving the role of public involvement. *Environ. Impact Assess. Rev.*, **23(4):** 415–439.

Rau, J.G. and Wooten, D.C. (1980). Environmental Impact Analysis Handbook. New York: McGraw-Hill, Inc.

Sikdar, P.K., Mondal, S., Saha, L., Sarkar, S.S. and Banerjee, S. (2002). Environmental impact assessment of a proposed Info-Tech Complex in East Calcutta Wetland. *The Environmentalist (now Environ. Syst. Decis.)*, **22(3):** 241–260.

Sorenson, .C. (1971). A Framework for Identification and Control of Resource Degradation and Conflict in the Multiple Use of the Coastal Zone. University of California Berkley, Department of Landscape Architecture. M.S. Thesis. University of California Press.

UNCED (1992). Rio Declaration, United Nations Conference on Environment and Development Rio de Janeiro.

UNEP (1980). Guidelines for Assessing Industrial Environmental Impact and Environmental Criteria for the Sitting of Industry, UNEP Industry and Environment Guidelines Series 1.

Wangwongwatana, S., Daisuke Sano, D. and King, P.N. (2015). Assessing Environmental Impact Assessment (EIA) in Thailand: Implementation Challenges and Opportunities for Sustainable Development Planning. Asian Environmental Compliance and Enforcement Network (AECEN) Working Paper. Institute for Global Environmental Strategies, Hayama, Japan.

WCED (1987). Report of the World Commission on Environment and Development: Our Common Future, Oxford University Press.

World Bank (1991). Environmental assessment sourcebook: volume 2 – Sectoral Guidelines (English). World Bank Technical Paper; no. WTP 140. World Bank, Washington, DC. http://documents.worldbank.org/curated/en/415971468137388990/Environmental-assessment-sourcebook-volume-2-sectoral-guidelines.

Wood, C. (1994). Lessons from comparative experience. *Built Environ.*, **20(4):** 332–344.

Zhu, T. and Lam, K.C. (eds) (2009). Environmental Impact Assessment in China. Research Center for Strategic Environmental Assessment, Nankai University, China and Centre of Strategic Environmental Assessment for China, The Chinese University of Hong Kong.

Zubair, L. (2001). Challenges for environmental impact assessment in Sri Lanka. *Environmental Impact Assessment Review*, **21(5):** 469–478.

Chapter 13
Life Cycle Assessment and Environmental Audit—Emerging Tools of Environmental Management in Businesses

Jhumoor Biswas

1 Introduction

Society and business have an interactive two-way relationship. It is well known that successful businesses lead to enhancement of quality of life and ultimately lead to economic development of a nation. However, businesses can thrive only in context of society. According to United Nations Environmental Program (UNEP, 2004), in the twenty-first century, no business can successfully operate in an economic and social vacuum, but must look towards meeting the needs and the expectations of all key constituents: customers, investors, employees and the greater society. The theme of sustainable business model is about enhancement of customer and value of business by addressing societal and environmental needs through the way business is done. Business models need to consider impact of business on the environment, society, economy and other key stakeholders. Historically, environmental regulations-based approach was used to control significant environmental impacts of organisations. Regulations are outcomes of government policies to reduce health and ecological risks, but command and control techniques adopted by regulatory bodies to minimise risks often resulted in a reactive approach to environmental management. Reactive approaches are mostly concerned with legal compliance and often do not have active participation from top management. Proactive corporate environmental practices in contrast go beyond compliance by emphasising corporate pollution-prevention activities, higher order learning and redesign of existing processes (Kim, 2018).

Historically, the United Nation's first Earth Summit held on the theme of Environment and Development in Rio de Janerio in 1992 paved the way for development of ISO 14000 standards by International Organisation of Standardisation (ISO) resulting in ISO's commitment to support objectives of environment

J. Biswas (✉)
Department of Environment Management, Indian Institute of Social Welfare and Business Management, Kolkata, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_13

management standards for sustainable development. Ever since then, corporates around the world have attempted to indoctrinate environmental practices into their main business strategies in pursuit of sustainable growth. Investors increasingly favour corporates who show commitment towards improving environmental performance, which is irrevocably linked with corporate economic performance. Many environmental costs can be significantly reduced or eliminated as a result of business decisions, ranging from operational (e.g. pollution mitigation and hazardous waste management practices lead to reduction of liability fines imposed by regulatory bodies, and secure operating consents and enhance corporate image), investment in “greener” process technology (e.g. clean energy technologies) and redesign of process/products to decrease energy and resource consumption. An organisation may also significantly benefit through processes such as selling waste to another company and adding value to a process, system, or product in another organisation as well (e.g. co-processing which enables recovery of energy from waste within a single industrial process: cement manufacturing). Assessment and management of environmental impacts of an organisation can result in improved environmental performance, accrue significant benefits to human health as well as ensure business success. Competitive advantage with customers can result from processes, products and services that can be demonstrated to be environmentally preferable.

Over the past decade, industrial leaders have recognised the importance of the environment in which they operate, and many have pursued a path of implementing voluntary tools for forward thinking corporations to deliver a range of benefits over and above environmental benefits and mere compliance. These ‘new millennium’ tools, which include Life Cycle Assessment and Environmental Audit in tandem with Environmental Management System (EMS) will transfigure how business creates new products and services and how consumers and government will compare, assess, regulate and purchase everyday goods. These tools are supported by UNEP. The primary objective of this study is to evaluate the role of these tools in context of business sustainability in developing countries and assess efficacy of implementation of these tools.

2 Life Cycle Assessment

Life cycle assessment (LCA) is a tool especially relevant from a sustainability perspective, because it covers the entire life cycle of a product or service and differs from other environmental methods of assessment. It does not merely concentrate on the environmental impact of a product or operation within a particular facility, but considers the impact of linkage of industrial processes through suppliers and customers and inter-dependence of products and by products through operations and processes and considers a systemic approach towards environmental impact assessment.

The international standards ISO 14040 (ISO 14040:2006) define LCA as the ‘compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle'. Thus, LCA is a tool for the analysis of the environmental burden of products at all stages in their life cycle—from the extraction of resources, through the production of materials, product parts and the product itself, and the use of the product to the management after it is discarded, either by reuse, recycling or final disposal ('from the cradle to the grave') (Ravindra and Jegannathan, 2014). The total system of unit processes involved in the life cycle of a product is called the 'product system'. The environmental burden covers all types of impacts upon the environment, including extraction of different types of resources, emissions of hazardous substances and different types of land use (ISO 14040:2006). The term 'product' encompasses physical goods as well as services at both operational and strategic levels. LCA differs from other environmental methods by connecting environmental performance to functionality, quantifying pollutant emissions and the use of raw materials based on the functional aspect of product or system. To a great extent as much as possible LCA is quantitative in nature. The life cycle concept is not limited to environmental impact. It may be combined with economic analysis, technical analysis and social analysis combining the different aspects of sustainability though this discussion is beyond the scope of this chapter.

2.1 Systemic Approach

The systemic approach to LCA is depicted in Fig. 13.1 where the region surrounding the boundary is the system environment that represents interaction of the industrial system with its environment. The inputs are raw materials inputs taken from environment and outputs are waste materials released back to the environment. This evaluation includes all releases to air, water and soil.

LCA should include measures of improvement in product, process, designs, raw material use, industrial processing, consumer use and waste management with primary aim to reduce environmental impact associated with energy, raw materials use, and environmental releases throughout life cycle of product, process or activity (Fig. 13.1). For example, a chemical compound may appear to be optimum selection for manufacturing or processing a product, but the LCA analysis may indicate that it will produce toxic environmental pollutants (e.g. usage of synthetic dyes to colour fabrics release toxic chemicals in surface water during dyeing process and later during fabric washing). The treatment costs and risks can be mitigated by changes in process design (e.g. digital printing on textiles, including cotton and other cellulosic fabrics like rayon with pigments rather than dyes that uses very little water, or selection of safer chemicals).

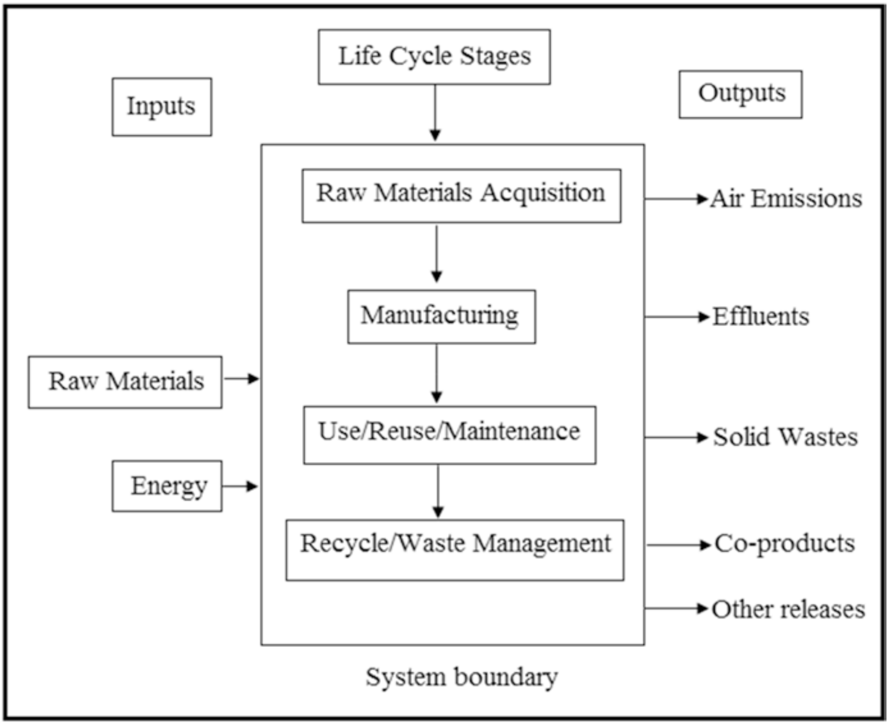

Fig. 13.1 Life cycle assessment stages and boundaries (*Source*: US EPA, 1992)

2.2 Historical Evolution of LCA

The historical evolution of LCA can be traced back to early seventies with cognizance of limited availability of resources and thence the energy crisis in 1970s that led to generalisation of balanced energy approach using methods such as Resource and Environmental Profile Analysis (REPA) and Product Ecobalance, which were earlier versions of LCA. Society of Environmental Toxicology and Chemistry (SETAC) was the first international organisation to take initiatives in development of LCA. It is a scientific body comprising of academia, industry and government that has been able to offer a science-based platform for the rational development of LCA as a scientific tool. SETAC's involvement with LCA dates from 1989, and is one of the main international scientific organisations involved in developing structural aspects of LCA through various SETAC working groups. These workshops set the scene for the emergence of two different schools of LCA development in North America and Europe, which have dominated the scene for many years. The European working groups have regarded the development and harmonisation of LCA methodology as their main aim, while the North American groups have focused on analysing the limitations of LCA and warning against its unwarranted use (Guinée, 2002). However, the two SETAC branches (North America and Europe) are also major areas of co-operation. A major example has been the development of a 'Code of Practice' for LCA. This was an important step towards harmonisation of the tool, as it presented the first internationally accepted technical framework for LCA. A third international player in the field of LCA is UNEP, represented by its Department of Technology, Industry and Economics in Paris. UNEP's focus is mainly on the application of LCA, particularly in developing countries (Guinée, 2002). The Code of Practice pointed out that, besides science, LCA also involves procedural aspects and value choices. These activities are now performed under International Organisation for Standardisation (ISO). Since 2015, a life cycle perspective has been obligatory in several parts of the updated version of ISO 14001, the international standard for environmental management systems (ISO 2015). According to the standard within the planning phase of EMS, 'the organisation shall determine the environmental aspects of its activities, products and services that it can control and those that it can influence, and their associated environmental impacts, considering a life cycle perspective'. The standard also has the clause operational planning and control under which it mandates life cycle perspective 'in procurement of products or services, communication of its relevant environmental requirements and provide information about potential significant environmental impacts associated with the transportation or delivery, use, end-of-life treatment and final disposal of its products and services'.

ISO published a series of ISO 14000 norms on LCA, in response to the demand to internationally effectively combine various methodologies used in LCA in 2006. These became a part of ISO 14001 environment management standards. Currently, the primary LCA norms consist of ISO 14040:2006—LCA—principles and framework, ISO 14044:2006—LCA—requirements and guidelines both amended in 2017, ISO 14045:2012—eco-efficiency assessment of product systems—requirements and guidelines, ISO 14046:2014—Water footprint—Principles, requirements and guidelines, ISO 14047:2012—LCA—illustrative examples on how to apply ISO 14044 to impact assessment situations, ISO 14048:2002—data documentation format, ISO 14049:2012—LCA, illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis. To cover a broader set of environmental impacts, the need for the accounting of pollutant emissions to air, water and soil also became apparent. This led to methodological developments, initially within the packaging industry, which were eventually applied to all economic sectors, as it turned out that the product often had a much larger environmental impact than its packaging. Eventually, the LCA combined these various types of accounting into a function-based analysis (Joliet et al., 2016).

2.3 LCA Methodology

LCA method starts with goal and system definition that determines the problem and defines the intended application of LCA results including the intended audience, the stakeholders, and the scope of the study. LCA evaluates the environmental impact of a product or service (the assessment is based on a particular function and considers all life cycle stages). It helps to identify where environmental improvements can be made in a product's life cycle and aids in the designing of new products. Primarily, this tool is used to compare various products, processes, or systems, as well as the different life cycle stages of a particular product or system

According to the definitions provided in the ISO standards and by SETAC, an LCA consists of a goal and scope definition, inventory analysis, impact assessment, and interpretation of results (Fig. 13.2). The assessment includes the entire life-cycle of a product, process or system encompassing the extraction and processing of raw materials; manufacturing, transportation and distribution; use, reuse, maintenance, recycling and final disposal (Khasreen et al., 2009). Employed to its full, LCA examines environmental inputs and outputs related to a product or service life-cycle from cradle to grave, i.e., from raw material extraction, through manufacture, usage phase, reprocessing where needed, to final disposal. ISO 14040, 2006 defines LCA as: 'A technique for assessing the environmental aspects and potential impacts associated with a product, by compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts and interpreting the results of the inventory analysis and impact assessment phases'. LCA is often engaged as an analytical decision support tool. The four iterative phases of LCA (ISO 14040) are defined as follows:

1. *Goal and scope definition*: The problem is described and the objectives and scope of the study are defined. A number of crucial elements are determined at this point: the function of the system, the functional unit on which the emissions and the extractions will be based, and the system boundaries. The base scenario and the alternatives are also discussed in details.
2. *Inventory analysis*: Life cycle inventory provides a detailed listing of time-integrated inputs and outputs of all process flows within the concerned system boundary. The polluting emissions to air, water and soil are quantified, as well as the extractions of renewable and non-renewable raw materials. The resource use

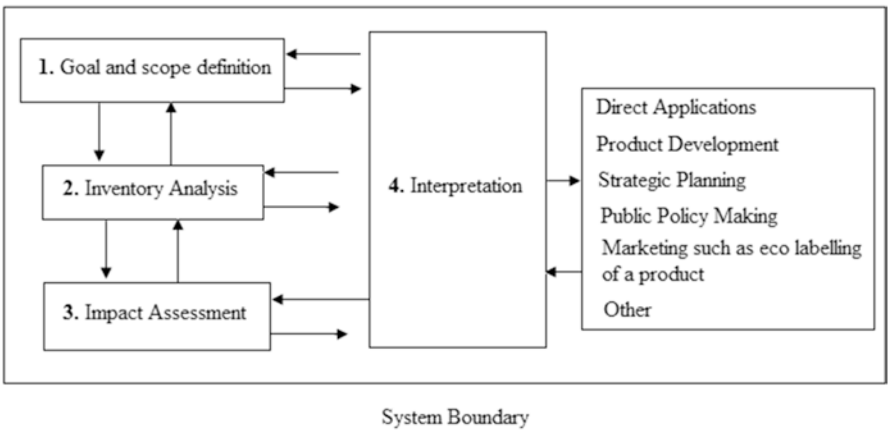

Fig. 13.2 The four iterative components of LCA (Source: ISO 14040, 2006)

required for the function of the system is also determined here. It also predicts both environmental performance (in terms of environmental aspects) and economic costs. Life cycle inventory (LCI) phase is the phase of data collection, all inputs and associated outputs related to study. Data collection is an important part of LCA study, the accuracy and reliability of data play an important part and the choice of data will influence the overall results.

3. *Impact assessment*: Evaluates environmental aspects and their potential impacts due to the inventoried emissions. Processes convert inputs into outputs within the system boundary. To quantify environmental impact of products, a functional unit is defined such as the greenhouse gas (GHG) output as per a functional unit, e.g., emissions produced for one million BTU/kg of fuel consumed (grams of CO_2 equivalent for these emissions). Since eliminating waste generates emissions, waste treatment should be included within the system boundaries. Impact assessment can be broken down into the following steps (Jolliet et al., 2016): the first mandatory element is a selection of a manageable number of impact categories (scenarios) of resource use and environmental impacts, indicators for the categories and models to quantify the contributions of different inputs and emissions to the impact categories, the second mandatory element (classification) is a task of the inventory data to the impact categories and the third mandatory element (characterisation) is a quantification of the contributions to the chosen impacts from the product system.
4. *Interpretation*: This is where the results obtained so far are interpreted and the uncertainties are evaluated. The key parameters and improvement options can be identified using sensitivity studies and uncertainty propagation, and a critical analysis evaluates the influence of the chosen boundaries and hypotheses. Finally, the environmental impacts can be compared with economic or social impact.

LCA methodology can be used to assess environmental impacts of products on a wide range of spatio-temporal scales. For example, it can be apparently as simple so as to assess environmental impact of a paper cup to complex analyses (such as assessing impact of aerosols on health and climate change) on regional and global scales. Several LCA software models can be used for assessment of LCA. Some commonly used LCA software are Integrated Solid Waste Management model-version 2 (IWM-2) (designed specifically for testing environmental impact of municipal solid waste) and SimaPro (a generic and widely used LCA software). The Sima Pro software (https://simapro.com/) uses different standard LCA inventory databases from Asia, North America and Australia. With global consensus, currently LCA methodology extends to assessment of climate change, water use, land use and particulate matter impacts using LCI framework (Frischknecht and Jolliet, 2016). The forte of LCA models is that they can quantify environment impacts on different scales as seen in the following case studies.

2.4 LCA Case Studies

2.4.1 Case Study 1.Optimisation of an Airline's Greenhouse Gas Emissions—Climate Change Issue

In 2016, the International Civil Aviation Organisation (ICAO), a specialised agency of the United Nations, reached an agreement to implement a global Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) system. CORSIA stipulates that airlines are obliged to offset their increases in emissions after 2020 by purchasing credits from projects that reduce emissions outside the aviation sector (ICAO, 2016). Emissions from aircraft are created from jet fuel burned in aircraft engines bulk of which is kerosene. The guidelines and methodology for developing an emissions inventory of greenhouse gas from combustion products of different types of aircrafts and their corresponding fuels can be obtained from IPCC (2006). The impact of different airlines fuel using a LCA model was studied by de Jong et al. (2017) who found introduction of renewable jet fuel (RJF), an important emission mitigation measure for the aviation industry to optimise GHG emissions. With the right feedstock and conversion technology formulated through different modelled scenarios, it was found GHG emission reduction in aviation industry could be above 85%. The GHG emission performance of RJF could be further improved by using sustainable hydrogen sources or applying carbon capture and storage.

2.4.2 Case Study 2. Environmental Assessment of Municipal Solid Waste Management (MSWM) System

In developing countries, urbanisation directly contributes to waste generation, and unscientific waste handling causes health hazards and urban environment degradation. Migration of population from low paying agriculture sector to more paying urban occupations, largely contribute to urbanisation leading to fast expansion of slums and informal housing in rapidly expanding cities of the developing world. Solid waste management, an enormous task in developing countries like India is increasingly getting difficult to manage with upsurge in urbanisation, changing lifestyles, increase in consumerism combined with financial constraints, institutional weaknesses, improper choice of technology and public apathy towards municipal solid waste (Vij, 2012). LCA an internationally recognised scientific method is established as an effective management tool for identifying and assessing the environmental impacts related with waste management options (Othman et al., 2013) as it facilitates study of different waste treatment technologies to determine the best option (Khoo, 2009). The eco-invent database, a global database (https://www.eco-invent.org) may be used as an inventory database for modelling solid waste management.

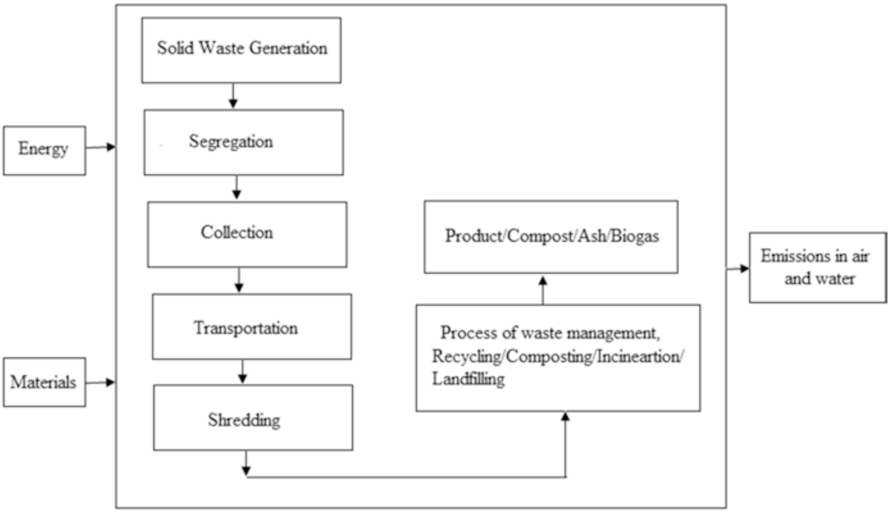

Fig. 13.3 System boundary of solid waste management. (*Source*: Ghinea et al., 2012)

The system boundary for solid waste management is described in Fig. 13.3. It includes inputs (E = energy, M = material), outputs (E1 = emission in air and water calculated in terms of FUS), solid waste generation, waste transportation, segregation, shredding, recycling and new product (recycled material).

In developing countries, several environmental impact assessments of MSWM are being carried out using LCA tools in urban regions (Othman et al., 2013; Yadav and Samadder, 2015). Recently, an environmental assessment of MSWM system has been conducted in Nagpur city, India (Khandelwal et al., 2019) under four different scenarios, i.e., composting combined with landfilling (S1), material recovery facility (MRF) and composting combined with landfilling (S2), MRF and anaerobic digestion (AD) combined with landfilling (S3) and MRF, AD and composting combined with landfilling (S4) using LCA tool. The sensitivity analysis was also performed for evaluating the influence of recycling rate of recyclables common in the commercial waste stream, which include paper, plastic, metals, food, yard trimmings, lumber, textiles and electronic devices in all the considered scenarios. S2 was found to have the least environmental impacts on global warming, human toxicity, eutrophication and photochemical ozone creation potential categories. The sensitivity analysis indicated an inversely proportional relation between change in recycling rate and total environmental burdens for all scenarios.

2.4.3 Case Studies 3 and 4. Life Cycle Assessment of the Existing and Proposed Plastic Waste Management Options in Developing Countries India and China

Plastic waste can cause a variety of environmental impacts and pose a formidable challenge for the consumer product industry. Understanding the environmental trade-offs of various end-of-life strategies for plastic waste is thus important for developing and deploying appropriate sustainable solutions.

LCA technique was used to assess possible environmental impacts of the existing and proposed plastic waste management scenarios on various impact categories for Dhanbad city, India (Ayan et al., 2019). The scenarios considered were: (a) landfilling without bio-gas recovery (denoted by S1); (b) incineration without energy recovery (denoted by S2); (c) recycling (denoted by S3) and (d) incineration with energy recovery (denoted by S4). The environmental impacts of all the four scenarios (S1 to S4) were evaluated and compared. The results from LCA showed that the scenario S3 had the least environmental impacts on most of the impact categories due to use of recycled plastic flakes and also due to less emissions during recycling process. Scenario S2 had the highest environmental impacts on most of the impact categories. S4 had lower environmental impacts than scenario S3 on natural resource (fossil fuel) depletion, and acidification impact categories.

China is the largest producer and recycler of waste plastics and hence it is necessary to explore the environmental impacts of actual end-of-life (EOL) treatments of waste plastics in China. (Chen et al., 2019). In this study, LCA was conducted for various plastic treatment plants to evaluate the environmental impacts of different treatment options: (a) mechanical recycling of waste plastics, (b) incineration and (c) landfilling with municipal solid waste. Mechanical recycling, a method by which plastic waste materials are recycled into 'new' (secondary) raw materials without changing the basic structure of the material had a minimum impact on terrestrial acidification potential and global warming potential. Incineration and landfilling options negatively impact environment. Scenarios of different treatment patterns and recycling technologies were used to analyse the potential reduction in environmental impacts of future EOL treatments of waste plastics. Increasing the proportion of mechanical recycling would reduce all environmental impacts, including up to 51.8% on particulate matter formation potential. According to the study, energy conservation and emission reduction in atmospheric pollutants are consequences of mechanical recycling. Banning waste plastics imports as a part of policy making would decrease the transportation distances of waste plastics by water transport, thereby reducing the related environmental impacts caused by dumping of those plastics on marine life.

2.5 Benefits of LCA

With increasing stringency of environmental regulations and a high level of public awareness, organisations need tools that provide them with detailed information about their environmental impacts. LCA is an environmental management tool that is used for identifying and evaluating the environmental impacts of products and services across their life cycle. It is used by a wide variety of organisations including academia, business organisations, local authorities, national governments and international organisations.

Life cycle thinking is fundamental in the development of key environ-mental policies around the world and is used to inform an array of decision making processes in organisations.

2.6 Limitations of LCA

LCA is time-consuming and complex process. For results to be accurate there is demand for high-quality data. Issues may arise with data availability and reliability. There are many datasets and databases; each has its own inherent assumptions and the user also makes assumptions when running LCA model. This can result in the same inventory producing different results. The selection of system boundaries in LCA can also significantly add to uncertainty of outputs from LCA.

