

Chapter 1

Introduction

1.1 Water Security

River safeguards and manages water resources essential for ecosystems, communities, agriculture, and industrial purposes. Metropolitan cities get water for daily demand from the river and play a vital role in the central urban water supply. The water environment supports biological aquatic life diversity and provides water for daily consumption to millions worldwide. Sustainable water management helps keep the river healthy, providing a better ecosystem for natural purification and improving the water quality parameters of concern for better survival of aquatic organisms in the water environment.

With over 1.4 billion people (16 % of the world's population), India accounts for only 4 % of global freshwater resources. According to the National Institution for Transforming India (NITI Aayog, 2019) report the severe challenges in water resources management, the best estimates indicate that India's water demand will exceed supply by a factor of two by 2030. Although India has several major rivers and a significant groundwater reserve, the country is grappling with growing water scarcity in major urban hubs like Delhi, Bengaluru, Chennai, and Hyderabad, which was projected to run out of groundwater. According to a UN report, India will suffer water scarcity by 2050.

The National Commission for Integrated Water Resource Development (NCIWRD), Ministry of Water Resources (MoWR, 1999), Government of India estimated that against a total annual availability of 1521 billion cubic meters (BCM), only 690 BCM surface water could be used, i.e., only 55.6 percent. The threat of water quality deterioration is an area of concern restricting water utilization in many Western countries, including the USA and Europe. The observed presence of Emerging Pollutants (EPs) in drinking water sources in

such developed countries is suggestive for economically developing countries to participate in taking preventive actions to stop such pollutants from entering the surface water sources for protection of human health and survival of aquatic organisms.

Population growth, urbanization, pollution, inefficient water management, and climate change are straining India's water systems, threatening rural and urban livelihoods. Over-extraction of groundwater and poor management of riverine systems should be prioritized, and proper actions should be taken to sustain natural water resources free from toxic contaminants, tackling the imbalance between water supply and demand for sustainable urban and rural development. Keeping water sources free from pollutants will ensure sufficient water availability to meet the country's growing demand. A river system free from contaminants is considered a reliable resource for the survival of ecological diversity and an economical solution to water scarcity.

1.2 Emerging Pollutants (EPs) in water environment

The term 'EPs' has often been used to refer to chemicals detected in low concentrations in surface and groundwaters. According to the United States Geological Survey, EPs are defined as 'all synthetic or naturally occurring chemicals that are not included in the routine monitoring program but have the potential to enter the environment and cause known or suspected negative ecological, (eco) toxicity, and/or human health effects' (USGS, 2017). Concerns about EPs in water started with the work of Rachel Carson in 1962. The widespread use of dichloro-diphenyl trichloroethane (DDT) to eliminate mosquitoes and other pests and diclofenac as antibiotics for humans led to disproportionate death and disappearance of vultures (Sauve and Desrosiers, 2014) and drew the attention of scientists and researchers to their long-term effects. Since then, the consumption of different classes of EPs has increased many times due to population and economic growth.

Today, more than 700 EPs, their metabolites, and their conversion byproducts are reported in the European aquatic environment (www.norman-network.net).

The detection of EPs in many surface water bodies all over the world has developed as a big environmental challenge in recent years (Bolong et al., 2009; Geissen et al., 2015; Maria Gavrilesu et al., 2015; Philip et al., 2018). Although these pollutants have not yet been monitored routinely due to their low concentrations, they are now being examined seriously as they have been found to influence the ecological function of rivers and water bodies (Farre et al., 2008; Poynton and Robinson, 2018). In general, EPs present in rivers have been grouped in six broad classes: (i) Personal Care Products (PCPs), (ii) Endocrine-Disrupting Chemicals (EDCs), (iii) Pharmaceutical Pollutants (PPs), (iv) Persistent Organic Pollutants (POPs), (v) Artificial Sweeteners (ASs), and (vi) Microplastics (MPs). Other classes include food additives, pesticides, fire retardants, etc. ([http:// www.norman-network.net](http://www.norman-network.net), Pena-Guzman et al., 2019, Ranjan et al., 2022).

Among these classes of EPs, pharmaceutical pollutants (PPs) are the most common contaminants in river waters. Hospital wastewater (HWW) and pharmaceutical industries are the primary sources of pharmaceuticals in sewage, contributing to a high load of PPs in river waters. Thus, HWW, if left untreated and discharged to water bodies, may create several undesirable effects on human health and aquatic organisms. It also increases ecotoxicity and microbial resistance in aquatic environments (Felis et al., 2019). Due to their toxic effects on aquatic organisms, they have drawn the global attention of the scientific community concerned with river ecosystems.

1.3 Pharmaceutical Pollutants (PPs) effects on aquatic organisms

Among the six major classes of EPs, PPs are more frequently reported in river waters worldwide, with concentrations from ng/L to $\mu\text{g/L}$ and their effects on the microbiological consortium have been reported by many researchers (Sharma et al., 2019;

Mutiyar et al., 2018; Subedi et al., 2018; Williams et al. 2019; Kumar et al., 2019; Fick et al., 2009; Mutiyar et al., 2014, 2018). The reported measured environmental concentrations (MEC) of PPs in river water up to the predicted no-effect concentration (PNEC) raises the alarm for the survival of three biotic indicators of river health: algae, macroinvertebrates, and fish. Different toxicity assessment measures, such as risk quotient (RQ), hazard quotient (HQ), and optimized risk quotient (RQ_f), are used to understand the risk level due to the presence of PPs on aquatic organisms present in the river environment.

1.4 The Concept of ‘River Health’

River health is a term used to represent the ecological status of a river (Karr and Chu, 1997; Barcelo, 2001). A river is considered healthy if different aquatic populations and communities can survive on it (Dos Santos et al., 2021; Bond et al., 2012). The Ganga River Basin Management Plan (GRBMP) under the Government of India, considered the river Ganga from four perspectives: i. Aviral Dhara (continuous flow), ii. Nirmal Dhara (unpolluted river), iii. Geological Entity, and iv. Ecological Entity (GRBMP, 2015). Biological parameters become important in health monitoring if the river is considered an ecological entity. Healthy rivers can support different aquatic communities and species within them. Different water quality parameters related to oxygen demand, nutrients, and other toxic compounds above the acceptable concentration affect the aquatic species present in the water and change river health dynamics (Leigh et al., 2012; Singh and Saxena, 2018).

1.5 River Health Restoration

In India, with continuously increasing water demand to meet the requirement, water sources need proper management for sustainable development. The increase in population and water consumption have led to an increase in total wastewater production in Class I and II cities, from 7,067 MLD in 1978-79 to 62,000 MLD in 2018-19 (CPCB, 2021). The

estimated wastewater generation is approximately 39,604 MLD in the rural regions. Further, NITI Aayog (2022) estimated wastewater generation from urban areas as 72,368 MLD for 2020-21. Wastewater in urban areas also include used waters from hospitals, which contains many pharmaceutical residues, resistant bacteria, viruses, and other pathogens, which enter the river, if not treated properly, adequately and efficiently (Kaur et al., 2020). The existing sewage treatment plants (STPs) have normally been designed to treat the wastewater up to secondary levels, suggesting improvements in DORPs. Other water quality parameters, such as NTs and PPs require tertiary level treatment for removal. This is a significant addition required to limit the concentration of water quality parameters under acceptable limits (CPHEEO, 2013).

1.6 Need of the Study

Pharmaceuticals are persistent and toxic compounds structurally designed to maximize the risk on biological cells and their residuals in water at low concentrations as PPs act adversely on aquatic life. Among EPs of concern, PPs are of particular significance as they have been found relatively in higher concentrations in many rivers worldwide.

The widespread consumption of antibiotic compounds and their discharge from the human body while reaching river environment increases antibiotic-resistant bacteria (ABRB) (Kummerer, 2009; Gaskins et al., 2002). A significant concern has been raised worldwide for river management systems. According to the World Health Organisation (WHO, 2008) report, removing ABRB from the water environment costs the global economy \$ 100 trillion, with an estimated death of 10 million by 2050. This potentially threatens the river water environment, affecting human and biological species' health (Gaskins et al., 2002; Kummerer, 2009). Due to the rapid rise of ABRB, national and international organizations such as the Ministry of Health and Family Welfare (GoI), the European Antimicrobial Resistance Surveillance Network (EARS-Net) (European Centre for Disease Prevention

and Control, 2017), and the Central Asian and Eastern European Surveillance of Antimicrobial Resistance (CAESAR) have launched action plans to combat its effects, including the key drug resistance trend.

In India, moving with time, heavy metals and pesticide residue measurements are part of river water quality monitoring programs for meeting drinking water quality standards (IS 10500: 2012). However, monitoring of EPs, including PPs in effluents from STPs or river water is yet to come (CPCB, 2016). The need of the hour is to initiate a river health monitoring program that includes all parameters of concern affecting the physical, chemical, and biological qualities of water and aquatic environments.

The overarching objective of the present study is to understand the ecological risk of PPs on biotic indicators of river health. The study has attempted to include PPs as an additional group of indicators in the RHI calculation framework based on risk analyses.