The results of an LCA can be complex and difficult to understand. Therefore, it is important to be clear about the application of the LCA from the beginning. As of now LCA considers only environmental impacts, but newer developments are aiming to integrate economic and social aspects in the future.

3 Environmental Audit

Organisations irrespective of size and complexity of operations interact with environment in manifold ways. There are direct effects ranging from accidental spillage of oil from oil refinery that may pollute open waterways or groundwater or air (aerosols, NO_x, SO_x or other toxic emissions). There are also indirect effects, such as environmental impact of the finished product from oil refineries such as petrol (emits VOCs) or acid rain produced by interaction of SO_x and NO_x released by power plants with atmospheric water vapour, vehicular pollution caused by suppliers of industries while conveying their supplies and dumping of non-biodegradable waste plastics in landfills from plastic packaging that release toxins, in soil or water bodies placing a huge chemical burden on environment. The environment in turn affects organisations in many ways, such as pollution from industries may compromise occupational health and safety of an industry's own workers and surroundings, environmental laws aimed at protecting the environment may place constraints upon an industry and require expenditures for new equipment for environmental controls, else fines may be imposed or consent to operate withdrawn by regulatory bodies. Thus organisations need to interact with environment in a beneficial way to assure its own sustenance and sustainability of society at large.

Environmental audit is a basic tool used by management to enable environmental controls. According to ICC (1989) broadly, it is an independent systematic evaluation of internal policy and principles, systems, procedures, practices and performance, and other elements of a business relating to environment. It also ensures that various environmental laws are complied with and adequate care has been taken towards environmental protection and preservation. Overall, it is a process of assessment of EMS of an organisation with regard to status of conformity with internal environmental policies and status of implementation of good environmental practices.

EMS is a set of internal policies and procedures that helps the organisation to systematically assess and reduce the environmental impact of its activities. One approach to ensure efficiency in industrial processes is the implementation of an EMS, addressing all environmental aspects of an organisations' activities, including raw materials consumption, energy usage, process control, waste generation and emissions. Traditionally, command and control measures have been used by regulatory bodies to control pollution, and industries are compelled to meet prescribed legal compliance standards, enforcement of which have led to significant decrease of environmental pollution globally. However, with rising awareness of environmental issues, there has been increasing pressure on organisations to control negative environmental impacts of their activities, products and services (Delmas and Toffel, 2004). Businesses also perceive this need in this era of competitiveness in context of increased environmental awareness related to impact of environment on health. Organisations are adopting a proactive approach that aims at reducing emissions below regulatory levels and usage of certified environmental management standards that structure environmental planning, operations, training of personnel and monitoring of environmental aspects.

ISO 14001 is the most widely accepted and most widespread certified environmental management standards created in 1996 by the ISO based on former environmental British Standards (BS 7750). Organisations voluntarily adopt the standards that grant flexibility in setting environmental objectives and systematically manage their impacts through various technological and management procedures to effectively implement controls and check their effectiveness through monitoring procedures and compliance evaluation. ISO 14001 is both a management tool and representation of environmental commitment from top management of the organisation (Boiral and Henri, 2012; Jiang and Bansal, 2003). It describes management practices that are anticipated to decrease consequences of an organisation's activities on natural environment (Bansal and Bogner, 2002). The organisation's practices under ISO 14001 usually results in cost reductions and higher efficiency due to promotion of more efficient use of resources (Rondinelli and Vastag, 2000). ISO 14001 standards have been revised twice since inception, first in 2006 (to align environmental standards with quality management standards in order to integrate environmental concerns with business processes) and then in 2015 (to place full responsibility on top management to take care of environmental concerns, assess environmental risks by LCA of products and services to gauge environmental impact beyond its boundaries including outsourced processes; and, understanding the needs and concerns of interested parties such as investors, suppliers, customers, regulatory body, employees and local community in context of the organisation).

Environmental audit can be internal (first check of deviation from ISO 14001 standards or violations of legal compliance) or external where certified third party auditing bodies approved by national regulatory bodies evaluate EMS against requirements of ISO 14001 standards adopted on a voluntary basis by industries. This means that no central authority gives rewards for adopting them or sanctions for not adopting them (Ingram and Silverman, 2002). Certified management standards systematise environmental practices and procedures, not outcomes in the environmental field. To obtain the certification, firms must pass a third-party audit, carried out by a private auditor, verifying the firm's adherence to the requirements of the standard. Therefore, it helps to reduce information asymmetries and the fear of opportunistic behaviours and enables organisations to demonstrate assurance of protection of environment and improve their relationships with stakeholders enhancing their credibility (King et al., 2005). This audit certification also helps firms to differentiate themselves from their competitors (Demirel et al., 2018) and improve market image in context of rising awareness of environmental sustainability issues.

3.1 Evolution of Environmental Auditing

Environmental auditing began as a voluntary compliance technique in the 1970s in the United States. Enforcement of environmental laws compelled organisations to assess their degree of compliance. Auditing was a method to evaluate adherence of compliance to these laws and perceive extent of non-compliance problems. These environmental audits were known as compliance audits. Environmental audit conducted on hazardous waste sites to avoid liability issues became known as liability audits. In Europe, environmental auditing began in the chemical and petrochemical industries, due to inherent environmental hazards of these businesses, and as a result of their involvement with American operations. In the 1980s and 1990s with development of EMS, pollution prevention strategies that go beyond compliance issues and pursue corporate sustainability goals such as environmental auditing became a proactive approach adopted by organisations. It is increasingly being applied in developing countries by both multinational enterprises and small and medium-sized enterprises. Environmental auditing is therefore becoming a common management tool in environmental management for organisations worldwide and may become a legal requirement in the future.

3.2 Environmental Auditing According to PDCA Cycle

ISO 19001 (2018) provides guidelines for successful planning, execution, and documentation of environmental auditing to all types of management systems irrespective of size and complexity of operations on conducting internal and external audit.

The ISO 14001 standard is structured around a Plan-Do-Check-Act (PDCA) cycle that leads to continual improvement of environmental management of organisation. This is a repetitive cycle of decisions, actions and evaluation. Environmental audit provides opportunities for enhancement of environmental performance of organisations by checking and pointing non-conformities present in the EMS throughout the entire PDCA cycle against ISO standards (14001:2015). Addressing non-conformity issues enables an organisation to improve its environmental performance. The customers, investors or any other interested parties are assured that organisation has an organised environment management system in accordance with ISO 14001:2015 requirements. This improves the image of company from the customer's point of view and helps to avoid financial losses due to potential environmental liability risks.

The plan phase consists of three clauses of the standard (context of the organisation, leadership and planning) (ISO 14001:2015). The auditor must ensure that there is documented evidence for a matrix that determines the company's issues, in terms of environmental context and processes are discussed in details, documented information on commitment of top management towards communication of EMS policy or budget allocation towards EMS maintenance to verify leadership clause. Top management is responsible that EMS can be managed by one or several competent persons. The planning phase must ensure that environmental aspects matrix has been set up and documented, achievable objectives have been set to address environmental aspects set in context of organisation. This also includes planned mitigation activities to manage impacts from these environmental aspects. The DO phase includes support and operational control of environmental aspects. The auditor must ensure that there is enough documented evidence that all employees of the organisation have EMS awareness and personnel related to EMS activities have EMS competency (competency evaluation and training records). For operational control a detailed description of the organisation's lifecycle perspective in case of control plans (waste management, air and water pollution control) is preferable and documented procedures for emergency preparedness. The CHECK phase includes analysing EMS performance based on EMS targets and must include monitoring records of environmental aspects, internal auditing results and documented details of management review. The auditors must check legal compliance in accordance to industry standards. The environmental audit of ACT phase of PDCA cycle must include review of corrective actions taken to address previous non-conformities and should include root cause analysis (RCA), with the goal to completely eliminate environmental problems. In course of the audit, the auditor collects audit evidence for each clause requirement of ISO 14001:2015, which become part of the audit records for the related audited clause or subclause. The final completion and effectiveness checks of documented corrective actions address whether this has led to the resolution of the non-conformity issues. This leads to continual improvement of an organisation's EMS.

3.3 Effectiveness of Environmental Audit

Organisations wishing to implement EMS and obtain ISO 14001 certification should get support and sufficient resources from top management to enable integration of EMS in operations. ISO organisation has recognised this need and the revised version of ISO 14001 standards, introduced at the end of 2015, has more focus on management by environmental objectives as well as specifications concerning the assessment of environmental performance (ISO 14001, 2015). Environmental auditing is a specialised type of auditing to evaluate progress in environmental quality in specific sites on the basis of generic standards and criteria. It is even more difficult to demonstrate that these improvements are the results of specific measures. Environmental auditing thus, poses explicit challenges for auditors when they are faced with the task of interpreting and applying the standards. Environmental certification audits should be more focused on substantive aspects of the management systems (Heras-Saizarbitoria et al., 2013) rather than only procedural aspects as provided in documented evidence. Policy makers should take into consideration that if implementation of ISO 14001 standards is made mandatory in government-implemented environmental improvement programs in its current format, then certification alone should not be a gurantor for organisations to receive benefits such as exemptions from regulatory requirements or tax credits.

4 Challenges in Environmental Sustainability

A cache of environmental sustainability tools (LCA, risk assessment, material flow analysis, carbon or water footprint, EMS, environmental audit etc.) are currently being used to enable organisations to meet increasingly stringent environment standards and fulfill expectations due to growing global awareness on environmental pollution and their impact on human health and ecology. Two such representative tools have been addressed in this chapter. These tools of analysing environmental impacts of organisations which include quantitative and procedural methods can enable an organisation to eventually develop a sustainable environmental management program. Successful implementation of these tools requires top management commitment and proactive approach as these are above and beyond legal environmental requirements. International bodies such as ISO, SETAC and UNEP have played key roles towards their development and implementations. However, some limitations are associated with each of these tools which need to be overcome, so that firms can use them effectively to manage their environmental resources in a sustainable manner.

LCA methodology is a sustainability tool that can be incorporated in decision making in the field of environmental management since the systems approach allows for integrated decision making from acquisition of raw materials to manufacturing of a product and finally its disposal. Current environment management practices call for a risk evaluation based approach and greater reliance on tools that prevent environmental pollutants from being generated, e.g., the substitution of safer substances upstream in case of product manufacture or process life cycle and this is where the LCA process can assume a significant role. However, challenges remain such as modelling variabilities, missing impact indicators and making LCI readily available for users. These can be addressed through continued research and development of the tool. Uncertainties also persist in setting of proper functional units or appropriately scoping the assessment and these need to be reduced through continued education and training to assist users in the proper application of the tool (Curran, 2014).

Environmental auditing has become an important tool in context of environmental management. But objectivity and neutrality linked to professionalism and transparency must be maintained during the audit procedure for the audit to become effective. An EMS is site based, whereas LCA is product oriented. However, EMS implementation encourages an organisation to think holistically about its environmental impacts, which includes indirect supply chain impacts and those resulting from customer use of products. Therefore, LCA is being used as a complementary tool to an EMS, providing organisations with information on the lifecycle environmental impacts of their products or services.

The challenge is that many organisations move towards a symbolic adaptation of ISO 14001 standards but do not necessarily improve environmental performance (Castka and Prajogo, 2013). Thus, environmental audit must ensure that there is functional application of the ISO 14001:2015 risk-based standards rather than only ensuring systematic documentation of procedures. The complexity of environmental processes makes this task additionally difficult as environmental impacts may be long-term and dependent on controlling factors (such as meteorological variability, land use changes etc.) and may also last for several years making it difficult to quantify and monitor them. These intrinsic uncertainties make it further difficult to assess audit efficacy of environmental audit.

However as discussed earlier, it is the signal of intent of an organisation towards sustainable development that will overcome these challenges. The increasing focus on environmental sustainability issues will help to identify crucial bottlenecks that can be addressed by instituting appropriate mechanisms developed through concerted and collaborative research and policy based initiatives of academia, industry, government and global bodies such as ISO and UNEP.

References

Ayan, Y., Yadav, P. and Samadder, S. R. (2019). Life cycle assessment of the existing and proposed plastic waste management options in India. *J Cleaner Prod*, **211:** 1268–1283.

Bansal, P. and Bogner, W.C. (2002). Deciding on ISO 14001: Economics, institutions, and context. *Long Range Planning*, **35(3):** 269–290.

Boiral, O. and Henri, J.F. (2012). Modelling the impact of ISO 14001 on environmental performance: A comparative approach. *J Environ Manage*, **99:** 84–97.

Castka P. and Prajogo D. (2013). The effect of pressure from secondary stakeholders on the internalization of ISO14001. *J Cleaner Prod*, **47:** 245–252.

Chen, Y., Cui, Z., Cui, X., Liu, W., Wang, X. and Li, S. (2019). Life cycle assessment of end-of-life treatments of waste plastics in China. *Resources Conserv Recycl*, **146:** 348–357.

Curran, M. (2014). Strengths and limitations of life cycle assessment. *In:* Klöpffer, W. (ed.), Background and Future Prospects in Life Cycle Assessment. LCA Compendium – The Complete World of Life Cycle Assessment. Springer, Dordrecht. ISBN -978-94-017-8697-3.

de Jong, S., Antonnisen, K., Hoefnagels, R., Lonza, L., Wang, M., Faaij, A. and Junginger, M. (2017). Life cycle analysis of greenhouse gas emissions. *Biotechnol. Biofuels*, **10:** 1–18.

Delmas, M. and Toffel, M.W. (2004). Stakeholders and environmental management practices: An institutional framework. *Business Strategy Environ*, **13(4):** 209–222.

Demirel, P., EIatridis, K. and EIatridis, E.K. (2018). The impact of regulatory complexity upon self-regulation: Evidence from the adoption and certification of environmental management systems. *J Environ Manage*, **207:** 80–91.

Frischknecht, R. and Jolliet, O. (Eds.) (2016). Global Guidance for Life Cycle Impact Assessment Indicators, Vol. 1. UNEP/SETAC Life Cycle Initiative.

Ghinea, C., Petraru, M., Bressers, J.T.A. and Gavrilescu, M. (2012). Environmental evaluation of waste management scenarios—Significance of the boundaries. *J Environ Eng Landscape Manage*, **20:** 76–85.

Guinée, J.B. (2002). Handbook on Life Cycle Assessment: Operational Guide to the ISO Standard. Kluwer Academic Publishers.

Heras-Saizarbitoria, I., Dogui K. and Boiral, O. (2013). Shedding light on ISO14001 certification audits. *J Cleaner Prod*, **51:** 88–98.

ICAO (2016). Global Air Navigation plan, 2016–2030, Doc 9750/ANS963, Fifth edition.

Ingram, P. and Silverman, B.S. (2002). The new institutionalism in strategic management. *In:* Ingram, P. and Silverman, B.S. (Eds.), Advances in Strategic Management, Vol. 19, pp. 1–30, JAI Press, New York.

ICC (International Chamber of Commerce) (1989). Environmental Auditing, Publication No. 468, ICC Publishing SA, Paris France.

IPCC (2006). IPCC Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies (IGES), Hayama, Japan.

ISO 14001 (2015). International Standards in Environmental Management Systems. International Organisation for Standardization, Geneva, Switzerland.

ISO 14040 (2006). Environmental Management Life Cycle Assessment Principles and Framework. International Standards Organization, Brussels, Belgium.

ISO 19011 (2018). Guidelines for Auditing Management Systems. International Organisation for Standardization, Geneva, Switzerland.

Jiang, R.J. and Bansal, P. (2003). Seeing the need for ISO 14001. *J Manage Stud*, **40(4):** 1047–1067.

Jolliet, O., Saddá-Sbeih, M., Shaked, S., Jolliet, A. and Crettaz, P. (2016). Environmental Life Cycle Assessment. ISBN-13:978-1-4398-8770-7. CRC Press, Taylor and Francis Group.

Khandelwal, H., Thalla, A.K., Kumar S. and Kumar, R. (2019). Life cycle assessment of municipal solid waste management options for India. *Bioresource Technol*, 288. Available online at https://doi.org/10.1016/j.biortech.2019.121515.

Khasreen, M.M., Banfill, P.F.G. and Menzles, G.F. (2009). Life-cycle assessment and the environmental impact of buildings: A review. *Sustainability*, **1:** 674–701.

Khoo, H.H. (2009). Life cycle impact assessment of various waste conversion technologies. *Waste Manage*, **29(6):** 1892–1900.

Kim, K. (2018). Proactive versus reactive corporate environmental practices and environmental performance. *Sustainability*, **10:** 1–19.

King, A.A., Lenox, M.J. and Terlaak, A. (2005). The strategic use of decentralized institutions: Exploring certification with the ISO 14001 management standard. *Acad Manage J*, **48:** 1091–1106.

Othman, S.N., Noor, Z.Z., Abba, A.H., Yusuf, R.O. and Hassan, M.A.A. (2013). Review on life-cycle assessment of integrated solid waste management in some Asian countries. *J Cleaner Prod*, **41:** 251–262.

Ravindra, P. and Jegannathan, K.R. (2014). Production of Biodiesel using Lipase Encapsulated in k-Carrageenan. Springer Publications.

Rondinelli, D. and Vastag, G. (2000). Panacea, common sense, or just a label? The value of ISO 14001 environment management systems. *Eur Manage J*, **18:** 499–510.

UNEP (2004). Voluntary Environmental Initiatives for Sustainable Industrial Development—Concepts and Applications. United Nations Publication. ISBN: 92-807-2480-0, pp. 1–61.

U.S. EPA (1992). Product Life-cycle Assessment: Inventory Guidelines and Principle. EPA/600/r-92/245.

Vij, D. (2012). Urbanization and solid waste management in India: Present practices and future challenges. *Procedia – Social Behav Sci*, **37:** 437–447.

Yadav, P. and Samadder, (2015). System Boundaries for Life Cycle Assessment of Municipal Solid Waste Management Options. *Int J Eng Technol Sci Res*. ISSN 2394-338, Vol. 2, Special Issue.

Chapter 14
Economic Values for the Environment with Special Reference to the Contingent Valuation Method

Anita Chattopadhyay Gupta and Nilendu Chatterjee

1 Introduction

Economic valuation of environmental goods is one of the most important aspects of the subject environmental economics. The key reason behind widespread destruction and degradation of natural resources is that the issue of environmental conservation and sustainable development is undervalued in developing countries. Such an outcome is due to the inability to understand the actual economic valuation of natural resources.

Valuation can simply be defined as an attempt to put monetary values to environmental goods and services or natural resources, which are mostly non-marketed. It is a key exercise in economic analysis and its results provide important information about values of environmental goods and services. This information can be used to influence decisions about wise use and conservation of forests and other ecosystems. Economic valuation of the environment deals with a series of techniques that economists use to assess the economic value of market and non-market goods, namely natural resources and resource services. It uses the concepts of producer's and consumer's surplus of welfare economics to determine the valuation of natural resources. Economic value in general is a measure of what is the maximum amount of expenditure that an individual is willing to forego on other goods and services in order to obtain some good, service or state of the world. This measure is formally expressed in terms of a concept called willingness-to-pay (WTP). The basic aim of valuation is to determine people's preferences by gauging how much they are willing to pay (WTP) for given benefits or certain environmental attributes, e.g., keep a forest ecosystem intact or its further improvement. It also deals with the issue like

A. C. Gupta (✉)
Deshbandhu College for Girls, Kolkata, India

N. Chatterjee
Department of Economics, Bankim Sardar College, Canning, West Bengal, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_14

how much worse off the stakeholders would feel as a result of changes in the state of the environment resulting from destruction of natural resource like forestry.

Without the observable price and quantity data that are available when goods or services are traded in the market, economists have devised innovative techniques for measuring changes in value for natural resources and the environment. Techniques like travel cost and hedonic pricing use various information to indirectly determine what a market might reveal in terms of value in case it exists. The contingent value technique attempts to measure the change in value directly.[1] Some goods and services like recreational fishing and wildlife viewing are not traded in a well-functioning, traditional market. That is, they are not supplied by private firms and consumers do not pay market prices. Nonetheless, individuals benefit from their use and, therefore, the loss of such environmentally related goods signifies welfare losses to these individuals. Conceptually, the same measure of benefit applies to market and non-market goods, that is, the maximum amount an individual would pay to avoid losing, or gaining, access to the good. Since these are non-market benefits there is no producer of the good.[2] There are a variety of methods that have been developed to measure this value concept in the absence of markets.

The issue of economic valuation of the environment becomes interesting when we can demonstrate it with the help of some case studies. Among the various methods of valuation, we have confined ourselves to the most popular and most applicable method of valuing environmental valuation which is contingent valuation method (CVM hereafter). Inspite of its inherent limitations, CVM is widely used for estimating the values of natural resources which have nonmarket as well as non-use values.

The most common method of estimating non-use value is by directly questioning individuals on their willingness-to-pay (WTP) for a good or service. CVM is the easiest way of determining this WTP. It is a survey or questionnaire-based approach to the valuation of non-market goods and services. The values obtained for the good or service are said to be contingent upon the nature of the constructed (hypothetical or simulated) market and the good or service described in the survey scenario. The contingent valuation (CV) technique has great flexibility, allowing valuation of a wider variety of non-market goods and services than is possible with any of the indirect techniques.

The purpose of the present chapter is to highlight the major techniques that are used in valuing the environment in general and to focus on the most widely used method like CVM in particular. We have demonstrated the random utility model (RUM) that explains the dichotomous choice (DC) interpretation of CVM and have explained in detail the econometric techniques that are associated with estimation of WTP, which is an integral part of this method. We have considered two case studies to illustrate CVM and they are confined to the dryland area of the state of West

[1] Hedonic pricing and travel cost methods are based on use value of the good/service/resource whereas contingent valuation method is based on non-use value of the good/service/resource.

[2] In this context, the consumer can be treated as both consumer as well as the producer of the good.

Bengal. For this purpose, we have selected Purulia district of the state which falls under this dryland area.

The literature on economic valuation of the environment is quite voluminous. It includes various path breaking works on hedonic pricing method, travel cost method and also CVM. For example, one can refer to the works of Lancaster (1966), Freeman (1979), Follain and Malpezzi (1979), Harris (1981), Willis (1980), Pearce et al. (1981) etc. for hedonic pricing, works of Hotelling (1949), Clawson and Knetsch (1966), McConnell (1985), Shaw (1991), Karasin (1998) etc. for travel cost method and also the works of Ciriacy-Wantrup (1947), Hanemann (1984), Hanley (1989), Park et al. (1991), Park and Loomis (1992), Arrow et al. (1993), Christie et al. (2006), Christie (2007), Christie and Azevedo (2009) etc. for CVM. We have summarised the major issues of all those works in terms of an overview of different methods of economic valuation of the environment. We have focused in detail on CVM and have demonstrated it with the help of two case studies. Thus, our work is an important contribution in the literature on economic valuation for the environment in the sense that it is a supplement to the earlier works in terms of methodology for CVM and also in terms of a practical application of CVM for forestry and drinking water.

The chapter is organised in the following manner. Section 14.2 deals with a brief overview of the different methods of economic valuation of the environment. Section 14.3 focuses on a detailed analysis of CVM which explains its theoretical background. Two case studies are demonstrated in section 14.4. Finally, the concluding remarks are summarised in section 14.5.

2 A Brief Overview of Different Methods of Economic Valuation of the Environment

When we consider economic values for environment, we usually classify the total economic value into two parts like use value and non-use value. Use value implies direct use of the environment or natural resource by an individual. In this case, the individual is interested to contribute something to protect the loss of ambient environment or to conserve the natural resource. Non-use value on the other hand implies that the individual does not use the benefits of the environment or is not dependent on the extraction of the natural resource but feels sad if there is destruction of the resource. Hence, the individual in this case also wants to pay some amount if a fund is collected to conserve the resource. Given that use value is based on direct market-based valuation we focus here on two major methods involved in this type of valuation. These are travel cost method (TCM hereafter) and hedonic pricing method (HPM hereafter).

TCM has been first introduced by Hotelling (1949) and after that it has been modified by Clawson and Knetsch (1966). Since then, it has been a widely accepted method of valuation and has been used mainly to value the recreational services of a recreational site or to value the changes in environmental quality of a recreational site. There are three approaches to TCM and they are zonal TCM, individual TCM and random utility TCM. We shall not discuss here random utility TCM in detail as random utility is most popularly used in the context of CVM and we would like to discuss it in the context of that method. Zonal TCM is mainly based on secondary data and is used to value recreational services or environmental quality of the recreational site. In this method, we need to classify the zones from which the visitors visit to the recreational site and they are made on the basis of geographic divisions like country or state or regions or towns or locality. These are done on the basis of concentric circles where the centre shows the location of the recreational circle. If the geographical region, from which trip has been made, lies quite far from the site then the zone lies in one of the outer circles. In this case, we collect information on number of visitors from each zone in the previous year. We next calculate the visitation rate per 1000 population in each zone. It is nothing but total visits per year from a zone divided by zone's population in thousand. To calculate the total travel cost per trip the average cost per trip to the site for each zone has to be considered first. It includes average round trip travel distance and travel time. For example, a zone very near to the recreational site implies zero average travel cost and travel time per trip. We multiply average travel distance for each zone by standard cost per kilometre (or per mile). Similarly, one can multiply average time for each zone by the cost of time.[3] The travel and the time costs are to be added after this to get the total cost per trip. We next regress the visitation rate on total travel cost from each zone to get the 'trip generation function'. On the basis of the 'trip generation function', we can construct the demand function for a site (which depends on hypothetical entry fee against visits). Value of a site is the area under the demand curve.

Zonal travel cost rests on some restrictive assumptions like population in zones are homogeneous, people from each zone face same travel costs, travel is viewed in the same way as an entry fee etc. The individual and random utility TCM address many of these assumptions. Individual TCM is similar to that of zonal TCM so we need not deal with its methodology in detail. However, individual TCM uses field survey data from individual visitors from each zone rather than average (secondary) data from each zone to estimate the 'trip generation function'. Individual TCM requires more data than zonal TCM and is more complicated but no doubt it is more precise. In case of random utility TCM the individuals pick the site they prefer out of all the sites and it involves a trade-off between site quality and price to be paid to visit the travel site. It helps to locate the factors that determine which site is to be selected. The method requires information about site quality which allows estimation of value of changes in quality of the site.