1.7 Research Objectives and Questions

The research objectives have been decided based on a few important questions and considerations as follows:

1. What are broad classes of EPs reported in river waters?
2. Among EPs, what are the pollutants of toxicological concern in the aquatic environment that should be included in routine monitoring?
3. What is the effect of pharmaceutically active compound (PAC) in river ecology?
4. How should the RHI calculation framework be reframed to include the effects of PPs on river health?
5. What approaches are required to reduce the load of pollutants for river health restoration?

1.8 Objective of the Study

In the present study, pharmaceutical pollutants (PPs) have been considered as a representative component of Emerging Pollutants (EPs) in the river environment.

The ultimate objective of the present study is to assess the risk posed by PPs to biotic indicators of river health and develop a framework to calculate RHI, including the effects of PPs, to understand river health conditions in a more realistic way and suggest appropriate strategies for river health restoration to acceptable levels.

The specific objectives planned for the study are:

1. Identification of PPs of major concern, based on:
 - a. Reported concentration above PNEC,
 - b. Frequency of occurrence and reporting,
2. Defining ecologically 'high-risk' conditions, threshold high-risk quotient (RQ_h), and threshold risk concentrations (RC_T) for PPs of major concern.
3. Development of an RHI calculation framework, including EPs/ PPs to assess the RHC.
4. Development of strategies for RHC improvement under three conditions:
 - Installation of a New Sewage Treatment Plant (STP)
 - Augmentation of existing STPs for significant removal of PPs
 - Reducing entry of PPs in a water environment through separation at source

1.9 Organization of the Thesis

The structure of the thesis is based on the defined objectives to reflect the ecological risk of PPs on river health assessment. Environmental Risk Conditions (ERC) of six rivers from India and seven from other parts of the world with reported concentrations of PPs

higher than the PNEC for the three biotic indicator groups have been assessed, analysed and the most frequently reported PPs have been identified.

A framework to calculate an RHI incorporating the possible effects of PPs as the third stress indicator group, in addition to the already accepted two broad indicator groups of DORPs and NTs; and considering three biotic indicator groups of algae, MI, and fish, has been developed and discussed. A color-coded river health hexagon has been developed to visually represent the RHC in pictorial form. Three possible strategies for the reduction of risk through the removal of PPs from wastewater streams have been discussed to improve the indicator group score of PPs and overall RHI to suggest a river health restoration plan.

The organisation of the thesis is as follows:

Chapter 1 briefly describes the presence of EPs, particularly PPs, in river waters, affecting ecological diversity. The included sections explain the need to include the effects of PPs in ecological risk assessment and river health monitoring programs. Some relevant research questions have been identified, and the objectives of the study have been defined.

Chapter 2 presents the literature review on the topics of relevance in light of the objectives of the present study. This includes a discussion on broad classes of EPs, the importance of PPs in river water quality, risk assessment methods, toxic effects of PPs on aquatic organisms, biotic indicators of river health, and the importance of PNEC in risk analysis for three biotic indicator groups. Various conventional sewage treatment technology options have been reviewed to understand their effectiveness for the removal/reduction of PPs from wastewater streams and suggest strategies for river health restoration programs. The research gaps and scope of the study have been identified and summarized at the end of this chapter.

Chapter 3 presents the Research Methodology and discusses various risk assessment methods, fixing threshold risk conditions, threshold risk concentrations for PPs, and the development of a framework for calculating RHI, including the effects of PPs.

Chapter 4 presents the Results and Discussion of the present work. This includes the identification of PPs of major concern in Indian rivers and a few other rivers across the world. The developed framework for RHI calculation is validated using the water quality and associated data of the river Ganga near Varanasi and changes in RHC once reported concentrations of PPs are included through their ecological risks on biotic indicators. Subsequently, case studies of six Indian rivers with available datasets of water quality parameters and seven other rivers from across the world with reported PP concentrations above PNEC have been presented and depicted through color-coded hexagons reflecting RHC. Finally, strategies for river health restoration have been suggested based on the application of Advanced Oxidation Processes (AOPs), primarily through ozonation as a tertiary treatment unit at STPs handling PPs in the influent. Installation of new STPs with advanced technologies, augmentation of existing facilities of STPs through the addition of tertiary treatment units, and source separation of urine from wastewater streams have been examined as three possible approaches to reduce concentrations of PPs reaching rivers, thereby improving RHI and RHC as part of river health restoration program.

Chapter 5 presents the Summary and Conclusions of the study. It also includes recommendations and scope for further studies.