TCM is best suited for sites which draw only day-trip visitors. However, when there are multi-destination trips or when people stop at the site because they happen

[3] The cost of time can be calculated in various ways. One common way is to consider the hourly wage rate that is foregone by the individual due to the visit. It is nothing but the concept of opportunity cost in Economics.

to pass by it, TCM is not an appropriate method for valuation. The issue of calculation of time cost also raises questions.

We now pass on to the other method HPM that deals with urban property prices (or urban housing) on the basis of the assumption that as environmental quality changes property prices change. It is based on Lancaster's (1966) characteristics theory of value. It implies people value the characteristics of a good rather than the good itself. The property prices reflect the value of a set of characteristics, including environmental characteristics that people take into account at the time of purchasing the property. The method is generally applied to housing market where the demand for housing depends on a number of characteristics that a particular site possesses. In terms of this method the price of a house depends on house-specific characteristics, location-specific characteristics and also on environmental factors that prevail in the particular locality. The demand side of HPM takes into account the bid function and the WTP for the housing, which is derived from expenditure function of the consumer that we find in case of standard consumer theory. The supply side is obtained from production theory. We obtain the offer curve of the producer on the basis of his profit maximising behaviour. The offer curve is thus a function of non-land input prices, the land price (which is a function of environmental factors) and profit from the sale of the product (housing). The offer function is actually the willingness to accept (WTA) function on part of the producer. We draw the offer function and the bid function for different levels of environmental quality and for any particular transaction to take place the maximum WTP of the consumer must match with minimum WTA of the producer. In the housing market there are different producers and consumers with different bid and offer functions. The hedonic price function is obtained on the basis of the equality of bid and offer functions of different agents and it can be shown that hedonic price is a function of environmental quality. If we take the derivative of hedonic price with respect to environmental quality, we get the marginal price function which we refer to as marginal WTP and it is nothing but the demand function for housing. Since the marginal price function represents the equilibrium path from the transaction data we do not know whether we are estimating a demand function or the supply function or a mongrel function. This is the classical identification problem of simultaneous equation system of econometric theory. However, the identification problem can be solved as the demand function and the supply function, apart from the common environmental factor, depends on many other factors which are totally different.

HPM is relatively straight forward and data for housing and property are relatively easily available. However, this method is more related to the property market and relatively less related to environmental good. The method depends on the knowledge of the individuals about the linkages between environmental values and property. The results are dependent on model specification and huge data set. Moreover, the method can only be applied for environmental goods which have use value and it cannot be applied for non-use values.

So far, we have discussed about direct use value of the environment. It depends on actual use of the environment. For example, use of safe air, free drinking water, visit to a lake or park for recreational purposes etc. The other type of value is non-use value, which is broadly classified as existence value and option value. Existence value implies when the individual is not using the environment directly though is willing to pay something to conserve the environment. Option value means the environment is not used in the present generation but is left for future use. It consists of future use value, bequeath value and vicarious value.

The most important method in the context of stated preference method using hypothetical market in case of non-use value is CVM. We shall discuss in detail about the theoretical background of CVM in the next section.

3 CVM: Theoretical Background

Contingent valuation surveys were first proposed in theory by Ciriacy-Wantrup (1947) as a method for eliciting market valuation of a non-market good. The first practical application of the technique was performed in 1963 when Davis used surveys to estimate the value hunters and tourists placed on a particular wilderness area. He compared the survey results to an estimation of value based on travel costs and found good correlation with his results. This type of contingent valuation (CV) exercise has several drawbacks. In response to criticisms of contingent valuation surveys, a panel of high-profile economists (chaired by Nobel Prize laureates Kenneth Arrow and Robert Solow) was convened under the auspices of the National Oceanic and Atmospheric Administration (NOAA) in 1990.

The NOAA panel tried to remedy this problem, by providing guidelines for use of the CVM. Among the various recommendations the NOAA panel members have recommended that conservative estimates of value are to be preferred and one important consequence of this decision is that they have recommended that contingent valuation surveys should emphasise more on willingness to pay to protect the good rather than willingness to accept to consider compensation for the loss of the resource.

As a result, current contingent valuation methodology corrects various shortcomings of its earlier measures. In the context of application of CVM, obtaining of bids in the context of field survey is the most important part of the study. A face-to-face interview by well-trained interviewers is needed for effective data collection. Individuals are asked to state their maximum WTP or minimum WTA for a proposed change in the environmental quality. To quantify the precise amount fruitfully, a number of alternative strategies are usually applied and two most important strategies in this context are:

(a) Closed-ended referendum
(b) Open-ended referendum

Average WTP calculation for a closed ended referendum is different from that of an open-ended bid. In case of open-ended bid, since exact information about maximum WTP is available, the average is calculated by using either arithmetic mean or median. Since the lower bids are more likely than higher bids for environmental goods (for free-riding problem), we find median WTP < mean WTP. But in case of dichotomous choice type closed-ended bidding, it is recognised that though the consumer knows his preference completely, it is not totally observable to the researchers. Hence, a random utility model (RUM) is chosen to represent the choice decision where the probability of a ‘yes’ response to a bid can be derived by applying logit estimation technique.

In this chapter, in the next section we shall deal with application of CVM for forestry and drinking water for the Purulia district of West Bengal. We now want to develop the theoretical background to consider the econometric applications of CVM for forestry and drinking water. In our work, single bounded dichotomous choice has been considered in closed-ended referendum. Here, one particular bid is shown to each respondent and the responses are in the form of either ‘yes’ or ‘no’ that is whether he is going to accept the bid or not. Accordingly, few statistical tests have been done to derive average willingness to pay. Next, open-ended referendum has also been considered and convergent validity test on the basis of above two results is also performed. In our questionnaire, we had mainly focused on asking the respondents about the amount of money they are willing to pay both for further development of the forestry sector and availing the facility of drinking water supply directly to houses, apart from asking about their socio-economic conditions which has been used as variables in our CVM study.

In this section, the focus will be on the methodological part related to dichotomous choice (DC) estimation under CVM and our task is to show the methodology of obtaining economic welfare from the dichotomous choice model. A RUM has been used for this purpose. This methodological aspect is widely used in the context of the literature on CVM. We have also followed this methodology as used in the literature and we are mentioning it in brief in the context of the present chapter.[4]

This model closely replicates the choices individuals face in a market situation. The respondent is presented with a specific monetary value (e.g. Rs. *X*) for a policy change and he/she is asked to make a judgement of accepting or rejecting the offer. The size of *X* is randomly varied across the sample of a study.

The DC elicitation method provides us only limited amount of information about the WTP value of the respondents, namely, ‘YES’ or ‘NO’ answer to a particular bid and nothing more.

If bid amount (X) > WTP, then the response is ‘NO’
If bid amount (X) ≤ WTP, then the response is ‘YES’

We now consider the random utility version of the model. An individual respondent will respond with ‘YES’ if his/her utility from the additional forestry conservation measure is larger than or equal to her utility compared to status quo position; and ‘NO’, otherwise.

$$\left(U_1 - U_0\right) \geq 0, \quad \text{the individual will accept to pay the bid } X \tag{14.1}$$

[4]We have followed the methodology as shown by Haraou et al. (1998).

$$\left(U_1 - U_0\right) < 0, \quad \text{the individual will reject to pay the bid } X \tag{14.2}$$

The utility U of the individual is not directly observable (hence the differences are also not directly observable). However, its determinants are observable. Under the two different scenarios, one with the acceptance and other with the rejection of the bid, the following specification of the utility function can be put forward:

$$U_1\left(1, y - X; S\right) = V\left(1, y - X; S\right) + e_1 \tag{14.3}$$

$$U_0\left(0, y; S\right) = V\left(0, y; S\right) + e_0 \tag{14.4}$$

where $V(.)$ is the utility function without random element and $U(.)$ is the utility function with random element. It is to be noted that in equations (14.3) and (14.4), we find y = total income; 1= acceptance of the bid; 0 = rejection of the bid; S = other socio-economic features; e = random error component due to the limited knowledge of the utility model of the individual by the analyst.

From equations (14.3) and (14.4), we can write

$$\Delta U = \Delta V - e \tag{14.5}$$

where, $(U_1 - U_0) = \Delta U$, $(e_0 - e_1) = e$ and $[V(1, y - X; S) - V(0, y; S)] = \Delta V$, given equation (14.5), the inequalities (14.1) and (14.2) can be written as,

$$\Delta V \geq e \rightarrow \text{Acceptance of X} \tag{14.6}$$

$$\Delta V < e \rightarrow \text{Rejection of X} \tag{14.7}$$

There are two types of models for estimating the mean WTP value from the DC bids—the probit and the logit models. Here, we have considered a logit model (logistic distribution of the error term) for our purpose.[5]

The probability that the individual agrees to accept the bid is therefore:

$$P\left(\text{accept}\, X\right) = P\left(Y = 1\right) = P\left(e \leq \Delta V\right) = F\left(\Delta V\right)$$

where Y is the observed dichotomous variable, acceptance = 1, refusal = 0.

Assuming that the random variable e follows a logistic probability distribution we can write:

$$P\left(\text{accept}\, X\right) = F\left(\Delta V\right) = 1 / \left[1 + \exp\left(-\Delta V\right)\right]$$

[5] The choice of the model depends on the probability distribution of the error term where probit is used if the error term follows a normal distribution and logit is used if the error term follows a logistic distribution. However, most of the studies that used DC format follow the logit model since the difference between the two is minor and the logistic function is simpler to deal with.

When the individual accepts to pay the proposed bid *X*, its means that the maximum WTP is greater than the proposed bid *X*. The probability of acceptance, given a bid *X*, is the probability of individual WTP ≥ *X*. Therefore, we can write:

$$P(\text{accept}\, X) = P(\text{WTP} > X) = 1/\left[1 + \exp(-\Delta V)\right]$$

This means that the probability the WTP is less than or equal to *X* is:

$$P(\text{WTP} \leq X) = G(X) = 1 - 1/\left[1 + \exp(-\Delta V)\right]$$

where *G* (*X*) is the probability distribution of the WTP.

The mean of the WTP distribution is commonly assumed to be indicators of the individual WTP. The mean of the maximum WTP can be calculated using the formula that relates the mean of a random variable to its probability distribution:

$$\text{E}(\text{WTP}) = \int_0^\infty \{1 - G(X)\}\, dX$$

We also need to specify the theoretical model into a functional form from which the unknown parameters can be estimated. Now we move to econometric analysis of CV results. On the basis of this methodology, we have considered econometric analysis of CVM.

4 Two Case Studies: Forestry and Drinking Water

4.1 Forestry

We have valued forest resources in the Purulia district of West Bengal through CVM in order to conserve the ecosystem, further improvement of forestry and also for sustainable development.[6] For selection of villages we have followed stratified sampling and for selection of households we have followed partly stratified and partly random sampling. The number of respondents interviewed in the three villages is 200 and it has been seen that the response rate is 100%, which is high. A higher percent of response rate in our study can be considered an unconventional but good outcome in a developing country.[7]

[6] See Chatterjee and Gupta (2018), Chatterjee (2017a), Chatterjee (2017b) and Saha (2016) in this context.

[7] We attribute this high response rate to the '*face-to-face in-person interviews*' that we have conducted, as suggested by the NOAA panel as developed by Arrow et al. (1993). One more reason for such high response rate could be the fact that we have seen the degree of forest dependency is 100% for the people of our surveyed areas. So, regarding upliftment of forestry, they might be very eager to respond in their own interest.

We first of all want to focus on the bidding game in the context of CVM. It constitutes the most important part of CVM under closed ended referendum. From demand theory we find that usually the level of acceptance is found to be high for the lower bids and it is low for the higher bids. For CVM it is important to determine the bid first and then to determine how these bids are to be shown to the respondents. The bids that we have considered are Rs. 2, Rs. 5, Rs. 8, Rs. 10, Rs. 15 and Rs. 25 (in terms of per month). Here, the bids are determined after discussing with the local people through pilot surveys which give us an idea of the maximum and minimum amounts that we should put forward to the respondents as bid amounts. The next step is to identify the 'valid' responses out of 200 respondents. For this, we have followed a strategy in the final survey. We have categorised the respondents in three bid groups, namely, *low*, *medium* and *high*. We have applied single-bound dichotomous choice CV method. The *low* bid group implies bids of Rs. 2 and Rs. 5 per month. For *medium* bid group the bid amounts are Rs. 8 and Rs. 10 per month. For *high* bid group the bid amounts are Rs. 15 and Rs. 25 per month.

We now explain how bids are selected under closed-ended referendum under single-bound dichotomous choice CVM. First of all, a dice has been thrown to each and every respondent. If the outcomes are '1' or '6' for a particular respondent, then the respondent is considered to fall under *low bid group*. Next, again the same dice has been thrown for the *second time* to the respondent and if the outcomes are 'odd numbers', that is, if the outcomes are any one of the three possible odd numbers −1, 3, 5, then the respondent has been categorised to accept the bid of Rs. 2, if the outcomes are 'even numbers', that is, 2, 4 or 6, then the respondent has been offered the bid of Rs. 5. In this case, the respondent has been asked whether he or she is willing to accept the bid Rs. 2, if the answer was 'YES', then we consider the bidding amount to be Rs. 2. If the answer is 'NO' we consider the respondent as a *protest bidder*.[8] Similarly, when the dice has been thrown in the front of the respondent for the *first time* if the outcomes are 2 or 5 then the particular respondent is categorised as a part of *medium bid group*. In the next step again, just described above, the dice has been again thrown for the *second time* and if the outcomes are any of the three possible 'odd numbers', then the respondent has been offered to accept Rs. 8, otherwise Rs. 10, in case the outcomes are any of the three possible 'even numbers' of the dice. Here also, we find that if the answer is 'YES' for any of the two bids as mentioned above then we can determine the bidding amount. If the answer is 'NO' for each of the above-mentioned two bids then we again consider the respondents as *protest bidders*. Lastly, if the outcomes from throwing dice for the *first time* are '3' or '4' to any respondent, then the respondent has been categorised in the *highest bid group*, that is, in the group of bids Rs. 15 or Rs. 25. Then again, the above-mentioned process has been followed after throwing the dice for the *second time.* In this way, a particular bid has been shown to a particular respondent from different events when the events are mutually exclusive, equally likely and independent. So, for a

[8]Protest bidders are those who do not prefer the stated programme and therefore provide zero WTP value.

particular respondent, we have thrown a dice twice, firstly, for randomly selecting the bid-group for each and every respondent and, secondly, for randomly selecting the amount of bid that was offered to the respondent.[9] In this way, a particular bid has been shown to a particular respondent from different events when the events are mutually exclusive, equally likely and independent. For the open-ended segment of our study, we have directly asked the respondents about their maximum willingness to pay (Max WTP).

Our present survey reflects that 67 respondents out of 200 respondents are not willing to accept the bids and thus we will consider 133 respondents as *'willing'* respondents and 67 respondents as *'non-willing'* for our further analysis. Here, 67 *'non-willing'* participants are considered as *'protest bidders'* (Bateman et al., 2002). It has been seen that these bidders give 'zero WTP values' but still have preference to participate in the programme and enjoy the benefits of it. So, we cannot omit those respondents. The respondents have responded to the offered bids in terms of either 'YES' or 'NO' to a concerned bid.

We now want to consider the econometric specification of the DC model for a closed-ended referendum. The purpose is to derive the mean WTP for the forestry of the dryland areas. To estimate the WTP, we have used a logit model and we have derived the values for the DC bids used for the respondents.

The logit model[10] used for the study contains the following variables.

Dependent variable: $\ln = \dfrac{p_i}{1-p_i}$

Given, p_i as the probability of WTP amount greater than or equal to an assigned bid. $\ln = \dfrac{p_i}{1-p_i}$ is the log odds ratio.[11]

The independent variables used in this model are described in terms of Table 14.1.

Table 14.1 Description of independent variables of the model

DC bid	Bids vector of Rs. 2, Rs. 5, Rs. 8, Rs. 10, Rs. 15 and Rs. 25
Income	Total monthly income from all sources
Family size	Household size
Age	Age of the respondent
Edu yrs	Total years of education of the respondent
Sex	Dummy variable. 0 for males and 1 for females
Caste	Dummy variable. 0 for General Caste, 1 for OBC, 2 for SC and 3 for ST
Dom animals	Dummy variable. 0 for having no animal and 1 for having any.

[9] This procedure of throwing a dice twice before offering a particular bid to the respondent was followed for bringing simplicity in the survey process.

[10] Most of the variables used in this model have been selected after going through the literature on CV technique.

[11] The ratio of probability of willingness to pay (P_i) and non-willingness to pay ($1 - P_i$). It is to be noted that as P_i increases the log-odds ratio increases.

The independent variables are the socio-economic variables and are more or less common for the CVM studies. We have used several socio-economic aspects as independent variables by using dummy. It has been done because in a poverty-stricken, backward area it is expected that these aspects can play an important role in the response of the respondents. The results related to valuation of forestry in terms of logit model are reported in Table 14.2. From Table 14.2, we find that age and sex are insignificant but others are significant. Among the significant variables, dichotomous choice bid has a negative sign before it, indicating the fact that for a unit change in the bid, the probability of willingness to pay or the log-odds ratio falls. The negative coefficient for the bid-vector can be explained on the basis of the fact that as bid value rises the probability of 'YES' (or acceptance) decreases. The negative sign of caste signifies the fact that people of General Caste are more willing to contribute and as we move from General Caste community to OBC, SC and ST respectively, this willingness to contribute decreases. This is also quite expected because, generally, people of so-called lower castes (SC, ST) are very poor. Income has a positive impact on WTP because it is expected that with an increase in income, people of Purulia would want to pay more for conserving the source of their livelihood. This result is irrespective of all types of income groups.

In Table 14.2, we find that larger the family size higher is the number of working members who are dependent on forest. So, the variable family size has a positive

Table 14.2 Results of the logit model in case of forestry

Variable	Coefficient	Marginal effects(dY/dX)
DC bid/ close-ended bid	−0.000651*** (−9.95)	−0.0000743*** (−5.86)
Income	0.000235*** (5.81)	0.0000289*** (3.73)
Family size	0.006542*** (11.73)	0.0020967*** (8.73)
Age	0.138366 (0.96)	0.001098 (0.71)
Edu yrs	0.903571** (2.01)	0.194257** (1.97)
Sex	0.902011 (1.31)	0.171291 (1.43)
Caste	−0.005011*** (−7.09)	−0.000359*** (−4.89)
Dom animals	0.317329** (2.09)	0.441937** (1.94)
Constant	−6.207381*** (−7.98)	
Log-likelihood	−230.2093	The terms in the parentheses for both coefficient and marginal effects are the *t*-values
LR chi-square	317.98	
Prob > chi-square	0.000	
Pseudo R^2	0.5423	
Total no. of observations	200	

*** denotes significant at 1% levels.
** denotes significance at 5% levels.
Source: Author's estimation.

sign before its coefficient. The coefficients of DC bid, income and family size are highly significant (at 1% level of significance). Education has a positive sign and is significant at 5% level. This is also expected because educated people are more aware about the protection of the forestry. Domestic animal is used as a dummy of economic asset. The coefficient having a positive sign indicates the fact that in the presence of domestic animal, people are in a better economic condition than others. Also, the fact that people having livestock get their fodder from the forestry and use forest as the grazing land for free of cost may have contributed to the positive sign of this coefficient. Hence, their WTP is quite high which justifies a high value of the coefficient for domestic animals which is highly significant with a positive sign. The goodness of fit of the model used is usually judged by the value of pseudo-R^2. In our model, the value of pseudo-R^2 is 0.5423. So, our model gives a good fit. It is important to examine whether some degree of multi-collinearity is present in the model as it is common in any cross-section data. The variance inflationary factor (VIF)[12] and the tolerance[13] for the model show that the models do not suffer from severe multi-collinearity problem as the value of 'mean VIF' is 3.99 which is well below the value of 5.[14] The marginal effects for the logit equation have also been estimated. It shows the rate of change in the probability of willingness to pay due to change in the value of an independent variable X_j ($j = 1, 2, \ldots, n$). This is shown in Table 14.2. From Table 14.2, we find that as income changes by one unit, holding other factors constant, the probability of WTP also rises; same explanation applies in case of variables like years of education, family size and domestic animals. The opposite explanation applies to the variables like dichotomous choice bid and caste. For these variables, one unit of change causes the probability to accept an assigned bid fall.

Our next task is to estimate the WTP in the case of closed-ended referendum under dichotomous choice model. The mean WTP of our model is Rs. 12.73 per month, with lower bound of Rs. 8.30 and upper bound of Rs. 19.83. These are shown in Table 14.3.

Table 14.3 Estimation of mean WTP for forestry in Purulia (DC model under closed-ended referendum)

Measure	WTP	LB	UB
Mean	12.73	8.30	19.83

Achieved significance level for testing H_0: vs. H_1: WTP>0.
LB: lower bound; UB: upper bound.
Source: Author's estimation.

[12]Variance inflationary factor (VIF) measure how much the variance of the estimated regression coefficients is inflated as compared to when the predictor variables are not linearly related. This is used to describe how much multi-collinearity (correlation between predictors) exists in a regression/logit analysis. When there is no collinearity, VIF will be 1.

[13] 1/VIF is known as tolerance.

[14]As 'the rule of thumb', if 1 < VIF < 5, it implies variables are moderately correlated and if 5<VIF<10, then the variables are highly correlated.

Though the mean WTP, in general, appears to take a low value, given the backwardness of our study area and also given the fact that a large portion of the respondents that have been considered for our study lie below the poverty line, the mean WTP figure of Rs. 12.73 per month to conserve the forests in the Purulia is quite reasonable. In other words, one can say that the forest-dependent communities in Purulia are willing enough for conservation and further development of the forestry.

So far, we have discussed closed ended referendum; we now want to examine the determinants of WTP under open-ended referendum. Here we consider WTP for forest conservation when open ended bids are offered by the respondents. In this case, we use OLS regression techniques to determine the WTP and the regression result is summarised in Table 14.4.

From Table 14.4, we find that the variables, which are significant in logit model are also significant here, with same signs (except for family size) before their coefficients.[15] We have used simple OLS estimation for the open-ended part. The value of adjusted R^2 implies the fact that more than 49% of the variation in dependent variable is explained by the independent variables included in the model (adjusted with respect to degrees of freedom). So, in terms of cross-section data one can say that it is a well-fitted model. Also, the *t*-values suggest that most of the parameter estimates are significant at 1% level. It is only years of education which is significant at 5% level. From Table 14.4, we can easily calculate the open–ended (maximum) mean WTP and it has been calculated to be Rs. 10.97 per month. If we consider the simple average of dichotomous choice WTP and open-ended WTP we find that the value of *'true WTP'* for conservation of forestry in the Purulia is Rs.11.85 (approximately Rs.12) per month.

Table 14.4 Regression results of open-ended referendum (Forestry in Purulia)

Variables	Coefficients	t values
Constant	−5.73641***	−5.09
Income	0.080935***	17.83
Family size	−0.450987 ***	−4.31
Age	0.054321	1.07
Edu yrs	0.473189**	2.05
Sex	0.309181	0.98
Caste	−0.865730***	−9.32
Dom animals	0.733493***	8.33
Dependent variable: Max WTP (open-ended maximum WTP).		
$N = 200$, $F = 122.54$, Prob > $F = 0.000$, adjusted $R^2 = 0.4973$.		

*** denotes significant at 1% level,
** denotes significant at 5% level.
Source: Author's estimation.

[15] The only reason before the family size may be due to the fact that large family size can cause relatively less per-capita income and hence reduces the maximum WTP to conserve forests.

We have tested for anchoring bias (called the convergent validity test) by comparing the two mean WTPs and have conducted the paired-*t* test for this purpose. From the above two analyses, we have got 'two willingness to pay' (one from logit model and the other one from OLS model). We have tested whether these two WTPs converge or not by performing the convergent validity test. Convergent validity refers to the degree to which two measures of constructs, that theoretically should be related, are in fact empirically tested to be related. From the perspective of the present study convergent validity for the two formats (viz. open-ended and single bounded dichotomous choice) is an important issue primarily for two reasons—first, to check whether the two formats lead to statistically different values for the WTP and second, to check whether *anchoring bias* plays a significant role such when the convergent validity is disturbed. The null hypothesis here refers to the difference of two mean WTPs (open ended and dichotomous choice) is zero against the hypothesis it is not. Here, the difference between 'two WTPs' is −1.63 and the value of paired *t*- statistic is –6.73 with 199 degrees of freedom. It is significant at 1% level. So, two mean WTPs are significantly different. It implies that anchoring bias exists in our CVM exercise for forestry in Purulia. This anchoring bias may be due to the fact that the people of the Purulia are not highly educated and also they do not have the proper perception about the issue of sustainability of forests. From our study, we find that in Purulia the 'true WTP' for conserving forests is approximately Rs. 12 per month.

4.2 Drinking Water

We now consider the case study related to use of CVM for drinking water in the Purulia district of West Bengal. Drinking water is usually considered to have 'use value' rather than 'non-use value', though CVM requires those resources and environmental goods, which have non-use values. The question that arises then is how drinking water can be considered for CVM. The logic for this is very simple. Though 'drinking water' has use value it is to be noted that the arrangement of 'in house drinking water facility' is almost nil in our study area, Purulia and people have to depend on '*common pools*' like tube wells, waterfalls and watersheds for drinking water in this region. As drinking water is not directly used through 'in house drinking water facility' in our study area conservation of watershed and waterfalls helps to provide supply of fresh and safe drinking water to the households. So, 'conservation and use' of drinking water in our study region implies overall conservation of water facility in the dryland area and it is not only considered as 'use value' but is also treated as a 'non-use value'. Thus, application of CVM is justified for drinking water.[16] For this part of the case study methodology, survey-design, bidding-process, number of bids offered—everything applied for evaluating forestry remains

[16] See Nam and Son (2004), Pour and Kalashami (2012), Chatterjee (2017a and 2017b) etc.

Table 14.5 Results of estimated logit model

Variable	Coefficient	Marginal effects(dY/dX)
DC bid/ close-ended bid	−0.0876543*** (-9.73)	−0.021098*** (-4.20)
Income	0.0031276*** (10.09)	0.001098*** (9.43)
Family size	−0.7955039*** (-7.21)	−0.106567*** (-6.85)
Age	0.0012448 (0.09)	0.000028 (0.007)
Edu yrs	0.3098711*** (3.01)	0.098659*** (3.73)
Sex	−0.1898675 (−0.99)	−0.087654 (−0.43)
Caste	−0.324321*** (-6.78)	−0.786453*** (-3.439)
Dom animals	0.788741** (2.03)	0.213132** (2.01)
Constant	−2.789333*** (−5.59)	
Log-likelihood	−229.87803	The terms in the parentheses for both coefficient and marginal effects
LR chi-square	321.97	
Prob > chi-square	0.000	
Pseudo R^2	0.6123	
Total no. of observations	200	

*** denotes significant at 1% levels.
** denotes significance at 5% levels.
Source: Author's calculations.

unchanged for evaluating drinking water also, including the variables used for econometric analysis. So, without going into all those details, we have briefly summarised our results for this part. The estimated result of the logit model is shown in terms of Table 14.5.

From Table 14.5, we find that the variables age and sex are insignificant but others are significant. The probability of willingness to pay falls with a unit increase in the bid. People of General Caste are more willing to contribute compared to OBC, SC and ST, respectively. This is also quite expected because, generally, people of so-called lower castes (SC, ST) are very poor. Income has a positive impact on WTP. Family size, having a negative co-efficient, signifies the fact that larger families have more members to fetch the water from the nearby resource and so their probability to pay falls with a unit increase in the bid. Expectedly, education bears a positive coefficient. Domestic animal is used as a dummy of economic asset, bears a positive impact.

We can say that our estimated model gives a good fit, as the value of pseudo-R^2 [6]is 0.6123. The variance inflation factor (VIF) and the tolerance for the model have been estimated and the reported results (mean VIF 3.23) show that the model does not suffer from severe multi-collinearity problem. We next proceed to find the mean willingness to pay of the close-ended referendum under dichotomous choice mode. This is given in Table 14.6.

Table 14.6 Estimation of mean WTP (DC model under closed-ended referendum)

Measure	WTP	LB	UB
Mean	11.28	5.98	16.87

Achieved significance level for testing H_0: WTP ≤ 0 vs. H_1: WTP > 0.
LB: lower bound; UB: upper bound,
Source: Estimated by the author.

Table 14.7 Regression results of open-ended referendum

Variables	Coefficients	t values
Constant	−5.674307***	−7.30
Income	0.030773***	17.77
Family size	−0.2572601***	−3.65
Age	0.0224171	0.97
Edu yrs	0.7071343***	6.07
Sex	0.8665087**	−4.09
Caste	−0.5788909***	−5.35
Dom animals	1.227722***	3.73
Dependent variable: Max WTP (open-ended maximum WTP)		
N = 200, F = 158.78, Prob > F = 0.000, Adjusted R^2 = 0.6541.		

*** denotes significant at 1% levels, ** denotes significant at 5% levels.
Source: Author's calculation.

The mean WTP of our model is Rs. 11.28 per month, with lower bound of Rs. 5.98 and upper bound of Rs. 16.87 per month. Given the backwardness of our study area and also given the fact that most of the stakeholders considered for our study lie below the poverty line, the mean WTP figure of Rs. 11.28 per month for getting drinking water facilities at home is quite reasonable. The marginal effects model for the above logit equation have also been estimated and shown in the last column of Table 14.5. The meaning of the values of marginal effects follows the same explanation as that of forestry in section 14.4.1.

We have also focused on the open-ended referendum. So, here the concept of probability to WTP does not apply, rather the concept of maximum WTP does. The results are shown in Table 14.7.

From Table 14.7, we observe that the variables which are significant in logit model are also significant here, with same signs before their coefficients. Additionally, sex as a variable has become significant here, but it is insignificant in logit model. So, male respondents are more willing to pay than females. High value of R^2 implies the fact that almost 65% of the variation in dependent variable is explained by the independent variables included in the model. Here, the mean VIF is 3.10. In our OLS model, the mean willingness to pay is Rs. 10.87 per month. So, The 'true WTP' turns out to be Rs. 11.08 per month for conservation-cum-availability of drinking water directly to the houses in Purulia.

The result of the convergent validity test gives the t value –4.02, with 199 degrees of freedom. This result vividly indicates that the mean WTPs obtained from the two different formats are significantly different implying that anchoring bias has occurred in the responds of the respondents.

5 Concluding Remarks

In this chapter, we have analysed the basic issues related to economic valuation of the environment with special reference to CVM. We have considered here two case studies related to application of CVM and they are related to forestry and drinking water for Purulia district of West Bengal. In this study, we have observed that as the people of Purulia are heavily dependent on forests for their livelihood, they are very much willing to conserve the forest base of the region. This is reflected from the high willingness to pay by the people for forestry in this region. Forestry is the main available renewable natural resource as well as source of livelihood to a large number of backward, tribal populations in this region. People of Purulia suffer heavily from the scarcity of drinking water and hence they also value conservation-cum-safe drinking water availability at a very high level. This is evident from little variation between WTP for forestry and drinking water. The figure is Rs. 12 per month for forestry and Rs. 11.08 per month for drinking water, Hence government should take initiative not only to improve the condition of the stakeholders associated with forestry in this region by promoting conservation of forests but also it should take special initiative for supply of drinking water through conservation of watersheds.

Acknowledgements Some parts of the present work is related to an earlier research of the second author, though the present study is widely different from his earlier research. The authors are indebted to Professor Kausik Gupta, Department of Economics, University of Calcutta, for his valuable comments and suggestions on an earlier draft of the paper. However, remaining errors, if any, that exist in the paper are the sole responsibility of the authors.

References

Arrow, K., Solow, R., Portney, P.R., Leamer, E.E., Radner, R. and Schuman, H. (1993). Report of the NOAA panel on contingent valuation. *Federal Register*, **58(10):** 4601–4614.

Bateman, I., Carson, R.T., Day, B., Hanemann, W.M., Hanley, N., Hett, T., Jones, A., Loomes, G., Mourato, S., Ozdemiroglu, E., Pearce, D.W., Sugden, R. and Swanson, J. (2002). Economic Valuation with Stated Preference Techniques: A Manual. Edward Elgar, Cheltenham.

Chatterjee, N. (2017a). Willingness to pay for drinking water in some selected dryland areas of West Bengal: A contingent valuation approach. *Vidyasagar Univ J Econ*, **XIX: 2014–2015:** 14–37.

Chatterjee, N. (2017b). Dependency on Natural Resources in Dryland Areas of West Bengal. Unpublished Ph.D. Dissertation, Department of Economics, Rabindra Bharati University, Kolkata, India.

Chatterjee, N. and Gupta, K. (2018). A dynamic model of forestry for the dryland areas of West Bengal. *Economic Affairs*, **63(2):** 557–567.

Christie, M., Hanley, N., Warren, J., Murphy, K., Wright, R. and Hyde, T. (2006). Valuing the diversity of biodiversity. *Ecol Econ*, **58(2):** 304–317.

Christie, M. (2007). An examination of the disparity between hypothetical and actual willingness to pay for red kite conservation using the contingent valuation method. *Can J Agric Econ*, **55:** 159–169.

Christie, M. and Azevedo, C. (2009). Testing the consistency between standard contingent valuation, repeated contingent valuation, and choice experiments. *J Agric Econ*, **60(1):** 154–170.

Ciriacy-Wantrup, S.V. (1947). Capital return from soil. Conservation practices. *J Farm Econ*, **29:** 1189–1196.

Clawson, M. and Knetsch, J. (1966). Economics of Outdoor Recreation. John Hopkins University Press, Baltimore.

Follain, J.R. and Malpezzi, S. (1979). Dissecting Housing Value and Rent: Estimates of Hedonic Indexes for Thirty Nine Large SMAs. The Urban Institute, Washington, D.C.

Freeman, A.M. (1979). The hedonic price approach to measuring demand for neighborhood characteristics. *In:* Segal, D. (ed.), The Economics of Neighborhood. Academic Press, New York.

Hanemann, W.M. (1984). Welfare evaluations in contingent valuation experiments with discrete responses. *Am J Agric Econ*, **66:** 332–341.

Hanley, N. (1989). Valuing rural recreation sites: An empirical comparison of approaches. *J Agric Econ*, **40:** 361–375.

Haraou, P., Markandya, A., Bellu, L. and Cistulli, V. (1998). Environmental Economics and Environmental Policy: A Workbook. Economic Development Institute (EDI) of World Bank.

Harris, A.H. (1981). Hedonic technique and valuation of environmental quality. *In*: Kerry Smith, V. (ed.), Advances in Applied Microeconomics. JAI Press, Greenwich, Connecticut, pp. 31–49.

Hotelling, H. (1949). Letter in 'An Economic Study of Monetary Evaluation of Recreation in National Parks'. National Park Service, Washington, DC.

Karasin, (1998). The Travel Cost Method: Background, Summary, Explanation and Discussion. Centre for Economic and Social Studies on the Environment, I'Universite Libre de Bruxelles.

Lancaster, K.J. (1966). A new approach to consumer theory. *J Polit Econ*, **74:** 132–157.

McConnell, K. (1985). The economics of outdoor recreation. *In:* Kneesy and Sweeny (eds), Handbook of Natural Resources and Energy Economics. Elsevier, Amsterdam.

Nam, P.K. and Son, T.V.H. (2004). Household Demand for Improved Water Services in Ho Chi Minh City: A Comparison of Contingent Valuation and Choice Modelling Estimates, *mimeo*. National Bank for Agriculture and Rural Development (NABARD). https://www.nabard.org (downloaded on June 30, 2018).

Park, T., Loomis, J.B. and Creel, M. (1991). Confidence intervals for evaluating benefits: Estimates from dichotomous choice contingent valuation studies. *Land Econ*, **67(1):** 64–73.

Park, T. and Loomis, J.B. (1992). Comparing models for contingent valuation surveys: Statistical efficiency and the precision of benefit estimates. *Univ Nebraska Agric Exp Station J*, **10176:** 170–176.

Pearce, D., Edwards, R. and Harris, A. (1981). The social incidence of environmental costs and benefits. *In:* Wagner, L. (ed.), Readings in Applied Microeconomics. Oxford University Press, Oxford, pp. 369–380.

Pour, M.T. and Kalashami, M.K. (2012). Applying CVM for economic valuation of drinking water in Iran. *Int J Agric Manage. Dev*, **2(3):** 209–214.

Saha, D. (2016). Some Economic Aspects of Forestry in the Sunderbans. Unpublished Ph.D. Dissertation, Department of Economics, Rabindra Bharati University, Kolkata, India.

Shaw, D. (1991). Recreational demand by tourists for saltwater beach days: Comment. *J Environ Econ Manage*, **20:** 284–289.

Willis, K.G. (1980). The Economics of Town and Country Planning. Granada, London.

Chapter 15
Geopolitics in Environmental Discourse

Jayanta Basu

1 Introduction

In December 2019, the Chile climate CoP (Conference of Parties) held at Madrid, Spain had to be extended nearly two days to extract a unanimous decision. This is not an exception but has actually become a routine over the last decade; as most of the climate summits during the period starting with Copenhagen summit in 2009 had spilled over the scheduled period of negotiation to ensure that all countries agree on the much discussed, and hence much diluted, final text coming out from respective summits. While many refer the trend as an indicator of unwillingness of the countries, particularly the more financially and carbon emission rich countries, to contribute adequately in the reduction of carbon footprint of the globe and hence also in temperature rise; it also underlines the increasing importance of geopolitics in global climate negotiation (Basu, 2019a). Over the last decade, climate change has graduated from an environmental issue to a key political agenda as scientists predict a bleak future of the earth unless the countries can roll out a prompt and collective action plan to combat the trend (Basu, 2019b). Not only climate change, environment and its management as a whole has increasingly become more of a political agenda as the relationship between natural resources and 'development', as the paradigm being understood by majority of political parties and their leaders, has become terse with natural resources reserves gradually getting dwindled and weakened, leading more pressure to be built on the resource—politics trade off. It is interesting to find that often the natural resource rich areas are found to be economically poor as politics play a spoilsport. Be in Jharkhand in India or African continent in global context; same trend is noticed. As a matter of fact, environment and

J. Basu (✉)
The Telegraph, ABP, Kolkata, India

Department of Environmental Science, University of Calcutta, Kolkata, India

EnGIO, Kolkata, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_15

management of its resources has always become associated with geopolitical discourse; the trend has only become more visible over the years as awareness is becoming stronger and availability of resources turning scarce (CSE, 2009).

2 Environment Coming Into Prominence

Though the environment, as an issue, has started to receive continual prominence since 1970s when the first global summit on environment was organised in Stockholm; the issue did come up earlier in public domain in sporadic manner. For example, British government had introduced similar environment acts in London and Kolkata (the then Calcutta, and arguably second most important city to British government after London) to prevent smoke nuisance in early part of twentieth century (Basu, 2005); or, the exposure of Rachel Louise Carson, an American journalist cum author who had lot of interest in conservation, regarding the impact of environmental and ecological degradation due to pesticide spread (Atwood, 2012). As a matter of fact, Carson first exposed the not too holy relationship between environmental crisis and vested interest lobby being cushioned by the political powers, which has almost become a trend in current time. Carson's writings not only had advanced global environmental movement but, perhaps for the first time, shed light on the trend and trade-off between environment and politics. In late 1950s, Carson focused her attention to conservation and found how an entire forest area was affected by synthetic pesticides; so much so that the forest had turned silent at the core of spring, which led to her path breaking book *Silent Spring* (1962), that had caught the imagination of common people about environmental virtues and brought the environmental concerns under scanner. *Silent Spring* met fierce opposition from chemical companies, who were supported by a range of political leaders but after a detailed enquiry Carson's allegation was found true and spurred a reversal in United State of America's national pesticide policy, and also led to a nationwide ban on DDT and other pesticides. The act also inspired grass root level environmental movement that led to the creation of the US Environment Protection Agency. However, as mentioned earlier, environmental concerns were further mainstreamed when first major global conference on environment was held at Stockholm in 1972, where various countries agreed to the need of working collaboratively and expeditiously on key environmental issues. India's the then Prime Minister Indira Gandhi joined Stockholm Conference; argued that poverty was key to pollution, a largely political statement and a set of environmental norms, from Water Act to Air Act, were subsequently promulgated in India and environmental governance infrastructure began to take shape (Grieger, 2012). Similar trend was observed in various other countries.

3 Green Geopolitics Gathered Momentum

However, the green geopolitics almost turned on its head in last two decades of twentieth century as a series of major global incidents having strong politico environment connections occurred one after one. The Iraq–Iran war (1980-1988) was the major starting point. The bitter 8-year long war not only devastated both countries to a large extent, but also impacted global environment in a manner that was not being witnessed earlier (McLaren and Willmore, 2003). As both the countries tried to damage, and put to flame, the oil resources of each other for making the opposition economically weak. The huge resultant carbon emission did affect the global environment in an irreversible manner. It's no coincidence that climate change and carbon emissions, terminologies almost unknown till 1980s, became the core issue of deliberation since mid-1990s as the global climate summit, formally known as CoP, started in Berlin to deliberate how the global impact of carbon emission, and warming, can be arrested (UNFCCC, 1995). Two other incidents, both highly devastating, also did shake global environment during the period. Bhopal gas tragedy, considered to be the world's worst industrial disaster that occurred in December 1984 at the Union Carbide India Limited (UCIL) pesticide plant in Bhopal within state of Madhya Pradesh in India (Mandavilli, 2018), not only killed thousands but also clearly showed how the environment violators of such scale were allowed to escape from major punishment with covert and overt support of political powers, that be in a position to negotiate and negate. Ditto in case of Chernobyl nuclear disaster; that happened two years after the Bhopal disaster.

However, the relationship of geopolitics vis-à-vis environmental agendas has never been as direct and critical as found now. Interesting to note, such relationship, growing ever so consistently, is found at all spatial levels; local, regional and global (Boccalett, 2017). Though number of issues can be possibly quoted as examples of the trend, here climate change, air pollution and water issues particularly rivers have been mainly considered to understand the relationship.

3.1 Climate Change

Climate change exposes the relationship of global geopolitics to environment in a manner, not being seen in case of any other agenda. The world has almost divided through the middle in global south and north as the negotiation to minimise carbon emission has currently reached its pinnacle. When Kyoto Protocol was signed in 1997, the industrialised countries accepted responsibility for the historical emission that they had thrust on global atmosphere and accepted to a 5.1% emission reduction by 2012, perhaps not clearly understanding the politico-economic impact of such emission cut. Kyoto all but flopped as a consequence and series of global climate summits since Copenhagen in 2009 failed to push the countries to have significant cut in carbon emission since an agreement was achieved in Paris in 2015, where all countries, irrespective of their carbon emission status, agreed to voluntarily cut down on emission toeing the much used 'common but differential responsibility' principal of UNFCCC. However, even before Paris Agreement is slated to start operating on ground—scheduled to be effective from 2020—questions are started to be raised on its on-ground success. In a body-blow to the agreement, United States under Donald Trump has announced its withdrawal from Paris Agreement and many other countries are trying to find ways and means to bypass the mandate. This is despite that several global scientific studies have clearly mentioned that the emission cut commitments made by various countries under Paris Agreement are not good enough to keep the global temperature rise within the span of 1.5–2°C, and prescribed that the countries should at least treble their emission cut ambition in order to keep the temperature rise within 2°C. Scientists have warned that the temperature rise can be even 3.2°C by the century end if business as usual emission is allowed to continue (UNEP, 2019). However, such stinging prediction has so far failed to push the countries, rather the political powers those run them, into real on-ground action, as they continue to give priority mostly to their narrow political interests and seem to gloss over global and people interest. It is interesting to note various country groups have been formed—based on geographical region (Africa Group, European Union), economic status (BASIC = Brazil, South Africa, India and China), political positioning (G77 and China, Umbrella group) and likewise—to negotiate and often same country is part of more than one such group to extract advantages out of negotiation as much as possible (Down to Earth, 2020).

3.2 Air Pollution

What Africa did yesterday, can south Asia do tomorrow? Will south Asian countries be able to rise over their political hiccup and come together to fight the likes of toxic air scare or climate change impacts? Though the long-term survival of south Asia may be embedded in responses to these vital questions; forget about responses, presently even discussions are not in immediate horizon. However, spate of recent reports, and multinationals like World Bank pushing, are likely to push the political leaders in the subcontinent to initiate transboundary response to this critical issue sooner or later.

Let us start with the air pollution report published by environmental outfit Greenpeace. Post Pulwama, as India and Pakistan were still busy exchanging fire to each other, the quietly published international report highlighted that the sparring countries are nothing short of *bhai (siblings)*, when it comes to inhaling toxic air. The report further shows that seven Indian and two Pakistani cities are in the top ten of 'most polluted' city list on basis of PM 2.5 pollution status; extremely polluted ultrafine particulate those can penetrate the deepest crevices of lungs and trigger a bevy of diseases from asthma to cardiac attacks to cancer. Moving from cities to countries, the same report underlines that Bangladesh, Pakistan and India are three most polluted countries in the world with respect to the particulate, while Afganistan, their south Asian neighbour, is close at the heel.

Experts including those from the likes of World Bank point out in private that it is difficult for any of these countries to find a solution on choking air pollution independently, and a transboundary—and collaborative—air shade management approach is actually required. Ditto, for the ever increasing climate change impact in the area. During the 2018 December's global climate summit held at Katowice in Poland, a report on climate vulnerability showed that while India had most climate related mortality in last two decade, Pakistan was not far behind being placed eighth in overall vulnerability ranking. Incidentally both countries, placed side by side in global hunger list, have lost millions of dollars combating the climate menace. During a chat at Katowice, Malik Amin Aslam, advisor to Pakistani prime minister Imran Khan on climate change and also de facto environment head in Pakistan, admitted to this author that South Asian countries need to rise beyond politics and start discussing critical climate change and environment issues among themselves; and raise strong regional voice to demand due support from global fraternity. Incidentally, poor people in these south Asian countries are worst sufferers to climate and environmental impacts despite contributing little in the causal cauldron. 'Tell me, is there any difference between Lahore and Delhi regarding air pollution?' asked Pakistani minister in Katowice. Few months down the line, the Greenpeace report has put Lahore at tenth and New Delhi in eleventh position within the global list of 4200 odd toxic cities.

The Pakistan minister recognised that unlike other climate hit regions in the world, Asia does not have any 'effective' regional group on climate change, which could have enhanced its bargain power in global negotiation. Though the countries in the region have formed a body called South Asia Co-Operative Environment Programme (SACEP) apparently to discuss the green issues, the body has hardly been made effective yet. In private senior environment department officials of India also admit the need to have serious regional discussion—cooperation and voice—in combating the critical green issues; while accepting in same breath that such initiative is unlikely in this atmosphere of mutual political repulsiveness, especially between India and Pakistan.

In sharp contrast, African or European countries are used to put up a unified voice during global climate negotiation to press for their 'legitimate' demand despite having significant political tension among them. As a matter of fact, in recent past 15 African countries were either involved in war, or experiencing post-war conflict and tension but that did not hamper their combined action in global platforms. Same with the European countries. Unless India, Pakistan and other south Asian countries quickly emulate their African or European counterparts; things will turn bad to worse (Basu, 2019c).

3.3 Water Issues

According to global environmental conflicts map, there are nearly 1800 such conflicts in presence; out of which around 325 are linked to water issues (IOL, 2018). There is hardly any region in the world, where one will not find any water related conflict; be it local, regional or transboundary and they mainly occur over an access to water resources and primarily driven by political interests. Not only in present time, even historically wide range of water conflicts had happened as water is often construed synonymous with development. A comprehensive database about water-related conflicts—the Water Conflict Chronology—has been prepared by the Pacific Institute that lists violence over water going back nearly 6000 years.

Cut to present time, and the water related conflict has become more frequent and intense with hydro-politics taking a centre stage within overall ambit of global politics. For example in South Asia, countries like China, India, Pakistan and Bangladesh are at loggerheads over the rivers like Brahmaputra, Ganga, Teesta, Sindhu/Indus and likewise. There are transboundary issues also with the like of Mekong river. India and Bangladesh, otherwise having comfortable political equation, having long drawn disputes over water sharing of Ganga and Teesta, as both countries want to get major share of dwindling water resources being triggered by climatic changes, human intervention and a range of issues. The matter often gets more complicated as the upper and lower riparian water relationship also gets influenced by regional and local relationship. For example, the state of West Bengal becomes a major player in the Ganga and Teesta river imbroglio between India and Bangladesh, and state political leaderships have played, and are playing key roles in forging, or not forging, the agreements on river water sharing (Basu, 2017). Incidentally, India—almost entirely by West Bengal—and Bangladesh shares 54 transboundary river and unless a holistic water sharing structure policy is framed within contiguous countries, such conflicts will only increase and become more complicated. It is also to be kept in mind that often the sparring countries have different—and even contradictory kind—of sectoral interests regarding river water use, which further magnifies the problem. For example, while China mainly wants to milk the hydroelectric potential of Brahmaputra, India and Bangladesh predominantly use the river water for agriculture (Ghosh, 2020). Similar energy versus agriculture or water security issues vis-à-vis transboundary rivers like Nile or Tigris can also be found. Cut down to conflict at regional level—for example, the likes of Kaveri and Krishna rivers in southern part of India—trend is similar and unless a holistic river usage policy is framed, irrational and lopsided river use will continue being propped up by narrow political interest and sustainable solution will not be found. Take West Bengal, the state that receives the end part of Ganga in India. Incidentally, due to large scale water extraction in upper echelon of Ganga basin leading to wide stretch of horizontal disconnect in the main course of river itself, even 1% of water generated in Gomukh (the point where Ganga river is born) does not come to West Bengal in most part of the year (Basu, 2019d).

While river politics is mainly macro-level, micro-level hydropolitics has also been increasing rapidly whether it is use of groundwater, provision of drinking water or maintenance of waterbodies and wetlands. As natural resources, as mentioned above, are hardly considered important by a large section of political leadership, administration and society *per se*, the collective indifference aided by the financial return, albeit illegal, for not investing their support in favour of environment, has been spoiling the resources. It is a common practice, especially in Asia and Africa, to find that politicians and environmental violators are working in tandem—both covertly and overtly—to maximise the short term return of exploiting natural resources following the 'political rent seeking' model as they say in economics.

4 Concluding Remarks

Overall, it can be safely argued that in today's world generally politics of environment aims to utilise natural resources in an unsustainable profiteering manner keeping mostly narrow and partisan interest in mind. As most of the natural resources are perishable, unsustainable as well as overoptimal use (or, should we call it 'abuse') of such resources will have critically detrimental effect on environment; and it is high time that a global, regional and local level 'Natural Resources Use' policy should be framed and implemented aggressively to save the world.

References

Atwood, M. (2012). Rachel Carson's Silent Spring, 50 years on. The Guardian, https://www.theguardian.com › books › dec › why-rachel-carson-is-a-saint.

Basu, J. (2019a). Climate emergency CoP 25: World is hotter than ever before, says WMO. Down to Earth, https://www.downtoearth.org.in/news/climate-change/climate-emergency-cop-25-world-is-hotter-than-ever-before-says-wmo-68262.

Basu, J. (2019b). Madrid talks could fail Paris Agreement, warn experts. The Telegraph, India. https://www.telegraphindia.com/world/madrid-talks-could-fail-paris-agreement-warn-experts/cid/1726531.

Basu, J. (2019c). South Asia must rise above political differences to fight toxic air and climate change. The Telegraph. https://www.telegraphindia.com/opinion/south-asia-must-rise-above-political-differences-to-fight-toxic-air-and-climate-change/cid/1688833?ref=also-read_story-page.

Basu, J. (2019d). Ganga in Bengal has little trace of Gomukh glacier's pristine waters. The Telegraph. https://www.telegraphindia.com/states/west-bengal/ganga-in-bengal-has-little-trace-of-gomukh-glacier-s-pristine-waters-says-waterman-rajendra-singh/cid/1681823.

Basu, J. (2017). Teesta has one-sixteenth of water needed. The Third Pole. https://www.thethirdpole.net/en/2017/04/14/teesta-has-one-sixteenth-of-water-needed/.

Basu, J. (2005). Save-Victoria Act 100 years old. The Telegraph. https://www.telegraphindia.com/states/west-bengal/save-victoria-act-100-years-old/cid/1272889.

Boccalett, G. (2017). The geopolitics of environmental challenges. The Nature Conservancy.

CSE Sixth Citizens' Report [SOE-6] (2009). Rich Lands Poor People: Is 'Sustainable' Mining Possible?. Center for Science and Environment (CSE).
Down To Earth (2020). COP1 to COP25 – Find all the information & News about COP. Down To Earth. https://www.downtoearth.org.in › climate-change › coplist.
Ghosh, N. (2020). Busting myths on the Brahmaputra. ORF. https://www.orfonline.org/research/busting-myths-on-the-brahmaputra-59844/.
Grieger, A. (2012). Only One Earth: Stockholm and the Beginning of Modern Environmental Diplomacy. Environment and Society.
IOL (2018). Atlas tracks the top 10 environmental conflicts worldwide. IOL. https://www.iol.co.za/news/opinion/atlas-tracks-the-top-10-environmental-conflicts-worldwide-15322176.
Mandavilli, A. (2018). The World's Worst Industrial Disaster Is Still Unfolding. The Atlantic.
McLaren, D. and Willmore, I. (2003). The environmental damage of war in Iraq. The Guardian.
UNEP (2019). Emissions Gap Report 2019. UN Environment Programme (UNEP).
UNFCCC (1995). Berlin Climate Change Conference, March 1995.

Chapter 16
Socio-cultural Challenges in Environmental Management: A Sociological Approach

Surajit C. Mukhopadhyay

1 Introduction

One of the biggest crises of humankind for the twenty-first century is that of our environment being increasingly damaged to a point where human living itself is threatened. Weather and climate changes are ever so visible and a large literature is already in existence about the pitfalls that threaten our planet, including such dire consequences as loss of land and livelihood for humankind. The threat to flora and fauna has been well documented and needs no reiteration here. Suffice it to say that the hazards are many and the consequences of the hazards are globally visible. Environmental hazards, its degradation and the severe consequences that are being engendered are no longer confined to a few corners of the globe. Fossil fuel emissions, for example, are a global threat and intrinsically linked with our economic and political development and growth trajectories that modern economic development has triggered. Wind and air blow the emissions from one corner of the earth to the other affecting people in distant places who are by no means the principal agents of such pollution creation. This is, what the author will argue is the globalisation of victimhood where principal agents or polluters and innocent victims are intertwined in an impending catastrophe of events.

2 The Background

What is also intriguing is the manner in which political leaders and key players of global capital have consistently denied and continue to do so, the empirical evidence that is brought up for their consideration on the matter. That the issue of

S. C. Mukhopadhyay (✉)
Amity Law School, Amity University, Raipur, Chhattisgarh, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_16

environment damage is anthropogenic has been by and large ignored in the hope that there would emerge some technological fix that would enable humankind to counter and resolve the problems. But the stocks of renewable energy and natural resources including water and forest lands are depleting fast coupled with the depletion of stratospheric ozone and atmospheric accumulation of greenhouse gases linked to global climate change. The oft repeated and tired argument that markets would solve the crises efficiently is no longer a strong tenable argument. The waning of distributive economic planning in the face of an upsurge of neo-liberal politics across the globe has made the discourse of conserving the environment highly contested and fragile. Market fundamentalism is the new mantra and wealth creation without taking adequate measures for distributive planning has created a society that is effectively distanced from any measure remotely seen as social welfarist in nature. The obsession with growth per se and the consequent alienated forms of living have become truly global. Cutting down rain forests and exploring them for minerals, as in Brazil, or clearing the forests in Indonesia for palm oil plantation are but a few examples where the myopia of the society is on display. A BBC report dated 24 July 2019 makes a startling statement for all of us. The report quotes a leading climate expert Hans Joachim Schellnhuber that time is running out to save the planet Earth from inevitable destruction or irreparable damage. 'The climate math is brutally clear: While the world can't be healed within the next few years, it may be fatally wounded by negligence until 2020', said Hans Joachim Schellnhuber, founder and now director emeritus of the Potsdam Climate Institute.[1]

3 Identifying the Cause(s)

The scare and alarm that is being raised worldwide however is not of recent vintage. Sociologists have since the 1990s of the last century been vocal about the world being in the grips of a 'risk society'[2]—a concept that can be linked to the idea of globalisation itself. It was widely recognised that environmental degradation, climate change and global warming are all part of this risk society and that such issues must now move centre-stage both politically and intellectually. More importantly, it became clear that the concept of risk society was truly universal and environmental problematic must be tackled by countries both in the global North and South.

The United Nations Conference on Environment and Development (UNCED) held in 1992 at Rio de Janeiro in Brazil was high on optimism about tackling the impending danger globally and in unison. The reasons for that level of optimism in tackling environmental degradation and damage can partly be explained by the fact that the conference was preceded by serious parleys between senior functionaries of

[1] https://www.bbc.com/news/science-environment-48964736, accessed on 26 July 2019.

[2] Following Beck (1986), we may conceptualise risk society as an advanced industrial solidarity that cannot escape the structural consequences of damage and severe risks that it itself creates.

major states and that the deliberations pointed to the dominant socio-economic milieu in which inequality and the global power positions were closely to be interrogated. The recognition that the overtly 'natural' problem facing the earth was not really a problem that was entirely 'natural' pointed to a shift in the debate on such issues moving towards a recognition that the causes were anthropogenic in nature. The author would argue, that despite the failure of the UNCED in getting a North–South dialogue going, it was successful in putting forth firmly the idea of an anthropogenic discourse and its concomitant power dynamics as the space from which a possible solution would emerge. In other words, the solution would lie squarely with humans playing a more critical and proactive role in sustaining, conserving and caring for an ecologically aware population.

That the identification of the causes did not provide relief is now evident. The North was successful in legitimising their industrial and military might through the idea of a 'Green Regime' that had emerged by advancing superior knowledge claims and thereby using the skewed power dynamics that it had acquired globally to scuttle a dialogue that would be based on ideas of equality and equity. The onus, it would seem, was back to the labours of the South and ideas of inclusionary practices and common concerns were waylaid by stark exclusions. The interests, cultural values and aesthetics of a few countries of the North were dominant—a reflection of the global power dynamics prevailing at that time. In other words, the consequences of the Rio conference ended up in an endorsement of the dominant position of the North, and within the North countries, the pre-eminence of a select few. The distribution of risks emanating from the course of economic action initiated and sustained by the North was clearly to be borne by the countries of the South and appropriation of the indigenous people and their resources by the North. It may be worthwhile to point out that the North as an idea, an abstract of global power domination and reproduction of its power dynamics and capitalist relations of production is present in the South by way of endorsements and replication through the ruling elites of these countries. A good example of this is the manner in which capitalism's dynamics threaten the rain forests of Brazil, Indonesia and India, where the indigenous population is confronted not only by the loss of forest cover but by consequent loss of livelihood as well.

The exclusion of the public by the imposition of the sovereign will that is itself underpinned by the liberal market economy imperatives is reflected in the emergent political struggle over resources where the indigenous and the subordinated people continually lose their rights over land, water and air. The exploitation of natural resources and its consequent debilitating effects on the environment has two significant propellants—one which uses state coercive power and associated technologies of overt coercion and the other more subtle, which uses the legal and technological languages of appropriation and promise of 'development' and 'growth'. The idea that there are immense rewards to be had by such exploitation of resources and subordination of the people is a common ploy that is especially deployed in the South to further the global domination of capital. In doing so more often than not the South is seen as the more obvious transgressor of environmental protection protocol.

A case in point is the manner in which the greenhouse emissions of leading industrial nations like USA and Japan were camouflaged in the report filed by the Washington-based World Research Institute (WRI). This was brought to attention by Vandana Shiva, a leading environmentalist of India, who felt that it was a good example of ‘Orwellian double-speak’ in so far as ecological destruction was being shown as conservation. This is an important argument for it gestures towards a North–South divide that is based on multiple factors, chief amongst which is the reproduction of the political power differential and the increasing clout of a neo-liberal world order that brooks no resistance to its inexorable hunger for more profits at any cost.

4 Where are the Social Sciences?

The social sciences have been rather late in taking up this debate for two significant reasons—one which is embedded in the very nature of the development of the social sciences and the other due to the general idea of modernity that each successive crisis has its own resolution that can be teased out of the problematic itself. In the first instance, the discourse of ‘nature’ and the discourse of the ‘social’ were seen as two different domains. Emile Durkheim, the father of sociology based his work on the precept that the social is distinct—a ‘social fact’ that animates the manner in which an agent works when confronted with this ‘thing’ like quality that ‘coerces’ the actor into doing something. The actor of course is unaware that her actions are not entirely of her own making, and that it is being enforced by larger forces that elude her consciousness in immediate time. To be in this state of agency where one is led to believe that one is making a choice out of volition is to normalise the entire sociological milieu in which the actor operates. The normalisation of action effectively removes from time the idea of reflection on action undertaken. Time is linear and in constant motion, thus triggering the idea of loss and reinforcing the dominant value of ‘here and now’. To act instantly is to minimise loss and maximise profit or gain for oneself.

Take the example of a sale in a shopping mall where large discounts are being advertised. The customer who goes in early believes that she makes most out of the deal and that to tarry awhile and check out other stores for similar deals would perhaps make her lose a good opportunity to pick up a bargain. The store keeps on communicating the finiteness of time and resource and the customer is coerced to accept that time is of essence. Since all who are potential shoppers are of the same opinion a situation of maximising time and thereby gain is instantly created. In what we may call *instant time*, the potential customer has no option but to execute her shopping plans hurriedly. Yet, while she is being hustled to buy she feels that she is exercising choice and therefore being rational and acting like everyone else does. This normalisation of the everyday action is a clear example of a ‘social fact’ in action. More critically for our consideration, there is no time to reflect on the choices that the shopper is confronted with. This compression of time creates a situation where the 'here and now' becomes important as a decision making exercise. The general unawareness about the impact of everyday life on the environment can be explained mostly by the disinclination of the actors to go beyond the immediacy of an act and the apparent.

Such acts also indicate the deep chasm between the social-economic on the one hand and the natural on the other. The progress of modernity riding on the success of technology and industrial production effectively uses nature as a repository to fuel a particular life-style and a certain path of growth. That which is natural or from nature is always relegated to the background by what the author would call a series of deceptions that divorces the social and the natural and makes it difficult for the social sciences to conceptualise the social-natural relationship in ways beyond extraction and exploitation. Or to put it differently, the development of modern civilisation as we know it is predicated on the idea of the extraction of natural resources and the constant supply of the same to fuel growth and profit. The history of colonialism is a history of this divide between the natural and the social or can be described as the supply of resources to the metropolitan centres of political and economic power from the 'uncivilised' to the 'civilised' in a relentless sequence of extraction, exploitation, appropriation and capitalist growth.

Colonialism began in guise of trade and commerce and over a period of time this generated political power that was unprecedented in the annals of human history. Archbishop Desmond Tutu summed up the matter succinctly when he said that the coloniser offered the Bible and asked the 'natives' to close their eyes and pray for salvation. When the prayer was over, Tutu says, the 'white man had the land and we had the Bible'.[3] This is what I will argue as the deception discourse for it not only effectively masks the extraction and exploitation of a land that is foreign but elevates this exercise to something that is morally superior and necessary to bring 'civilisation' to those who have been left out of its wonderful embrace. In making this discursive classification it created a register of civilised and uncivilised where the exploitation and appropriation of resources from the colonised (uncivilised) was not ethically problematic but on the contrary beneficial for those who have not come in touch with modernity. In other words, the discourse of colonialism declared that the victims were actually being benefitted from the loss of their land and livelihood, though the logic of the economic extraction pointed to benefits accruing to the coloniser.

The idea that there are people who need to be saved created a liberal political discourse in which the binary of the civilised and uncivilised worked to the advantage of new found commerce and its consequent political hegemony. But more critically this binary positioned the 'uncivilised' on the margins of humanity. The 'uncivilised' could be made into slaves and not paid money. Their land could be appropriated and not compensated rightfully. Both human and natural resource in the 'uncivilised' lands were repositories that were to feed into a gigantic industrial

[3] When the missionaries came to Africa they had the Bible and we had the land. They said 'Let us pray.' We closed our eyes. When we opened them we had the Bible and they had the land. https://www.brainyquote.com/authors/desmond-tutu-quotes accessed on 30/08/19.

and mercantile world located historically in Europe. Adam Smith in his magnum opus ‘An Inquiry into the Nature and Causes of the Wealth of Nations’ states quite candidly about the advantages that Europe has derived from the colonisation of America. He writes that ‘the general advantages which Europe has derived from the discovery of and colonisation of America, consist, first, in the increase of enjoyments; and, secondly, in the augmentation of its industry’ (Smith, 2012: 586). Modern anthropology further cemented this idea of the ‘uncivilised’ through a series of ethnographies and field work records in the continent of Africa especially and in other parts of the globe. This reduction of vast areas of the world and their inhabitants into recipients of ‘civilisation’ and therefore knowledge systems developed in the West made a particular type of science supreme—an idea of science that is closely linked with political power and which ultimately legitimises the immiseration of the poor and the marginal.

Shiva argues that the premise of modern science, which is the greatest source of legitimacy for colonialism, is essentially violent. It is violent according to Shiva (1988: 232) because modern science is reductionist in nature and its ‘reductionist nature undergirds an economic structure based on exploitation, profit maximisation and capital accumulation’. She further argues that this kind of a science is ‘also at the root of a growing ecological crisis, because it entails a transformation of nature such that the processes, regularities and regenerative capacity of nature are destroyed’ (Shiva, 1988). The nexus between the hegemonic presence of modern science, profit maximisation and therefore by extension the capitalist system and the historical process by which we have come to disregard all other knowledge system as obsolete, redundant or bogus is laid bare in this argument. This politics of epistemology is in direct confrontation with nature and people whose lives are organically linked to the ecological system and whose epistemological bases have been systematically removed from the idea of science itself.

Modern science or the major and hegemonic part of it is in direct confrontation with nature and by extension ecology and the environment. Nature often seen as that which is abundant in the wild conveys to the ‘civilised’ a space that has to be conquered and tamed, trophies to be hunted and displayed. This can only be done through ‘superior’ knowledge and it must fall back upon the power of the corporate-state combine to push through its agenda. Further, as it becomes mired more and more in this nexus, its claim to be an avenue of emancipation and usefulness for the poor and the needy falls apart. The ecological crises that haunt the planet Earth today would first and foremost affect the poor of this world. The marginal farmer, the sea going fisher folk, the hunter-gatherers of the forest are the potential victim or are already the victims of the destruction of the earth, water and air. The reckless pillage of resources affects them the most and directly—a fact that was recognised by the current Pope in Papal Encyclical, Laudato si. Pope Francis recalls in this encyclical that way back in 1971, the then Pope Paul VI had at the Food and Agricultural Organisation (FAO) of the United Nations stated that there is a possibility of an ‘ecological catastrophe’ due to the ‘explosion of industrial civilisation’ and had warned that science by itself or technological advances by themselves would not be able to stem the crises until and unless there were 'authentic social and moral progress'.

Pope Francis shows compassion, perspicacity and a nuanced understanding of the socio-economic issues involved in paragraph 25 of his encyclical, when he goes onto say that the climate change is a global problem and that 'It represents one of the principal challenges facing humanity in our day'. He rightly points out that 'its worst impact will probably be felt by developing countries in coming decades. Many of the poor live in areas particularly affected by phenomena related to warming, and their means of subsistence are largely dependent on natural reserves and ecosystemic services such as agriculture, fishing and forestry. They have no other financial activities or resources which can enable them to adapt to climate change or to face natural disasters, and their access to social services and protection is very limited'.[4]

5 Critical Discourses

The critical observations of Vandana Shiva and the Catholic Popes are but a few examples of the critique of environmentalism that challenges the primacy of culture in the field of sociology and acknowledges the role of the physical environment and biological inheritance. These approaches, the author would argue, have had apart from highlighting the need to go beyond given disciplinary boundaries forced scholarship in sociology to enter trans-disciplinary areas of interest and see the debate on environment and ecological concerns as a global and truly universal phenomenon, to be understood and explained by invoking a cohort of disciplines and voices. One of the outcomes of this has been the manner in which the methodology of enquiry has been accommodative of those who are not considered to be experts. The 'lived in' experience of those who primarily would be seen as the sociological 'laity' has increasingly become critical in creating sociological perspective that tries to grapple with this global problem.

The other impediment in the sociological imagination of environmental consciousness comes from an understanding that resources are substitutable and that science and technology would be saviours in fending off a collapse brought about by expending finite resources. The deployment of modern science in this context is to ensure that civilisation is not threatened by the lack of resources that drives it. The substitutes of natural products have additionally the advantage of being cheaper to produce and thus fit into the discourse of big capital and its ability to fund research that increases profits and cuts losses. The rise of plastic and other artificially produced material as a substitute in producing shopping bags in place of jute based products is a classic example of how science and capital in tandem have produced

[4] http://www.vatican.va/content/francesco/en/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.html (accessed on 30/08/19).

this idea that the natural resources are always substitutable through innovation and technology. Discourse has the ability to interpret the world around us and to create a storyline that makes sense of our milieu and the not so immediate surroundings. It links the institutions, the agents and the knowledge claims into an inter-related fabric or a mosaic of meanings that becomes powerful over a period of time and has the ability to mobilise, validate and propel action in a particular manner.

In order to understand why despite the clamour of many, environmental crises is overlooked or is sought to be downplayed one must understand the manner in which the discursive field is organised. At the very top of the pecking order is the dominant discourse, the field that usually regulates the meaning world around us and is usually the creation of those who are socio-economically powerful. In the fora that regulates, determines and shapes the policies on environment the discourse on display is one of dominance. The scientific discourse, to which scholars like Shiva are gesturing to as described above, feeds into this dominant discourse by objectifying nature and identifying it as a means to an end – where the end is to promote the triumph of man over nature through the means of science. Interestingly, nature beyond science is usually seen as matter for poets and writers—an idyllic romantic niche which begins and ends with the idea of aesthetics per se. This romanticisation of nature is in stark contrast to the objectification of nature by science but has similar results. Whereas science marginalises nature through the dominant discourse of discovery, invention and use value so that all of nature can be useful so long as it feeds into the industry-science-capitalism complex, whereas, by eulogising nature through arts a different sort of marginalisation is invoked.

In this case, marginalisation is through an excess of aesthetics, an overflow of eulogy to the spirit of nature that is seen to be diametrically opposed to the 'real' world of science and commerce. In this instance excess kills the possibility of nature to be seen as useful and necessary to the very idea of living and capitalism ensures that such an excess becomes an object d'art to be valued but differently and in isolation of everyday living. By reducing the narrative of nature into one of beauty and aesthetics, wonderment and leisure, while putting technology and science in charge of 'harnessing' it for the use of society, a false duality is created whereby the latter will, by the application of positivist logic always be seen as rational and necessary.

6 Power and Political Economy

This duality is not an accident of history. It is a carefully crafted division related to a particular form of economic organisation and production. The industrialisation of society and the emphasis on mass production creates its own compulsions of profit maximisation and efficiency criterion. All production would have to judge on this twin axes even as this process effectively destroys and depletes the natural resources or bludgeons through the socio-economic bases of a marginal community and its sensibilities. The several confrontations and fights over natural resources all over the world bear testimony to this—from the Niyamagiri Hills in Odisha, India to the confrontation of indigenous people in the United States or the 'Indians' in the Brazilian rainforest. In this confrontation between the people and the company, the company wins the battle for it has been a priori accepted that it is a confrontation between the 'advanced' people and the 'backward'. The lines of the division is similar to the lines developed by the discourse of colonialism and can be seen as merely an extension of this modernist argument.

Further, the political might of the state both in terms of the use of repressive state apparatus and ideological state apparatus upholds the rights for extraction and exploitation of resources as part of its 'development' agenda. The citizen's mind is sought to be changed by a mix of coercion and ideology on the basis of the assumption that the citizen is not an 'expert' and therefore her views are irrelevant. The state-market nexus blunts and elides the lived in experiential knowledge of the people and consigns such knowledge systems onto the plane of ignorance and irrelevance.

What emerges from this standoff is a situation where state and its people are talking past each other in mutual incomprehension and the state promoting and impressing upon the people a certain manner of living. This is politics at its best and over the last few decades an understanding has emerged that the problems posed by environmental degradation cannot be addressed without making structural changes in the body politic. In short, the matter is now more than ever political in nature rather than purely technical and solutions therefore must be sought from sociological, economics and political 'scapes' of view, including the interventions from concerned ecclesiastical leaders whose arguments on the moral plane border on the theological. But the responses from various quarters amply demonstrate that the discourse and debate on the issue of environment and ecology is no longer the exclusive prerogative of the 'experts'. A wide range of voices are articulating the concerns and the question that is germane at the moment is this—are these voices being heard?

One of the major stumbling blocks in bringing in the voices of the people who are supposedly 'non-experts' into the discursive field of the environmental crisis has been the state. Shiva (1988: 239) argues that the link between the state and the creation of surplus value provides the power by which modern industrialism establishes its power that obfuscates the steady depletion of resources that are finite. To change the story then is to mount a challenge to the manner in which modern society sees development, growth, science and all things that are associated with a particular way of life that have become etched in the very consciousness of the collective.

This is not easy, as routinised everyday existence makes it extremely difficult to imagine alternatives that can lead to different sociological imaginations. We live in the era of globalisation where identities, cultures and politics are simply 'one dimensional' and persons are at the end of the day mere consumers. It would seem that keeping the wheels of mammoth industries running is the only reason why a population exists. We must also recognise at the same time, that not only are we consumers of material goods but also of dreams. These dreams that industrial-capitalism spins usually sell the idea of good life that can be lived only when one moves from the 'confines' of the traditional villages into mega-urban centres.

Sociologically speaking, the idea of a society that is bound through age old ties and of solidarities created by norms that foster collective living has given way to a more competitive lifestyle underpinned by material success.

The allure leads to a discursive system that is spatio-material in nature and where acquisition of goods is the only marker of 'happiness' and that happiness can be achieved if one migrates to urbanism as a way of life. Therefore, the question is, of imagining an alternative world where populations live a life free from basic wants, where extreme poverty has been addressed and the question of health, education, sanitation and the protection of nature from the rapaciousness of the powerful. This alternative must therefore critique the grand narrative of capitalist modernity, which though based in particulars has always laid a false and pretentious claim to be universal.

The twenty-first century concerns in ecology therefore cannot merely be about managing the nature and taming it for the increase in private accumulation and profit seeking as it has been done so far. It has to recognise that the question of ecology and environment management must undergo a paradigm shift in the Kuhnian sense of the term. In doing so, it must therefore recognise that the tension is between an economic organisation and its goals and the ecological goals. The rift between the dominant world economic system and ecological concerns are underpinned by the domination of human beings by human beings. The inequalities based on class and the state's support in underwriting the system of production that creates these inequalities cannot be seen as merely confined to the socio-economic milieu alone. A human value based ecological management system must first and foremost surmount this capitalist driven idea of growth and integrate the human and the non-human in an organic manner. We may argue that this is the new theory of holism where no part of the whole can ever be greater than the mere sum of its parts.

One example of this is the manner in which the countries of the North and those of the global South have fared in the management of the environment. The capitalist system does not create inequalities within the boundaries of the nation-states only. The wealthier nations gain disproportionate access to capital and externalise the costs to the countries of the global South. Toxic waste dumping by the countries of the North and exporting hazardous production facilities to the South makes for an apparent greening of the wealthier nations while the countries of the South seemingly are less concerned about the environment. This capacity to outsource injurious production to the periphery is made possible by the global inequalities of political and military power.

Based on these building blocks of economic inequalities epistemic societies and mass media organisations located in the countries of the North and aligned to the dominant political power centres there transmit cultural values all over the globe. In such mass communication the valourisation of consumption oriented lifestyle normalises the ecological degradation discourses and leads to what we may call the institutionalisation of ecological injustice. The ecological injustice discourse recognises that the problems associated with environmental degradation are fundamentally a social issue that is driven and legitimised by the dominant social structures and ideologies that are prevalent.

7 Conclusion

So, the moot question is this: can we reverse all that we have learnt in our everyday living as markers of progress and well-being and find alternatives to sustain recover and recoup the loss of flora and fauna? Is sustainable development the way forward or is it that it too fails the litmus paper test? The answer to this question holds in many ways the keys to the question of the fight against ecological disasters and environmental protection. Can the world so mired in modern consumption shift to a more reduced and manageable level of comfort leading to a reduced material world of living? This perspective in the management of the global environment raises a rather tricky issue from a sociological perspective, for it asks us to recast the ways and means of living and to achieve a ‘good life’. Recasting our ideas about ‘good life’ is not easy even in this post-Fordist, techno-capitalist world of production. What constitutes a ‘good life’ is always going to be a contested terrain and with ‘over-development’ of development an argument can be made for a sustainable culture. A sustainable culture learns from those that are seen as populating the margins of the ‘developed’ world, from indigenous people and their organic linkages with the biosphere. Nadarajah (2013) argues that though the Brundtland Report ‘was admirable’ the solutions are a re-hash of the trodden path of capitalist development. It may be further argued that the socialist experiment of society and economic production did not differentiate itself greatly from an industry driven, resource hogging path of development. USSR is a prime example of the emphasis on heavy industrial expansion and modern China too shows that a different political system does not guarantee a path that will walk the ecological sustainable talk.

To come out of this bind, Nadarajah (2013: 83) proposes to fall back upon ‘cosmologies of sustainability that are non-materialistic and development patterns that are not growth-oriented’. Whether a substantial population of the globe can voluntarily move to such a philosophy of living where the principle of ‘limit and balance’ and ‘values as critical as sacredness, compassion, love, respect, harmony, empathy, service, joy, wisdom and peacefulness’ (Nadarajah, 2013) would be active is a huge ask, one that is essentially a question of political will and a revolutionary break from the manner in which the unfinished project of modernity would respond. We may justifiably draw upon Thomas Piketty’s argument to state that ‘the history of inequality is shaped by the way economic, social, and political actors view what is just and what is not, as well as by the relative power of those and the collective choices that result’ (Piketty, 2017: 28). The question of the environment and its care cannot simply be a discourse of good intentions.

References

Beck, U. (1986). Risk Society: Towards a New Modernity. Sage, New Delhi.
Nadarajah, M. (2013). Living Pathways: Meditations on Sustainable Cultures and Cosmologies in Asia. Areca Books, Penang.
Piketty, T. (2017). Capital in the Twenty-First Century. The Bellknap Press of Harvard University Press, London.
Shiva, V. (1988). Reductionist science as epistemological violence. *In:* Science Hegemony and Violence: A requiem for Modernity. The United Nations University and OUP, Delhi
Smith, A. (2012). An Inquiry into the Nature and Causes of the Wealth of Nations. Wordsworth, Hertfordshire.

Chapter 17
Policies and Legal Aspects of Environmental Management

Paulami Sahu

1 Introduction

Environment is one of the key components of sustainable development of human race. Therefore, to protect human civilisation, environment must be conserved. The world today is facing many environmental challenges posed by unregulated human activities. These include air pollution and worsening of air quality, water pollution and depletion of water resources, noise pollution and associated problems, soil pollution and contamination of soil, depletion of water table, climate change, depletion of forests, loss of biodiversity, depletion of ozone layer, problems associated with mounting garbage and wastes including hazardous and toxic wastes. To prevent deterioration of environment, proper environment management plans should be adopted. But to chalk out appropriate management plan, an environmental policy should be framed. The word *policy* is defined as a course of action, which has been proposed or adopted by any government, organisation or an individual. An *environmental policy* is course of action for the protection of environment, wildlife and natural resources. In a developing country like India, an environmental policy is especially required because there is a consistent need for balancing between environment on one side and the needs of human development on the other, considering the public opinion representing the views of both the elite expert and lay public. A good environmental policy is a precursor for ensuring sustainable development. Policy formulation becomes indispensable because policy is an instrument of transformation or a board guideline for planners and administrators to convert a given environment into a preferred environment. It is through a policy that we can precisely identify the problems; fix priority to form alternative approaches and solutions; make a choice among alternatives on the basis of comprehensive analysis of

P. Sahu (✉)
School of Environment & Sustainable Development, Central University of Gujarat, Gandhinagar, India
e-mail: paulami_sahu@cug.ac.in

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_17

benefits and costs; articulate the choice in terms of goals expressed; provide organisation, personnel and resources to ensure effective implementation and to lay down a mechanism for continuous monitoring of the policy (Shandilya, 2015). The policy is the overall environmental intention and direction, forming the backbone and skeletal framework, from which all other environmental components such as environmental management systems, audits, assessments and reports are connected (Sharathchandran, 2005). The goals of the environmental policies may cover several environmental issues such as pollution of water, air and soil, land degradation, industrialisation, urbanisation, depletion of natural resources, human health protection, conservation of wild life, preservation of historic monuments etc. Though environmental policies and laws play a very crucial and important role in regulating the use of natural resources and in protecting the environment, success of environmental legislations mainly depends on the way they are enforced. Legislation also serves as a valuable tool for educating masses about their responsibility in maintaining healthy environment. Many international initiatives and legislations have already been put forth at national and international levels. Some of the important international conventions related to environment and climate are discussed briefly in the next section to get an overall idea of the initiatives taken to protect environment and reduce the impact of climate change.

2 International Response to Environment and Climate Related Issues

2.1 Stockholm Conference 1972

The first global conference on environmental protection was held in Stockholm, Sweden in June 1972 and the name of the conference was United Nations Conference on the Human Environment (UNCHE), popularly known as Stockholm Conference. A total of 26 principles were chalked out during the UNCHE, 1972, which were to be adopted and followed by all participating nations. These principles became guiding principles for developing countries like India to frame environmental policies. The UNCHE also proposed to celebrate 5th June (the starting date of the UNCHE, 1972) as the World Environment Day (www.unep.org; accessed on 13.05.2019). This conference led to the creation of the United Nations Environment Program (UNEP), which is still a leading global environmental authority. The authority promotes the coherent implementation of the environmental dimension of sustainable development within the United Nations system (Desai, 2006).

2.2 CITES 1975

CITES or the Convention on International Trade in Endangered Species of Wild Fauna and Flora is an international voluntary agreement between governments that came into force in 1975. CITES aims to ensure that international trade in specimens of wild animals and plants does not threaten their survival. CITES must be implemented by individual country at the national level under the laws of the respective country. India became a party to CITES in 1976 and since then, has played an active role to discourage international trade in endangered species.

2.3 The World Heritage Convention 1975

The World Heritage Convention is a convention concerning the protection of the world's cultural and natural heritage and is overseen by the United Nations Educational, Scientific and Cultural Organisation (UNESCO). Like CITES, The World Heritage Convention came into effect in 1975 and was ratified by India in the year 1977.

2.4 Ramsar Convention 1971

The Ramsar Convention came into being in the year 1971 and is an international treaty for the conservation of wetlands of international importance. According to the Ramsar Convention, all lakes, rivers, aquifers, swamps, marshes, wet grasslands, peatlands, oases, estuaries, deltas, coastal areas, coral reefs and all human-made sites such as fish ponds, rice paddies, reservoirs and salt pans are known as wetlands. Since wetlands are the primary source of fresh water and provide many other services to us, the Ramsar Convention calls for the protection of those wetlands, which provide direct benefit to large number of people. India became a signatory to the Ramsar Convention in 1982 (www.ramsar.org/about-the-ramsar-convention; accessed on 13.05.2019).

2.5 Bonn Convention 1983

In 1983, the Convention on the Conservation of Migratory Species of Wild Animals (also known as the Bonn Convention since it was first put forward at Bonn, Germany) came into effect. Migratory species are those species of animals who migrate from one area to another (usually from breeding ground to feeding ground and vice versa) in a periodic and seasonal manner. In doing so, they often cross national boundaries thus making their conservation a trans-boundary and international issue. India became a signatory to the Convention in 1983 itself and has been taking significant measures for the conservation of migratory species since then (https://pib.gov.in/pressreleaseshare.aspx?prid=1563577; accessed on 19.05.2019).

2.6 Brundtland Commission 1983

The year 1987 can be considered as a turning point in environmental advocacy and policy making due to the publication of a report entitled *Our Common Future*. Also known as the Brundtland Report, the *Our Common Future* report was released by the World Commission on Environment and Development (WCED) set up by the UNEP in 1983. The WCED was chaired by Norwegian Prime Minister Gro H. Brundtland (hence called the Brundtland Commission) and initiated the policy shift to sustainable development. The report was one of the first documents, which defined sustainable development. The definition of sustainable development put forward by the Brundtland Commission Report is *development that meets the needs of the present generation without compromising the ability of the future generations to meet their own needs.* The Brundtland Commission Report brought developing countries like India a step closer to frame a comprehensive environmental policy for themselves since the goal (of achieving sustainable development) was clear (https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf; accessed on 18.05.2019).

2.7 Montreal Protocol 1989

In 1985, a hole in the ozone layer above Antarctica was discovered. This layer protects us from the harmful radiations of the sun and a hole in it meant that we were now increasingly getting exposed to sun's harmful radiations. Further studies revealed that the cause of this ozone hole was the release of certain ozone depleting substances by industrial processes, and therefore, world leaders showed utmost urgency to address this issue. In this regard in 1985, the Vienna Convention for the Protection of Ozone Layer came into existence and led to the formulation of the Montreal Protocol on Substances that Deplete the Ozone Layer in 1989. India became a party to the Vienna Convention in 1991 and signed the Montreal Protocol in 1992 (https://unep.ch/ozone/pdf/Montreal-Protocol2000.pdf; accessed on 12.05.2019).

2.8 Basel Convention 1992

In 1992, the Basel Convention, an international agreement for restricting the transfer of hazardous waste from one country to the other, came into force. More specifically, the Basel Convention is aimed at restricting the transfer of hazardous waste from a developed country to a developing or under-developed country. It was signed and joined by India in 1992 (http://www.basel.int/TheConvention/Overview/History/Overview/tabid/3405/Default.aspx; accessed on 15.05.2019).

2.9 Earth Summit 1992

The United Nations Conference on Environment and Development (UNCED) took place in Rio de Janeiro, Brazil in June 1992. Also known as the Rio or the Earth Summit (1992), the UNCED, 1992 was the first major international conference since the release of the Brundtland Commission Report. The outcome of the conference was the Rio Declaration on Environment and Development, Agenda 21 and the Forest Principles. In addition, a legally binding Convention on Biological Diversity was opened for signatures by all nations at the Rio Summit. India signed the Convention on Biological Diversity in 1992 itself. The United Nations Framework Convention on Climate Change (UNFCCC) was also negotiated and opened for signature at the Rio Summit. India signed the UNFCCC in 1992 itself. The parties to the UNFCCC have met annually since 1995 for ensuring comprehensive and global action for preventing global warming. It was in one such Conference of Parties (CoP) meeting held in Kyoto in 1997, some developed nations accepted legally binding obligations to reduce their greenhouse gas emissions. The outcome of this meeting came to be known as the Kyoto Protocol (https://climate.nasa.gov; accessed 13.05.2019).

2.10 Convention on Biological Diversity (CBD), 1993

The Convention on Biological Diversity (CBD) was opened for signature at the Earth Summit in Rio de Janeiro on 5 June 1992. It entered into force on 29 December 1993. The Convention has the following key objectives: (a) the conservation of biological diversity, (b) the sustainable use of the components of biological diversity and (c) the fair and equitable sharing of the benefits arising out of the utilisation of genetic resources. India signed the CBD on 5 June 1992, ratified it on 18 February 1994 and became a Party to the Convention on 19 May 1994. As part of the CBD, a Cartagena Protocol on Biosafety of the Convention, also known as the Biosafety Protocol, was adopted in January 2000. The Biosafety Protocol seeks to protect biological diversity from the potential risks posed by living modified organisms resulting from modern biotechnology. Another protocol, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilisation, was added to the CBD as a supplementary agreement on 29 October 2010. It provides a transparent legal framework for the effective implementation of the fair and equitable sharing of benefits arising out of the utilisation of genetic resources. The protocol is named after the place Nagoya in Aichi Province, Japan (where it was conceived) and entered into force on 12 October 2014 (https://www.cbd.int/intro/; accessed on 16.05.2020).

2.11 World Summit on Sustainable Development, 2002

The Rio Summit was followed by the World Summit on Sustainable Development (WSSD) which was held in Johannesburg (South Africa) in 2002. The conclusion of this summit came to be known as the Johannesburg Declaration on Sustainable Development and mainly called for participating countries like India to continue the path of sustainable development (https://enb.iisd.org/2002/wssd/WSSDcompilation.pdf; accessed on 15.05.2020).

2.12 The Cartagena Protocol on Biosafety, 2003

Advancements in biotechnology raised new hopes regarding fulfilment of the needs of mankind, in particular food requirements. However, like other scientific advancements, advancements in biotechnology had their own perils on human health and environment. Therefore, there was a need for reconciling advancements in modern biotechnology, economic interest and safety and protection of human health environment and biodiversity. Use of Living Modified Organisms (LMO) as a result of modern biotechnology, genetically engineered crops and the trade in them necessitated regulatory mechanism on biosafety. In pursuance of the provisions contained in CBD, efforts began in 1994 for development of Protocol on Biosafety. Cartagena Protocol on Biosafety to the convention on Biological diversity entered into force on 11 September 2003. The Cartagena Protocol governs and regulates the movements of LMOs from one country to another and thereby reducing the potential adverse effects of LMOs on biodiversity (https://bch.cbd.int/protocol; accessed on 18.05.2020).

2.13 *Stockholm Convention on Persistent Organic Pollutants, 2004*

The Stockholm Convention on Persistent Organic Pollutants was adopted on 22 May 2001 and entered into force on 17 May 2004. It is a Convention for regulating the manufacture of certain toxic and stable chemicals, which can accumulate in our environment after being manufactured. India signed on the Stockholm Convention in 2002 and ratified in 2006 (http://www.pops.int/TheConvention/Overview/tabid/3351/Default.aspx; accessed on 18.05.2020).

2.14 *Nagoya Protocol, 2010*

CBD was enacted as an instrument for dealing with biological diversity with the following main objectives: (a) conservation of biodiversity, (b) sustainable use of biodiversity and its components and (c) fair and equitable sharing of the benefits arising from the utilisation of genetic resources. In the context of the third objective, an ad hoc Open-ended Working Group on Access and Benefit Sharing under the CBD was constituted in 2004 in the seventh meeting of the Conference of Parties. After six years of arduous negotiations, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilisation to the Convention on Biological Diversity was adopted on 29 October 2010 in Nagoya, Japan at the tenth meeting of the conference of parties.

The protocol recognises the sovereign rights of states over their natural resources and the interdependence of all countries with regard to genetic resources for food and agriculture, for attaining food security. The protocol also recognises the interrelationship between genetic resources and sustainable use of genetic resources and the role of Access and Benefit Sharing (ABS) in conservation and use of biodiversity (https://www.cbd.int/abs/about/; accessed on 16.05.2019).

2.15 *Rio+20, 2012*

The United Nations Conference on Sustainable Development (UNCSD) was held in Rio de Janerio, Brazil as the third international conference after Earth Summit 1992 and WSSD 2002. It came to be known as Rio+20 since it took place in 2012, exactly 20 years after the first Earth Summit. Rio + 20 focused on two broad themes: (a) a green economy in the context of sustainable development and (b) setting the institutional framework for sustainable development. The outcome of Rio + 20 focused on continuing the pathway of sustainable development. The outcome document was aptly entitled, *The Future We Want*. Participating nations like India also agreed for developing Sustainable Development Goals, which would build upon the existing

Millennium Development Goals (MDG). Rio+20 concluded with some forward-looking decisions on several areas such as energy, food security, oceans and urban areas (https://sustainabledevelopment.un.org/rio20; accessed on 17.05.2020).

2.16 Paris Agreement, 2016

Adopted in 2015 at the end of the United Nations Climate Change Conference (COP 21), the Paris Agreement is the first universal and legally binding agreement on climate change. The Paris Agreement entered into force on 4 November 2016, after being ratified by 55 countries—representing at least 55% of total greenhouse gas emission. The central aim of the Paris Agreement is to strengthen the global response to the threat of climate change by keeping the global temperature rise of this century, well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C. Additionally, the agreement aims to strengthen the ability of countries to deal with the impacts of climate change. As a result, 195 countries made bottom up commitments and to submit updated climate plans called Nationally Determined Contributions (NDCs) every five years. NDCs are at the heart of the Paris Agreement in order to achieve its long-term goals. This may lead to a reduction of greenhouse gas emissions by 70% to 80% by the second half of this century (https://assets.nrdc.org/sites/default/files/paris-agreement-climate-change-2017-ib.pdf; accessed on 10.05.2019).

Though all these international efforts have guided immensely to form and update environmental legislations of India, the devices and rules for protecting environment were also discernible in ancient India. In the next section, India's multi-temporal concerns about environment and climate change have been addressed.

3 Indian Concern

3.1 Ancient Scenario (500 BC–1638 AD)

In the ancient times, Earth was referred to as Mother Earth and Sun, Moon, forests, air, sacred rivers like Ganga, Saraswati etc. were worshipped as God and Goddesses as they provided the basic necessities essential for human survival. In this context, Hindu religious texts have references that there was emphasis on utilisation of these resources with restraint and a zest for their protection and conservation**.** Protection of forests and environment has always been part of *dharma* (custom) (Joshi and Pant, 2007). Conservation of forests formed an integral part of the Vedic tradition of India as early as 300 BC. According to Vedic tradition, there were 'van' (forests) which were worshipped as they provided human beings with essential commodities such as timber for fuel, food and other resources for survival. The Maurya kingdom recognised the importance of forests. During the reign of Chandragupta Maurya (324 or 321 – c. 297 BCE), an officer was appointed to look after the forests (Shobajasmin, 2013). Therefore, conservation and sustainable use of forests used to be an important subject since ancient times in India. The rules for the city administrator pronounced by *Chanakya* in the fourth century BCE testify that the ancient rulers were keen on maintaining hygiene and cleanliness. According to ancient Indian scriptures, cleanliness is Godliness. In Hindu theology forests, trees and wildlife protection held a place of special reverence. Cutting green trees was prohibited and punishment was prescribed for such acts. *Manu* (legendary author of an important Sanskrit law code, the Manu-smriti or Laws of Manu) advised not to contaminate water by urine, stool or coughing, impious objects, blood and poison. *Yagyavalkya Smriti* (Dharma-related texts of Hinduism composed in Sanskrit) and *Charaka Samhita* (Sanskrit text on Indian traditional medicine) gave many instructions for the use of water for maintaining its purity. The earliest concern for wildlife could be traced to third century BCE when King Ashoka enacted the law of preservation of wildlife and environment. *Arthashastra*, an ancient Indian Sanskrit treatise on statecraft, economic policy and military strategy, prescribed punishment for causing pollution, cutting trees and damaging forests and these rules were applicable to all: from common man to royals. Thus, traditionally, environmental ethics formed an inherent part of Indian religious philosophy and it can be concluded that ancient India had a philosophy of environmental protection and management (www.germanwatch.org/en/download/20503.pdf; accessed 09.06.2019). Guru Nanak (founder of the Sikh Religion, 1469–1539), said '*Pawan Guru, Pani Pita Mata Dhart Mahat, Divis Raat Doi Daia, Khele Sagal Jagat*' (air is like God, water is father and Earth is the mother). It is through the harmonious interaction of all these three vital ingredients that the whole universe is being sustained (Singh, 2009).

3.2 Scenario of Medieval India (1638–1800 AD)

During the Mughal period, forests were considered as mere woodlands. Barring 'royal trees', which enjoyed patronage from being cut except upon a fee, there was no restriction on cutting of other trees and as a consequence forest cover during this period shrank steadily in size. However, the religious policy of Akbar, based on the principal of complete tolerance, also reflects concern for protection of birds and beasts in so much so as endeavours were taken during his reign to stop their unnecessary killing.

3.3 Scenario of British India (1800–1947 AD)

With the establishment of British Colonial rule, many changes were brought in the religiously oriented indigenous system. The British regime saw the beginning of organised forest management. It was the forestry, wildlife and water pollution, which attracted their attention. During the reign of Britishers though several laws were enacted as a strong step towards the conservation of ecological system of India, they served only as a veil to conceal the imperialist policies under which the Britishers exploited the natural resources of its colonies, specifically the forest areas to draw timber for shipbuilding, iron-smelting and farming. In India, this process greatly intensified in the early years of building of the rail network after about 1853. Various belts, for instance, the sub-Himalayan forests of Garhwal and Kumaon, were declared as 'Protected' forests under the proprietorship of the British government.

In the field of forest protection, the enactment of the Forest Act, 1865 was the first step at asserting the State Monopoly Right over the forests and it was later revised in 1878. The customary rights of rural communities to manage forests were curtailed by this Act. On 19 October 1884, the British Government declared its first Forest Policy by a resolution, stating three prime objectives:

1. Promoting the general well-being of the people in the country,
2. Preserving climatic and physical condition in the country, and
3. Fulfilling the need of the people.

This policy classified the forests into four categories:

1. Forests, the preservation of which was essential for climatic and physical grounds,
2. Forests which offered a supply of valuable timber for commercial purposes,
3. Minor forest which produced only the inferior sort of timber, and
4. Pastures which were forest only in name.

The Forest Act of 1927 specifically denied people having any rights over the forest produce/forest products, simply because they were domiciled there. In the field of wildlife protection, the British practiced selective wildlife conservation. Under the Indian Penal Code (IPC), 1860 the term 'animal' was defined and it declared maiming and killing of animals as an offence punishable under various Sections of the Code. The British Government passed the Elephants Preservation Act, 1879 which prohibited killing, injuring, capturing or any attempt of the same to elephants.

The first direct codified law for wildlife protection was enacted by the British Government – The Wild Birds Protection Act, 1887, which prohibited possession or sale of any kind of specified wild birds. In 1912, the Wild Birds and Animal Protection Act was passed to fulfil the inadequacies of the Wild Birds Protection Act, 1887. The Indian Forest Act, 1927, thereafter consolidated the law relating to forests and the transit of forest produce. During this period, the concern for protection and management of water resources in India came through the Bengal

Regulation VI of 1819, which did not mention protection of water environment from pollution but invested the Government with sovereignty over water resources. It marked radical shift from earlier practices, which treated the water resources as 'common property' with control lying in the hands of the people. The Shore Nuisance (Bombay and Kolaba) Act of 1853 and the Oriental Gas Company Act of 1857 imposed restrictions on the fouling of water. The Merchant Shipping Act of 1858 dealt with prevention of pollution of sea by oil. In 1860, for the first time, an attempt was made to control especially water and atmospheric pollution through criminal sanctions under the IPC, 1860. As against prohibitive provisions under the IPC, 1860, the Easement Act of 1882, allowed a prescription right to pollute the water but it was not an absolute right (one was not to 'unreasonably pollute' or cause 'material injury to other'). Some other earlier laws enacted during the British period were the Fisheries Act, 1897; the Bengal Smoke Nuisance Act, 1905 and Bombay Smoke Nuisance Act, 1912, aimed to control air pollution; Wild Birds and Animals Protection Act, 1912 etc. The Indian Forest Act, 1927 consolidated the law relating to forests, the transit of forest-produce and the duty leviable on timber and other forest products (www.researchgate.net/publication/202780931_National_Forest_Policy_in_India_Critique_of_Targets_and_Implementation; accessed on 01.03.2019).

Thus, the environmental policy during the British rule was not directed at the conservation of nature but rather was directed at the appropriation and exploitation of common resources with a primary objective of earning revenue. Neither were there effective laws for the protection of environment. Further, these laws had a narrow scope and limited territorial reach.

3.4 Scenario after Independence

The Indian Constitution adopted in 1950 did not deal with the subject of environment or prevention and control of pollution as such and there was no precise environmental policy and not much attempts were made to frame any specific policy or law for the protection of environment.

3.4.1 Environmental Policy and Acts—Pre-Stockholm Period (prior to 1972)

Early post-independence period had more stress on the development of infrastructure with little concern for environmental issues and as a result the country witnessed a rapid degradation of the environment (Sharma, 2009–2010). By early 1972, it had been realised (as observed in the Fourth Five-Year Plan earlier) that unless a national body was established to bring about greater coherence and coordination in environmental policies and programmes and to integrate environmental concerns in the plans for economic development, an important lacuna would remain in India's planning process.

Nine early post-independence acts related to environment are as follows:

(a) The Factories Act, 1948: The Factories Act, 1948 provides that the liquid effluents, gases and fumes generated during a manufacturing process should be treated before their final disposal to minimise the adverse effects.
(b) The Prevention of Food Adulteration Act, 1954.
(c) The River Boards Act, 1956 under which river boards were established and empowered to prevent water pollution of inter-state rivers.
(d) The Mines and Minerals (Regulation and Development) Act, 1957.
(e) The Ancient Monuments and Archaeological Sites and Remains Act, 1958.
(f) Prevention of Cruelty to Animals Act, 1960 and as a promotion for enactment of this act there was formation of the Animals Welfare Board of India in 1962. This Act was amended in 2017.
(g) The Atomic Energy Act, 1962.
(h) The Insecticides Act, 1968.
(i) The Wildlife Protection Act, 1972. The act of 1960 was enacted to prevent the infliction of unnecessary pain or suffering on animals. The Wildlife Protection Act, 1972 was enacted to provide protection to wild animals, birds and plants and for matters connected therewith or ancillary or incidental thereto with a view to ensure ecological and environmental security of the country.

Some States took initiative in the field of environmental protection, for example, Orissa River Pollution Prevention Act, 1953 and Maharashtra Prevention of Water Pollution Act, 1969. While the Orissa Act was confined only to rivers, the Maharashtra Act extended to rivers, watercourses, whether flowing or for the time being dry, inland water both natural and artificial, and subterranean streams. Thus, there were scattered provisions for checking pollution of air, water, etc., but there was no unified effort in developing any policy concerning the pollution emanating from these areas.

3.4.2 Environmental Policies and Acts—Post-Stockholm Period (After 1972)

The importance of preserving the quality of life and promoting the environment along with development was stressed in the fourth Five-Year Plan (1969–1974) with a chapter on long-term perspective.

The Stockholm Declaration of 1972 turned the attention of the Indian Government to the boarder perspective of environmental protection. In February 1972, a National Committee on Environmental Planning and Co-ordination (NCEPC) was established in the Department of Science and Technology. This was the apex advisory body in all the matters pertaining to environmental protection and improvement. The Committee was assisted by the Department of Science and Technology and an Office of the Environmental Planning and Co-ordination (OEPC) was set up under the direction of the Chairman of the Committee. Major activities of the OEPC included collaboration with the Project Appraisal Division of the Planning Commission in developing guidelines for evaluating the relevant costs and benefits of developmental projects by considering environmental factors, and formulation of proposals and co-ordination of research programmes on environmental problems. During the tenure of fourth Five-Year Plan, the Wildlife (Protection) Act, 1972 was implemented for rational and modern wild life management.

However, it was only during the fifth (1974–1979) and sixth (1980–1985) five-year plans, concerns that were expressed in the fourth plan were given attention by initiating several programmes.

3.4.2.1 Fifth Five-Year Plan

The fifth five-year plan (1974–1979) emphasised on the involvement of the National Committee on Environmental Planning and Co-ordination (NCEPC) in all major industrial designs and established a link and balance between development planning and environmental management without compromising the quality of life of human beings. In this context, Minimum Needs Programme (covering rural education, health, nutrition, drinking water, etc.) received a fairly high priority, and was expected to minimise environmental pollution and degradation in rural areas.

During the tenure of the Fifth Five-Year Plan, the Water (Prevention and Control of Pollution) Act, 1974 was implemented which established the Pollution Control Boards at Centre and States (CPCB and SPCB) to act as watchdogs for prevention and control of pollution. Stockholm Declaration of 1972 had a huge impact on Indian Republic and the law dealing with Water Pollution was the outcome of the same and reflected the Indian Republic's commitment towards environmental protection. However, as stated earlier, 'Water' is a state subject whereas Water (Prevention and Control of Pollution) Act, 1974 is a Union Legislation. Interestingly, Parliament drew legislative competence to enact Water (Prevention and Control of Pollution) Act, 1974 from the resolutions passed to this effect under Article 252 by 12 States. In 1977 the Water (Prevention and Control of Pollution) Cess Act, hereinafter referred to as Cess Act was enacted by the Parliament and came into force on 1 April 1978 to augment the resources of the CPCB and SPCBs and Pollution Control Committee (PCC) of the Union Territories established under the Water (Prevention and Control of Pollution) Act by imposition of cess on water usage by specified persons and authorities. Cess Act was complementary to Water Act as it generated revenue for the Boards so that they could function smoothly and achieve the objectives of Water Act. Like Water Act, Cess Act was also enacted by Union Legislature, that is, by the Parliament. Cess Act was a relatively small enactment having only seventeen sections. The Cess Act was abolished through the Taxation Laws Amendment Act, 2017 with the implementation of the Goods and Services Tax (GST).

3.4.2.2 Sixth Five-Year Plan

In the sixth five-year plan (1980–1985) an entire chapter on ‘Environment and Development’ was included to emphasise sound environmental and ecological principles in land use, agriculture, forestry, wild life, water, air, marine environment, minerals, fisheries, renewable energy sources, energy and human settlements. It provided guidance on environmental concerns to administrators and resource managers in formulating and implementing programmes and laid down an institutional structure for environmental management in the country.

During this time, Acts like (i) The Forest (Conservation) Act, 1980 aimed to check deforestation, diversion of forest land for non-forestry purposes, and to promote social forestry and (ii) The Air (Prevention and Control of Pollution) Act, 1981 (hereinafter referred to as Air Act), aimed at checking air pollution by Pollution Control Boards were passed by the Parliament. Air Act was enacted under Article 253 of the Constitution. The Act came into force on 16 May 1981 and it applied to whole of India. The objectives of the Air Act, as stated in the Preamble, are as follows:

(i) To provide for the prevention, control and abatement of air pollution,
(ii) To provide for the establishment of Central and State Pollution Boards for carrying out the purposes of the Act,
(iii) To confer powers upon Central and State Boards for carrying out the functions assigned by the Act and
(iv) To preserve the quality of air.

3.4.2.3 Seventh Five-Year Plan (1985-90)

The basic approach taken by the Seventh Plan (1985–1990) was to emphasise on sustainable development in harmony with the environment, as the federal government had recognised the negative effects that development programmes were having on the environment. The Plan called for the government and voluntary agencies to work together to create environmental awareness: ‘This is a philosophy which must permeate the entire effort in the field of environment. However, even today this basic philosophy has still not taken hold because the entire emphasis on industrialisation, agribusiness and power-generation projects (form First to Fourth Five-Year Plans), with little concern for environmental protection, has not relinquished its grip on decision makers’.

The Seventh Plan recognised that the nation’s planning for economic growth and social well-being in each sector must also work to secure improvement in environmental quality. The leaders of the country had realised that poverty and underdevelopment, as opposed to development activities, had led to many of the country’s environment problems. The first National Water Policy was also adopted in September, 1987.

In the Indian context, many legislations have emerged specifically focusing on the kinds of pollution, like the Air (Prevention and Control of Pollution) Act, 1981 or the Water Prevention and Control of Pollution) Act, 1974. But, the Environment Protection Act, 1986 is one of the most exhaustive legislation for the protection for the environment. It was enacted during this Plan period under Article 253 of the Constitution. The Environment (Protection) Act, 1986, a landmark legislation provides for single focus in the country for protection of environment and aims at plugging the loopholes in existing legislations. It provides mainly for pollution control, with stringent penalties for violations.

National Forest Policy '(NFP), 1988 was implemented during seventh Five-Year Plan with the basic objectives of maintenance of environmental stability and restoration of the ecological balance (www.researchgate.net/publication/202780931_National_Forest_Policy_in_India_Critique_of_Targets_and_Implementation; accessed on 03.03.2019). NFP, 1988 laid emphasis on people's participation through Joint Forest Management Programme and together with Forest (Conservation) Act, 1980 helped in stabilisation of country's forest area over the last three decades in spite of huge demand on forest land for development and the ever-increasing pressure for forest produces. The Forest Conservation Act was amended in 1988 to strengthen the legislative framework required for conservation of forests and its resources. The amended Act provides environmental stability and maintenance of ecological balance. As a progressive policy, NEP, 1988 highlighted primary functions of forests in maintaining ecological and environmental balance and preservation of biodiversity, four years before UNCED (Rio Earth Summit).

3.4.2.4 Eighth and Ninth Five-Year Plans

During the time frame of eighth Five-Year Plan (1992–1997) and ninth Five-Year Plan (1997–2002), few acts, rule and policies relevant to environmental management were formulated and implemented.

The Public Liability Insurance Act, 1991, provides for mandatory insurance for providing immediate relief to persons affected by accidents occurring while handling any hazardous substance. The National Environment Tribunal Act, 1995 was formulated since civil courts litigations took a long time (as happened in Bhopal Gas Tragedy case). The Act provides for speedy disposal of environmental related cases through environmental tribunals. Under the Act, four benches of the tribunal were set up in Delhi, Calcutta (now Kolkata), Madras (now Chennai) and Bombay (now Mumbai) and 8000 of the most hazardous industrial units in the country were brought under its surveillance. National Environment Tribunal Act (1995) provides strict liability for damages arising out of any accident occurring while handling any hazardous substance. The Biomedical Waste (Management and Handling) Rules, 1998 is a legal binding on the health care institutions to streamline the process of proper handling of hospital waste such as segregation, disposal, collection, and treatment. These rules have been suppressed by the Bio-Medical Waste Management Rules, 2016. According to the Noise Pollution Rules (2000), the state government has the authority to categorise industrial, commercial and residential or silence zones and to implement noise standards as per the category of the area. Batteries (Management & Handling) Rules, 2001 deal with the proper and effective management and handling of lead acid batteries waste. The rules require all manufacturers, assemblers, re-conditioners, importers, dealers, auctioneers, bulk consumers, consumers, involved in manufacture, processing, sale, purchase and use of batteries or components thereof, to comply with the provisions of Batteries (Management & Handling) Rules, 2001.

Policies relevant to environment, formed during eighth and ninth Five-Year Plans, are as follows:

- National Conservation Strategy and Policy Statement on Environment and Development, 1992: It is an expression in response to the need for laying down the guidelines that will help to weave environmental considerations into the fabric of our national life and of our development process. It is an expression of our commitment for reorienting policies and action in unison with the environmental perspective (http://moef.gov.in/wp-content/uploads/2017/07/introduction-csps.pdf, accessed on 16 May, 2020).
- Policy Statement on Abatement of Pollution, 1992: The objective of this policy is to integrate environmental considerations into decision making at all levels. To achieve this, steps have to be taken to: prevent pollution at source; encourage, develop and apply the best available practicable technical solutions; ensure that the polluter pays for the pollution and control arrangements; focus protection on heavily polluted areas and river stretches and involve the public in decision making.
- National Agriculture Policy, 2000: This policy aims to attain growth: (i) based on conservation of soil, water and biodiversity, (ii) at a rate >4% per annum in the agriculture sector, (iii) with equality, (iv) that is demand driven and caters, the small markets and maximises benefits from exports of agricultural products in the face of the challenges arising, from economic liberalisation and globalisation and (v) that is sustainable technologically, environmentally and economically (https://www.economicsdiscussion.net/articles/highlights-on-national-agriculture-policy-2000/2086, accessed on 17 May, 2020).
- The National Population Policy, 2000: This policy provides a policy framework of achieving goals and prioritizing strategies to meet the reproductive and child health and to prevent and control communicable diseases. It also aims to stabilize population by 2045 (http://www.yourarticlelibrary.com/law/highlights-on-national-population-policy-2000-india/31384, accessed on 17 May, 2020).

3.4.2.5 Tenth Five-Year Plan

During the tenure of the tenth five-year plan (2002–2007), the Indian Government had adopted the following Acts, Policy and Notification:

1. Biological Diversity Act, 2002

2. Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006
3. National Environmental Policy 2006
4. Environmental Impact Assessment (EIA) Notification, 2006

Biological Diversity Act, 2002: Central Government had enacted this Act in the year 2002. The genesis of the law can be traced to the Convention on Biological Diversity (CBD), which was signed at the Rio Summit in 1992 and India was a Party to the Convention. The Convention recognized the sovereign rights of States to use their own biological resources and expected the parties to facilitate access to genetic resources to other parties subject to their national legislation and on mutually agreed terms (Article 3 and 15 of CBD). Some salient features of this Act are: (a) to regulate access to biological resources of the country with the purpose of securing equitable share in benefits arising out of the use of biological resources; and associated knowledge relating to biological resources, (b) to conserve and sustainably use biological diversity, (c) to respect and protect knowledge of local communities related to biodiversity, (d) to secure sharing of benefits with local people as conservers of biological resources and holders of knowledge and information relating to the use of biological resources, (e) to conserve and develop areas of importance from the standpoint of biological diversity by declaring them as biological diversity heritage sites, (f) to protect and rehabilitate threatened species and (g) to involve institutions of state governments in the broad scheme of the implementation of the Biological Diversity Act through constitution of committees.

Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006: This Act recognizes the rights of forest-dwelling scheduled tribes and other traditional forest dwellers over the forest areas that are inhabited by them. It was for the first time that through this Act the rights of the forest dwelling people got recognized in the Indian Forest Policy formation. Traditionally the forest dwellers held only the right to collect and use the forest produce. This Act recognized the rights of scheduled tribes and forest dwellers to forest land in terms of living, holding, and occupying the forest land under Section 3 of this Act. The Act also provides for certain duties of the forest dwellers to protect the wildlife and diversity of the forests and to promote sustainability in the ecological areas (http://www.epw.in, accessed on 5.11.2019).

National Environmental Policy, 2006: This policy is a response to India's national commitment to a clean environment, mandated in the Constitution in Articles 48 A and 51 A(g), and strengthened by judicial interpretation of Article 21. It is intended to be a guide for regulatory reforms, programmes and projects for environmental conservation; and review and enactment of legislation, by agencies of the Central, State, and Local Governments (https://www.india.gov.in/national-environment-policy-2006 accessed on 18.4.2019). National Environmental Policy, 2006 was adopted:

- To protect and conserve critical ecological systems and resources,
- To ensure equitable access to environmental resources and quality for all sections of society, and in particular, to ensure that poor communities, which are most

dependent on environmental resources for their livelihoods, are assured secure access to these resources,
- To ensure judicious use of environmental resources to meet the needs and aspirations of the present and future generations,
- To integrate environmental concerns into policies, plans, programmes, and projects for economic and social developments,
- To ensure efficient use of environmental resources in the sense of reduction in their use per unit of economic output, to minimize adverse environmental impacts,
- To apply the principles of good governance (transparency, rationality, accountability, reduction in time and costs, participation, and regulatory independence) to the management and regulation of use of environmental resources and
- To ensure higher resource flows, comprising finance, technology, management skills, traditional knowledge, and social capital, for environmental conservation through mutually beneficial multi-stakeholder partnerships amongst local communities, public agencies, academic and research community, investors, and multilateral and bilateral development partners.

Environmental Impact Assessment (EIA) Notification, 2006: Till January 1994, obtaining environmental clearance from the Central Ministry was only an administrative requirement intended for mega projects undertaken by Government and Public Sector Undertakings. For environmental clearance, EIA was introduced in the Indian legal system by adopting EIA Notification in January 1994 by the Ministry of Environment and Forest (MoEF), Government of India. The Notification made EIA statutory for various developmental activities. With time various constrains in the environmental clearance process under EIA Notification, 1994 were identified and therefore, MoEF conducted a comprehensive review of the 1994 environmental clearance process, under the World Bank assisted Environmental Management Capacity Building (EMCB) Project in 2001. The Central Government also set up the Govindarajan Committee in 2002 to examine procedures for investment approvals and implementation of projects and suggests measures to simplify and expedite the process of both public and private projects. Both the studies brought out the need for reframing the EIA Notification 1994. On the basis of their recommendations MoEF, published EIA Notification, 2006 on 14.9.2006 to formulate a transparent, decentralised and efficient regulatory mechanism to: (i) incorporate necessary environmental safeguard at planning stage, (ii) involve stakeholders in the public consultation process and (iii) identify developmental project based on impact potential instead of the investment criteria (Nomani, 2010).

3.4.2.6 Eleventh Five-Year Plan

During the tenure of the eleventh five-year plan (2007–2012), the Indian Government had adopted the following Act, Notifications and Policy:

1. National Green Tribunal Act, 2010

2. Coastal Regulation Zone (CRZ) Notification, 2011
3. Island Protection Zone (IPZ) Notification, 2011
4. National Water Policy, 2012

The National Green Tribunal Act, 2010: The National Green Tribunal Act, 2010 had been enacted with the objectives to establish a National Green Tribunal (NGT) for the effective and expeditious disposal of cases related to environment protection and conservation of forests and other natural resources. It also includes enforcement of any legal right related to environment and giving relief and compensation for damages to persons and property and for matters connected with it (http://cpcbenvis.nic.in/pdf/National Green Tribunal Act 2010/pdf accessed on 16.5.2020).

Coastal Regulation Zone (CRZ) Notification, 2011: The Ministry of Environment and Forests, Government of India had issued the Coastal Regulation Zone Notification *vide* Notification no. S O. 19(E), dated January 06, 2011 with following objectives: (a) to ensure the livelihood security to the fishing communities and other local communities living in the coastal areas, (b) to conserve and protect coastal stretches and (c) to promote development in a sustainable manner based on scientific principles, taking into account the dangers of natural hazards in the coastal areas and sea level rise due to global warming (www.indiaenvironmentportal.org.in/content/431036/report-of-the -committee-to-review-the-issues-relating-to-the-coastal-regulation-zone-2011-shailesh-nayak-committee/ accessed on 2.5.2019).

Islands Protection Zone (IPZ) Notification, 2011: On January 07, 2011 the Indian Ministry of Environment and Forests (MoEF) released for the first time, an Islands Protection Zone Notification (IPZ), 2011 to cover the coastal stretches of Middle Andaman, North Andaman, South Andaman and Greater Nicobar and entire area of the other islands of Andaman and Nicobar and the Lakshadweep and their water area up to territorial water limit (12 nautical miles) (http://environmentclearance.nic.in/writereaddata/SCZMADOCUMENTS/Island% 20Protection%20 Zone%20Notification,%202,011.pdf assessed on 16.5.2020). The Notification restricts the areas from the setting up and expansion of any industry, operations or processes and manufacture or handling or storage or disposal of hazardous substances. The separate Island Protection Zone Notification, 2011 was required as the geographical areas of Andaman and Nicobar and Lakshadweep islands are so small that in most of the cases the 500 metres CRZ regulations overlap. The objectives of IPZ, 2011 are: (a) protection of livelihoods of traditional fisher folk communities, (b) preservation of coastal ecology and (c) promotion of economic activity that have necessarily to be located in coastal regions. The new provisions included easing floor area ratio (FAR) in coastal urban areas and slashing the No Development Zone (NDZ) in densely populated coastal rural areas to 50 metres from High Tide Line. It also includes NDZ of 20 meters for all Islands.

Under this notification, the coastal areas of Andaman and Nicobar Islands are classified as:

ICRZ-I: The areas that are ecologically sensitive and between Low Tide Line and High Tide Line.

ICRZ-II: The areas that have been developed up to or close to the shoreline.

ICRZ-III: Areas that are relatively undisturbed and those do not belong to either category above which include coastal zone in the rural areas (developed and undeveloped) and also areas within municipal limits or in other legally designated urban areas, which are not substantially built up.

ICRZ-IV: The water area from the Low Tide Line to 12 nautical miles and tidal influenced water area.

National Water Policy, 2012: The first National Water Policy was adopted in September 1987 to govern the planning and development of water resources in India and their optimum utilization. It was reviewed and updated in 2002 and later in 2012. The policy envisages: (a) to establish a standardized national information system with a network of data bank and data bases, (b) resource planning and recycling for providing maximum availability, (c) to give importance to the impact of project on human settlement and environment, (d) to set guidelines for the safety of storage dam and other water-related structures, (e) to regulate exploitation of groundwater, (f) to set water allocation priorities in the following order: drinking water, irrigation, hydropower, navigation, industrial and other uses and (g) to rationalize water rate for surface water and groundwater keeping in mind to the interest of small and marginal farmers (http://mowr.gov.in/sites/default/file/NWP2012Eng6495132651_1.pdf, accessed on 17.5.2020).

3.4.2.7 Twelfth Five-Year Plan

During the tenure of the twelfth five-year plan (2012–2017), the Indian Government had adopted the following rules relevant to environment:

1. Bio-Medical Waste Management Rules, 2016
2. Solid Waste Management Rules, 2016
3. Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016

Bio-Medical Waste Management Rules, 2016: Medical care is vital for our life and health, but the waste generated from medical activities represents a real problem for nature and human beings. Every day, relatively large amount of potentially infectious and hazardous wastes are generated in the health care institutions around the world. Such waste includes soiled cotton, bandages, hypodermic needles, syringes, tubing's such as intravenous sets, and urinary catheters etc. Such waste is commonly called as bio-medical waste (BMW). In order to tackle the problem of bio-medical waste, the Ministry of Environment, Forests and Climate Change (MoEFCC), Government of India in exercise of the powers conferred by Sections 64, 85 and 256 of the Environment (Protection) Act, 1986, published the Bio-Medical Waste (Management and Handling) Rules, 1998 which were amended in 2000 and 2003. The MoEFCC had notified the new rules known as the Bio-Medical Waste Management Rules, 2016 under the Environment Protection Act, 1986 to replace the earlier rules and the amendments. The new rules are comprehensive, stringent and several new provisions have been added in the new rules. They are: (a) every occupier generating bio-medical waste including health camp and *ayush* requires to obtain authorisation, (b) duties of the operator (a person who owns or controls a Common Bio-medical Waste Treatment Facility) listed, (c) biomedical waste divided into four categories (yellow, red, white and blue), (d) treatment and disposal of bio-medical waste made mandatory for all health care establishment, (e) a format for annual report appended with the rules and (f) number of schedules reduced from six to four (https://dhr.gov.in/sites/default/files/Bio-medical_Waste_Management_Rules_2016.pdf; accessed on 10.3.2019).

Solid Waste Management Rules, 2016: Solid Waste Management (SWM) Rules, 2016 were notified on 8th April 2016 and these rules replaced the Solid Waste (Management and Handling) Rules, 2000. Enactment of new rules of 2016 was part of the initiative of MoEFCC to update, consolidate and amend all rules related to waste management in India. The new rules have made various changes in waste management in India including imposition of responsibilities upon various stakeholders regarding minimization, recycling and management of waste to preserve and protect the environment (CPCB, 2017). The salient features of SWM Rules, 2016 are: (a) the source segregation of waste has been mandated to channelize the waste to wealth by recovery, reuse and recycle, (b) responsibilities of waste generators have been introduced to segregate waste into three streams (wet, dry and domestic hazardous wastes) and handover segregated waste to authorized rag-pickers or waste collectors or local bodies, (c) generator will have to pay 'user fee' to waste collector and 'spot fine' for littering and non-segregation, (d) bulk and institutional generators, market associations, event organisers, hotels and restaurants have been made directly responsible for segregation and sorting the waste and manage in partnership with local bodies, (e) all resident welfare, market associations, gated communities and institution with 5000 m^2 or more area should segregate waste at source into valuable dry waste and handover recyclable material either to the authorised waste pickers or the authorised recyclers or the urban local bodies, (f) the biodegradable waste should be processed, treated and disposed off through composting or bio-methanation within the premises as far as possible, and the residual waste should be given to the waste collectors or agency as directed by the local authority, (g) all manufacturers of disposable products who sale or market their products in such packaging which are non-biodegradable should put in place a system to collect back the packaging waste generated due to their production and (viii) the concept of 'refused derived fuel' (RDF), and the need of waste-to-energy (WTE) are also mentioned in the Rules.

Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016: In order to achieve systematic management of hazardous and other wastes in an environmentally sound manner by way of prevention, minimization, reuse, recycling, recovery, utilization including co-processing and safe disposal of waste, the MoEFCC notified the Hazardous and other Wastes (Management and Transboundary Movement) Rules, 2016 on 4th April, 2016. These Rules were framed by the government while exercising powers under Sections 6, 8 and 25 of the Environment Protection Act, 1986. These Rules supersede the Hazardous Wastes (Management, Handling and Transboundary Movement) Rules of 2008.

The salient features of Hazardous and Other Wastes (Management & Transboundary Movement) Rules, 2016 include the following: (a) the ambit of the Rules has been expanded by including 'Other Wastes', (b) waste management hierarchy in the sequence of priority of prevention, minimization, reuse, recycling, recovery, co-processing; and safe disposal has been incorporated, (c) all the forms under the rules for permission, import/export, filing of annual returns, transportation, etc. have been revised significantly, indicating the stringent approach for management of such hazardous and other wastes with simultaneous simplification of procedure, (d) the basic necessity of infrastructure to safeguard the health and environment from waste processing industry has been prescribed as Standard Operating Procedures (SOPs), specific to waste type, which has to be complied by the stakeholders and ensured by SPCB/PCC while granting such authorisation, (e) procedure has been simplified to merge all the approvals as a single window clearance for setting up of hazardous waste disposal facility and import of other wastes, (f) co-processing as preferential mechanism over disposal for use of waste as supplementary resource, or for recovery of energy has been provided, (g) approval process for co-processing of hazardous waste to recover energy has been streamlined and put on emission norms basis rather than on trial basis, (h) the process of import/export of waste under the Rules has been streamlined by simplifying the document-based procedure and by revising the list of waste regulated for import/export, (i) import of metal scrap, paper waste and various categories of electrical and electronic equipment for reuse purpose have been exempted from the need of obtaining Ministry's permission, (j) responsibilities of State Government for environmentally sound management of hazardous and other wastes have been introduced, (k) list of processes generating hazardous wastes has been reviewed considering the technological evolution in the industries, (l) list of waste constituents with concentration limits has been revised as per international standard and drinking water standard, (xiii) State Government has been authorized to prepare integrated plan for effective implementation of these provisions, and have to submit annual report to MoEFCC and (m) SPCB/PCC has been mandated to prepare an annual inventory of the waste generated, waste recycled, recovered, utilised including co-processed, waste re-exported and waste disposed, and submit to the Central Pollution Control Board by the 30th day of September every year (https://upload.indiacode.nic.in/showfile?actid=AC_RJ_83_1096_00001_00001_1563872109827&type=rule&filename=hazardous_and_other_wastes_(management_and_transboundary_movement)_rules,_2016.pdf; accessed on 18.05.2020).

3.4.2.8 Post Twelfth Five-Year Plan

The important environmental management instruments post 2017 promulgated by the Government of India are:

1. Plastic Waste Management *(Amendment)* Rules, 2018
2. Draft Environment Impact Assessment (EIA) Notification 2020

Plastic Waste Management (Amendment) Rules, 2018: Under the provisions of Environment (Protection) Act, 1986, India had enacted The Plastic Manufacture, Sale and Usage Rules, 1999 to deal with the growing menace of plastic waste. These rules provided that the minimum thickness of plastic bags should be 20 micron. These rules were amended by Recycled Plastics Manufacture and Usage Rules, 2003. The Rules provided that the recycled plastics shall not be used for packing of food stuffs. These rules were replaced by 2011 rules i.e. Plastic Waste (Management and Handling) Rules, 2011 (Gupta, 2011). The rules established assigned responsibilities for plastic waste management to the urban local body (ULB), set-up a state-level monitoring committee and increased the thickness of plastic carry bags to 40 micron (i.e. it prohibited the use of plastic carry bags of less than 40 micron thickness) with a mandate for retailers to charge a fee for each plastic bag made available. The rules further provided that plastic cannot be used for storing packing, selling or storing *gutkha* (betel quid) and *pan masala* (a mixture of areca nut with slaked lime, catechu and other flavouring agents). The 2011 rules were replaced by Plastic Waste Management (PWM) Rules, 2016, which were far more comprehensive and extend its purview and applicability to rural areas and plastic importers in the supply chain. The minimum thickness of plastic carry bags was raised to 50 micron. The rules also mandated the producers and brand owners to devise a plan in consultation with the local bodies to introduce a collect back system. This system known as the Extended Producers Responsibility (EPR) would assist the municipalities in tackling the plastic waste issue. As a part of the EPR, it also provides for collection of a fee from the producers, importers of plastic carry bags/multi-layered packaging in order to strengthen the financial status of local authorities and, therefore, the plastic waste management system. The 2016 rules were revised on March 27, 2018 to be known as the Plastic Waste Management (Amendment) Rules, 2018. The new rules give thrust on plastic waste minimization, source segregation, recycling, involving waste pickers, recyclers and waste processors in collection of plastic waste fraction either from households or any other source of its generation or intermediate material recovery facility and adopt polluter's pay principle for the sustainability of the waste management system. The other important changes are: (a) the term 'non-recyclable multi-layered plastic' has been substituted by 'multi-layered plastic which is non-recyclable or non-energy recoverable or with no alternate use' (Section 9(3)), (b) the pricing of carry bags has been omitted (Section 15) and (c) the brand owners and producers operating in more than two states have to register with the CPCB through a centralised registration system (https://mpcb.mizoram.gov.in/uploads/attachments/2969833da6ce158354a30c4bb51f2d78/pwm-gazette.pdf; accessed on 19.05.2020).

Draft Environment Impact Assessment (EIA) Notification 2020: The MoEFCC has proposed a revised set of rules for environmental clearance of developmental projects or expansion or modernization of such existing projects requiring capacity addition as there have been several amendments issued to the EIA Notification, 2006, from time to time, for streamlining the process, decentralization and implementation of the directions of Courts and National Green Tribunal. The draft EIA Notification 2020, which is going to replace the EIA notification 2006, was put in the public domain on March 12, 2020 and MoEFCC has sought views and comments from all stakeholders on it within the next 60 days. The intentions of the draft notification are: (a) to make the process of environmental clearance more transparent and convenient through implementation of online system, further delegations, rationalization, standardization of the process etc, (b) to set a mechanism to bring under the regulations projects which have started the construction work, or have undertaken expansion or modernisation or change in product mix without prior environmental clearance or in other words to allow post-facto approval of such violation projects and to waive off any environmental damage that the project may likely to have on the environment against fine or punishment, (c) to reduce the minimum notice period provided to the public for furnishing their response from 30 days to 20 days during public hearing for any application seeking environmental clearance, (d) to reduce the public hearing process from 45 days to 40 days, (e) to reduce the submission of compliance report from twice in a year to once in a year with a rider that Regulatory Authority may seek such compliance reports at more frequent interval, if deemed necessary and (f) to categorize projects related to national defence and security or involving other strategic considerations, as determined by the Central Government as 'strategic' and no information related to such projects shall be placed in the public domain (http://moef.gov.in/wp-content/uploads/2020/03/Draft_EIA2020.pdf; accessed on 19.05.2020).

4 Concluding Remarks

Environmental pollution is causing widespread destruction of natural habitats to the extent that the survival of many of the natural ecosystems and species are at grave risk. The international community has made various efforts to combat such hazards and established organisations to cope up with environmental issues. Various countries across the globe, including India, have enacted legislations dealing with variety of environmental challenges. Though various legislative and policy measures have been taken at the national and international levels yet the environment remains a serious concern and the efforts have not sufficed. Humanity is at risk and we are on pollution bombshell, which is ready to explode anytime and take millions of lives within its sweep unless we act and act stringently. The Constitution of India is a dynamic document and Indian judiciary has, by using interpretative tools, declared various unenumerated rights as fundamental rights. However, despite active role played by the judiciary, the environmental pollution is on the rise. Moreover, no right can be fully protected and guaranteed unless the entire community recognise their moral, ethical, social, and constitutional duties and rise up to abide by them. It is also true that no government efforts can succeed until and unless we, the people of India, unite and fight against environmental degradation and also take measures at our end to reduce the pollution.

References

CPCB (2017). Annual Report (2015-16). Central Pollution Control Board.

Desai, B.S. (2006). UNEP: A global environment authority. *Environ Policy Law*, **36:** 137.

Gupta, K. (2011). Consumer Responses to Incentives to Reduce Plastic Bag Use: Evidence from a Field Experiment in Urban India, SANDEE Working Paper no. 65–11.

Joshi, P.C. and Pant, A.K. (2007). Fighting forest fire: An enviro-socio-legal study in Kumaon Himalaya, M.D.U. *Law J*, **XII, Part-I:** 165–179.

Nomani, Z.M. (2010). Environment Impact Assessment Laws, Satyam Law International.

Shandilya, R. (2015). Evolution of Environmental Policy in India, 1–11.

Sharma, M.K. (2009-10). Judicial control of environmental pollution in India. *Chotanagpur Law J*, **2(2)**.

Singh, J. (2009). Legislative and judicial control of environmental pollution in India: An appraisal. *Law J*, **XVII:** 37–54.

Sharathchandran, U. (2005). Environmental Legislation in India. Unpublished dissertation submitted for partial fulfilment of the requirement for the degree of Master of Laws of the University of Cochin.

Shobajasmin, K.S. (2013). An Economic Analysis of Role of Forests in Carbon Sequestration in Kanyakumari District Tamil Nadu, available at http://shodhganga.inflibnet.ac.in/handle/10603/132835.

Chapter 18
Environment and Development: Looking Towards the Future

Pradip K. Sikdar

1 Introduction

The range of environmental services provided by nature (Chapter 1) helps the Earth's systems to function and allows human to survive on the Earth. The finite resources of the Earth, which should have been shared by all living creatures, are now controlled by human. Human being is now the main custodian and consumer of the Earth's resources. The resources were shared by 3.3 billion people in 1960, which is now being shared by 7.7 billion people. The development activities have also increased manifold during this period resulting in over-exploitation of natural resources and threat to the environmental services provided by nature.

Recognising that the environment is under threat, the world leaders with the help of the United Nations organised the Earth Summits to understand the link between environment and development and define ways and means to encourage environmental-friendly development. The main objective of these summits was to assemble the world leaders, organisations and individuals to identify environmental challenges that the Earth is facing, quantify them, identify cost-effective solutions and prepare doable action plan. This action plan is called the Agenda 21. The other important outcomes of these summits are the 2000–2015 Millennium Development Goals and the 2015–2030 Sustainable Development Goals. The first summit took place in Stockholm (Sweden) in 1972, the second in Nairobi (Kenya) in 1982, the third in Rio de Janeiro (Brazil) in 1992 and the fourth in Johannesburg (South Africa) in 2002. The last Earth Summit, called Rio+20, also took place in Rio de Janeiro in 2012. Apart from these summits, reports were prepared on environment and development by the World Commission on Environment and Development (WCED) (also known as the Brundtland's Commission) in 1987 and World Bank in 1992 to understand the links between economic development and the environment.

P. K. Sikdar (✉)
Department of Environment Management, Indian Institute of Social Welfare and Business Management, Kolkata, India

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0_18

2 The Earth Summits

The United Nations Conference on Human Environment in 1972 at Stockholm was the first to recognise that the human environment is very fragile. There are serious environmental concerns and that the concerns are linked to human behaviour. The Conference declared 26 principles concerning environment and development, an Action Plan with 109 recommendations, and a Resolution (Baylis and Smith, 2005).

The 26 principles of the Stockholm Declaration are as follows:

1. Human rights must be asserted, apartheid and colonialism condemned.
2. Natural resources must be safeguarded.
3. The Earth's capacity to produce renewable resources must be maintained.
4. Wildlife must be safeguarded.
5. Non-renewable resources must be shared and not exhausted.
6. Pollution must not exceed the environment's capacity to clean itself.
7. Damaging oceanic pollution must be prevented.
8. Development is needed to improve the environment.
9. Developing countries therefore need assistance.
10. Developing countries need reasonable prices for exports to carry out environmental management.
11. Environment policy must not hamper economic development.
12. Developing countries need money to develop environmental safeguards.
13. Integrated development planning is needed.
14. Rational planning should resolve conflicts between environment and development.
15. Human settlements must be planned to eliminate environmental problems.
16. Governments should plan their own appropriate population policies.
17. National institutions must plan development of states' natural resources.
18. Science and technology must be used to improve the environment.
19. Environmental education is essential.
20. Environmental research must be promoted, particularly in developing countries.
21. States may exploit their resources as they wish but must not endanger others.
22. States should develop international law concerning liability and compensation for the victims and other environmental damage.
23. Each nation must establish its own standards.
24. There must be cooperation on international issues.
25. International organisations should help to improve the environment.
26. Weapons of mass destruction must be eliminated.

The second Earth Summit held in 1982 at Nairobi reviewed the measures taken to implement the Declaration and Action Plan adopted at the Stockholm Conference, expressed serious concern about the then state of the global environment, discussed issues like climate change and ozone depletion, and envisaged the formation of a special commission for framing long-term environmental strategies for accomplishing sustainable development for 2000 and beyond.

The third conference on Environment and Development took place in 1992 in Rio de Janeiro, Brazil where 178 countries, 2400 non-governmental organisations and 17,000 participants participated. The conference gave unparalleled emphasis and interest in the environment and how to achieve balanced solutions. The outcomes of this Summit are: (i) Rio Declaration on Environment and Development, (ii) Agenda 21, (iii) Convention on Biological Diversity, (iv) Forest Principles, (v) Framework Convention on Climate Change and (vi) establishing the Commission on Sustainable Development (CSD) which began operating in 1993. The Rio declarations are non-binding and consist of 27 principles intended to guide future sustainable development around the world. The key highlights of Rio declarations are:

1. Humans at the centre;
2. States have the right to use their own resources as they see fit;
3. Must integrate the environment into development plans;
4. Should facilitate increased public participation;
5. States should enact environmental legislation and should cooperate where needed;
6. Should actively discourage or prevent relocation of activities or substances harmful to the environment or human health;
7. Apply the precautionary approach;
8. Internalise environmental costs and use economic instruments;
9. EIA should be undertaken for proposed activities;
10. Peace, development and environmental protection are interdependent and indivisible.

Agenda 21 is a comprehensive blueprint of action to be taken globally, nationally and locally by organisations of the United Nations, governments and major groups in every area in which humans influence the environment. The task is to balance economic development with social and environmental objectives. There are 40 chapters, four sections, 100 programme areas. The actions are non-binding. The four sections are:

Section I: Social and economic dimensions which includes combating poverty, changing consumption patterns, population and demographic dynamics, promoting health, promoting sustainable settlement patterns and integrating environment and development into decision-making.

Section II: Conservation and management of resources for development, which includes atmospheric protection, combating deforestation, protecting fragile environments, conservation of biological diversity (biodiversity) and control of pollution.

Section III: Strengthening the role of major groups including the roles of children and youth, women, NGOs, local authorities, business and workers.

Section IV: Means of implementation which includes science, technology transfer, education, international institutions and mechanisms and financial mechanisms.

In 2002, the World Summit on Sustainable Development (WSSD) also known as Rio+10 was held in Johannesburg, South Africa. In this Earth Summit, the

Johannesburg Plan of Implementation was established to assess progress on implementation of the results of the Rio summit—in particular Agenda 21. This implementation plan affirmed UN commitment to 'full implementation' of Agenda 21, alongside achievement of the Millennium Development Goals and other international agreements. It is non-binding. In this summit, the quantitative targets set for economic factors and poverty reduction were to (i) reduce by 50% the population living on less than $1 a day by 2015 and (ii) ensure by 2015 all children complete primary education. The non-quantitative targets for environment were to (i) substantially increase global share of renewable energy sources and (ii) achieve by 2010 a significant reduction in the current rate of loss of biodiversity. The summit focused on (i) the social pillar of sustainable development, (ii) fighting poverty, (iii) equitable access to resources, (iv) debt relief programs and (v) increasing Official Development Assistance (ODA).

The WSSD was followed by the United Nations Conference on Sustainable Development in 2012 held in Rio de Janeiro. This conference is also known as Rio+20 or Rio Earth Summit 2012. A non-binding document 'The Future We Want' was an important outcome of this Earth Summit in which the heads of state of 192 governments renewed their political commitment to sustainable development and declared their commitment to the promotion of a sustainable future by (i) reaffirming the Rio Principles and past action plans, (ii) assessing the progress to date and the remaining gaps in the implementation of the outcomes of the major summits on sustainable development and addressing new and emerging challenges, (iii) engaging major groups and other stakeholders and (iv) promoting green economy. The document also gave an outline of framework for action and follow-up for achieving sustainable development which includes (i) poverty eradication, (ii) food security and nutrition and sustainable agriculture, (iii) water and sanitation, (iv) energy, (v) sustainable tourism, (vi) sustainable transport, (vii) sustainable cities and human settlements, (viii) health and population, (ix) oceans and seas, (x) disaster risk reduction, (xi) climate change, (xii) forests, (xiii) biodiversity, (xiv) desertification, land degradation and drought, (xv) mountains, (xvi) chemicals and waste, (xvii) sustainable consumption and production, (xviii) mining, (xix) education and (xx) gender equality and women's empowerment. The means of implementation of the follow up action are enhancing (i) financial support for all countries, in particular developing countries, (ii) technology transfer to developing countries, (iii) capacity-building and (iv) international trade, especially trade in environmental goods and services. For detailed reading of this document the reader is referred to https://sustainabledevelopment.un.org/futurewewant.html.

Two important achievements of these Earth Summits were: (i) an agreement on the Climate Change Convention, which in turn led to the Kyoto Protocol and the Paris Agreement and (ii) enhance the welfare of indigenous people and not to carry out any activities on their lands that may lead to environmental degradation or endanger their cultural heritage, practices and traditional knowledge.

2.1 Kyoto Protocol

The Kyoto Protocol is an international agreement signed by 192 countries in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005 to reduce carbon dioxide and other greenhouse gas (methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)) emissions during the period 2008–2012. The Kyoto Protocol separated countries into Annex I (Developed countries) and Non-Annex I (Developing countries). Emission limits were placed only on Annex I countries that were required to reduce greenhouse gases by 5.2% on average as compared to 1990 emissions for carbon dioxide, methane, and nitrous oxide and 1995 emissions for fluorinated gases. The Non-Annex I countries participated by investing in projects designed to lower emissions and earning carbon credits which could be sold to Annex I countries. The Annex I countries could then emit higher level of emissions. A second commitment period (2013–2020) was agreed in 2012, known as the Doha Amendment to the Kyoto Protocol in which 37 countries (Australia, European Union (and its 28 member states), Belarus, Iceland, Kazakhstan, Liechtenstein, Norway, Switzerland and Ukraine) have binding targets. As of 3 July 2019, 129 countries have accepted the Doha Amendment, while entry into force requires the acceptances of 144 states. Of the 37 countries with binding commitments, only seven have ratified. For detailed reading of the Doha Amendment, the reader is referred to https://unfccc.int/files/kyoto_protocol/application/pdf/kp_doha_amendment_english.pdf.

2.2 Paris Agreement

Paris Agreement in 2015 (https://unfccc.int/sites/default/files/english_paris_agreement.pdf) is the result of the negotiations in the 17th United Nations Framework Convention on Climate Change (UNFCCC) on measures to be taken after the second commitment period ends in 2020. This agreement is not an amendment of the Kyoto Protocol but a separate instrument which aims to hold 'the increase in the global average temperature to well below 2 °C above pre-industrial levels' by the end of the 21st century and pursue efforts 'to limit the temperature increase to 1.5 °C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change'. Till date, 185 parties have ratified of the 197 parties to the Convention. Each participating country requires communicating an updated climate plan called as 'nationally determined contribution' every five years. The agreement also specifies that developed countries must provide financial assistance to mitigate greenhouse gas emission and adaptation to climate change through simplified approval procedures, especially to least developed countries and small island developing countries.

3 Reports on Environment and Development

In 1987, the report of the World Commission on Environment and Development (WCED, 1987) known as 'Our Common Future' discussed environment and development on single platform and placed environmental issues firmly in the global political agenda. The report asserted that poverty reduction, gender equity, and wealth redistribution was critical to framing strategies for environmental protection. The report also recognised that environmental-limits to economic growth in developed and developing societies existed and that poverty reduces sustainability and accelerates environmental stresses—creating a need for the balancing between economy and ecology.

In 1992, the World Bank published the World Development Report (1992), which also explored the links between economic development and the environment, and emphasised on the need to integrate environmental considerations into development policymaking for sustained economic and human development. To achieve such development, the report proposed a two-fold strategy. The first strategy proposed exploitation of the links between efficient income growth and the environment by (i) eliminating policies that promotes over-use of natural resources such as water, energy, forest products etc., (ii) giving emphasis on population programs, female education, agricultural extension and research, and sanitation and clean water, (iii) encouraging more local participation in the design and implementation of development programs and (iv) emphasising on open trade and investment policies, which encourage technological innovation and transfer. The second strategy is to establish policies and institutions which will lead to decision makers to adopt less-damaging forms of behaviour. The report also calls for an assessment of the costs and benefits of the alternative policies in case there is a possibility of trade-offs between income growth and environmental quality keeping in mind the uncertainty and irreversibility that are associated with environmental processes.

4 Environmental Management for Sustainable Development: The Way Forward

Keeping the above in mind, it was felt that a book dealing with the issues and concerns for human environment in the 'developing countries' would be useful for both academics and policy planners. Thus, this book discusses and tries to understand the natural processes and systems, pollution removal technology, energy conservation, environmental impact assessment process and other tools for environment management, environmental disaster management and risk reduction, water security and aspects of economics, culture, political structure and societal equity from a management point of view. The solutions to the emerging problems of environment need a paradigm shift in approach from a process-based model to a socio-political-economic model involving equality and control over use of the finite natural resources and the balance between Earth's biocapacity and human ecological footprint for environmental management in the developing countries. Therefore, this book has depicted a road-map that seeks to provide an entirely different paradigm of environmental management for sustainable development in developing countries. The model has been elaborated thus:

Understanding the Earth: Much of human history has been influenced by earth science. Ever increasing human activity is disturbing the natural balance of our environment and ecosystem in addition to natural disasters such as flood, hurricanes, volcanic eruptions, earthquakes. Over-withdrawal of groundwater has resulted in water table depletion, water quality deterioration and caused land subsidence. The non-renewable energy sources such as coal and petroleum are fast depleting to generate electricity and drive cars, and in the process, polluting the environment. Landslides and radon gas emission are natural phenomenon but can be accentuated by human intervention. To protect the environment and landscapes from natural and human induced environmental disaster environmental management should integrate an in-depth knowledge of Earth Science, which includes geology, physical geography, landscape ecology, remote sensing, hydrology, environmental geochemistry etc. (Chapter 2).

Ecological Footprint: Ecological footprint shows the effect inhabitants of a particular region have on the environment they live in and on the natural resources they use. The current level of human consumption is more than the Earth's ecological potential, that is, the ecological footprint of all the countries in the world exceeds nature's capacity for regeneration. Recent investigations have reported that ecological footprint is insufficient for ensuring sustainable utilisation of natural resources. A more integrated approach called 'footprint family' involving ecological footprint, carbon footprint and water footprint seems to be more holistic approach for measuring and guiding sustainable use of natural resources. Therefore, benchmarking of 'footprint family' is important for formulating sustainable development strategy of any region by incorporating social and environmental protection policies, political norms and aims more precisely. Also, relevant changes in terms of personal motivation and behaviour are essential at individual level for ensuring a sustainable society (Chapter 3).

Pollution and Treatment Technologies: Air pollution is a major and pressing challenge in today's world faced by developed and developing nations which also includes odour and noise pollution. Goals 3, 7, 11 and 13 of Sustainable Development Goals serve as weapon against air pollution. Goal 3 focuses on good health and well-being for all; Goal 7 targets access to clean and affordable energy; Goal 11 focuses on sustainable cities and communities and Goal 13 tackles climate change. Every step taken to control air, odour and noise pollution through intervention and technological solutions is a step towards these goals which will create a healthy, sustainable world by the year 2030 (Chapter 4).

Water pollution, both surface water and groundwater, is also considered to be a global problem and addressing it is a top priority for sustainable development. Goal 6 of Sustainable Development Goals targets to ensure availability, improve water quality by reducing pollution, increase water-use efficiency, ensure sustainable withdrawals and supply of fresh water and sustainable management of water and sanitation for all. Water pollution has severe negative impacts on ecosystems, fisheries, food production, health and social development, and economic activities. To alleviate these negative impacts surface water treatment technologies like floatation, sedimentation, filtration, adsorption and disinfection may be adopted. Similarly, groundwater in different countries, especially in developing countries is polluted with iron, manganese, arsenic, fluoride and uranium. Iron and manganese can be removed by aeration followed by precipitation or sedimentation; arsenic by oxidation, coagulation–flocculation/co-precipitation, adsorption, bio-sorption, ion-exchange, membrane process and electro-coagulation; and fluoride by chemical precipitation/coagulation, electro-coagulation, adsorption, ion-exchange, membrane technology; and uranium by reduction, biological reduction, inhibition of re-oxidation, adsorption, bio-sorption and incorporation into stable mineral phases (Chapter 5).

Solid wastes create air pollution, groundwater contamination and soil contamination. Open dumping of wastes generally becomes breeding ground for various dreadful disease-causing pathogens and vectors, particularly in the vicinity of the disposal sites. Population growth and consequent increase in the volume of solid waste in cities and towns is also posing a major challenge in developing countries. Governments, therefore, are putting priority to scientific disposal and solid waste management for healthy and hygienic environment of cities and towns, and it is being included as a component in the Urban Planning and Development. But there is an urgent need to promote community awareness and change the attitude of people towards waste for sustainable waste management (Chapter 6).

Environmentally Sustainable Practices and Energy Conservation: Modern technology for protecting the environment has its root in ancient civilisation across the globe. Therefore, understanding the ways of living as practised in ancient and medieval times, blending them with modern scientific knowledge and developing simple solutions to environmental problems through environmentally sustainable practices may be a key to sustainable development (Chapter 7).

Energy generation from fossil fuels coupled with its inefficient use can irreparably harm the environment as burning of fossil fuels emit greenhouse gas which leads to global warming and consequent catastrophic changes in the Earth's climate. Technologies such as carbon capture and storage may help to reduce greenhouse gas emissions, construction of energy efficient buildings, use of renewable resources, etc. may help to reduce greenhouse gas emissions generated by fossil fuels (Chapter 8).

Water Security: Water security is a conceptualised term which ensures every citizen with the amount of quality water they need for their everyday life. In urbanised areas, water insecurity can be a product of unrestricted population growth, poor governance and mismanagement of the water supply system. Parallel physical processes, such as anthropogenic climate change accelerate the insecurity of water further. Urban water security is a result of socio-economic activities in metropolitan, urban and sub-urban areas. Due to the complicated economic conditions and the delicate socio-political circumstances, achieving urban water security status is still lagging behind in developing countries. Therefore, it is imperative to understand the dimensions, measurement approaches and indicators used to define urban water security and then to build a comprehensive framework for measuring and evaluating water security for the cities, particularly for emerging countries (Chapter 9).

Tools for Environmental Management: Remote sensing and Geographic Information System play a pivotal role in environmental mapping, mineral exploration, agriculture, forestry, geology, water, ocean, infrastructure planning and management, disaster mitigation and management etc. In the recent years, very high spatial and spectral resolution satellite data are available on various environmental parameters. These data can be used to measure the changes in the physical environment in time and space which would help in better managing environmental issues like, climate change, mining environment, urban mapping and land use change analysis, wetlands and watersheds mapping, groundwater investigation, coastal and marine environment, mapping of invasive species, and disaster management (Chapter 10).

Environmental Disaster Management and Risk Reduction: Environmental disaster risks are threats to human well-being that adversely affect the sustainable development. Disaster risk is an inherent characteristic of human society, originating from the interaction between bio-physical and anthropogenic factors (sometimes combinedly) and subject to be controlled by the human itself. Therefore, a well-planned 'disaster management and risk reduction strategy' which is integrated and inclusive with state of art methods applied is imperative for a comprehensive environmental management for sustainable development (Chapter 11).

Environmental Impact Assessment (EIA): In recent years, major projects have encountered serious difficulties because insufficient account has been taken of their relationship with the surrounding environment; of resource depletion; of public opposition; financially encumbered by unforeseen costs; held liable for damages to natural resources; and held responsible for the cause of disastrous accidents. As a result, it is very risky to undertake, finance or approve a major project without first taking into account its environmental consequences—and then siting and designing the project so as to minimise adverse impacts. Thus, EIA has been considered to be a pillar for robust, economically-viable projects apart from economic analysis and engineering feasibility studies for better and more successful projects (Chapter 12).

Imperatives of Environmental Management Systems: Most developing nations have successfully established environmental regulations over the years setting limits for environmental contamination. Enforcement of these laws resulted in approaches of mere environmental compliance. Organisations rarely took the onus of handling their environmental burdens in a proactive manner, thus eventually resulting in inefficient energy consumption, compromising health and safety due to increasing emissions and disposal of hazardous waste in an inconsequential manner. Most developing nations still face tremendous challenges in their efforts to develop a cleaner environment. Tools such as life cycle assessment and environmental audit should be used proactively by organisations in developing nations to enhance their environmental management systems, thereby reducing environmental liabilities and improve their image (Chapter 13).

Economic Values of the Environment: Economic values to the environmental effects of development projects are becoming increasingly important in decision-making about projects and policies. Economic valuation of the environment deals with a series of techniques that economists use to assess the economic value of market and non-market goods, namely natural resources and resource services. Contingent valuation method (CVM) is the most popular and most applicable method of estimating the values of natural resources which have non-market as well as non-use values (Chapter 14).

Geopolitics: Environment and its management as a whole has increasingly become more of a political agenda as the natural resources are gradually dwindling and weakening leading more pressure to be built on the resource-politics trade off. This is being reflected in the climate CoP held during the last decade where the summits are being extended to arrive at a unanimous decision. Many refer to this trend as an indicator of unwillingness of the countries, particularly the more financially and carbon emission rich countries, to contribute substantially in the reduction of carbon footprint of the globe and hence also in temperature rise; it also underlines the increasing importance of geopolitics in global climate negotiation (Chapter 15).

Socio-cultural Challenges: Political leaders and global capital consistently deny the scientifically established facts of global warming and climate change. The reasons for this denial are located in the large-scale inequalities that have emerged in the recent past due to a particular socio-economic system that has gained traction globally. Social sciences have been late in entering the debate on environment as it banked heavily on the discourses of modernity, which led it to believe that solutions to the crisis would emerge from the discourses of modernity itself. The solutions may lie in falling back upon cultures of sustainability rather than seeking answers in sustainable development (Chapter 16).

Legal Framework: Legal instruments play a key role in ensuring the sustainable management, which includes a complex and interlocking body of treaties, conventions, statutes, regulations, and common law that, very broadly, operate to conserve natural resources for their better use by present day society as well as by future generations as well as regulate the interaction between human beings and natural resources. Understanding and strengthening of the legal aspects both at national and international levels are vital to protect environment and reduce the impact of climate change (Chapter 17).

5 Future Environmental Manager

The present environmental mangers are ecologists who are concerned with the abundance and distribution of organisms and the relationships between organism and their environment. They are not much concerned with management goals, policies and practices. Future environmental managers should understand the structure and function of the Earth's system, benchmark 'footprint family' for sustainable use of natural resources, develop and measure success of schemes for pollution reduction and prevention, develop waste recycling and management strategies, promote renewable energy, and devise the best tools and systems to monitor environment as well as environmental performance. The future manager must be equipped to implement policies, ensure compliance with environmental legislation, and incorporate social and environmental protection policies, social and political norms and aims. They should also work to increase the adaptability and resilience of human societies to actual or expected climate change and consequential hazards by bringing in changes in processes, practice and structures to lessen potential damages related to climate change.

References

Baylis, J. and Smith S. (2005). The Globalization of World Politics (3rd ed.).Oxford University Press, Oxford, pp. 454–455.

WCED (1987). Report of the World Commission on Environment and Development: Our Common Future. Oxford University Press.

World Development Report (1992). Development and the Environment. Oxford University Press.

Index

P. K. Sikdar (ed.), *Environmental Management: Issues and Concerns in Developing Countries*, https://doi.org/10.1007/978-3-030-62529-0

F

G