Chapter 13
A Coherent Review on Approaches, Causes and Sources of River Water Pollution: An Indian Perspective

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Abstract Non-contaminated water or sustaining each sector of fresh water is essential for the survival of all living beings in current and upcoming generations. However, the degradation of freshwater qualities is a significant concern in developing countries (India). The need for clean water is increasing sharply to meet rising human demands constantly. River water is rich in ecological community and plays a vital role in surviving all living beings. Still, presently it is the most threatened ecosystem due to various human-made activities. Hence, meticulous monitoring of river water qualities (RWQs), assessment of numerous variables (physicochemical, bacteriological, pathogenic), and heavy metals content are imperative indicators for finding out the actual health of river water ecosystems. Upsetting the concentration of multiple RWQ variables and metals content leads to deteriorating the RWQ and ultimately affects human well-being. Simultaneously, applying a multivariate statistical approach and computing water quality index (WQI) and comprehensive pollution index (CPI) is also a vital role in understanding the actual status of RWQ. This comprehensive study is focused on various processes, causes, and sources of river water pollution in India. It provides extensive information and better understanding to enable policymakers, preservationists, and environmentalists to develop strategies to mitigate river pollution and strengthen aquatic ecosystems rejuvenation.

Keywords Water · River water pollution · Heavy metals · Multivariate statistics · Water quality index · Comprehensive pollution index

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13.1 Highlights

- This review covers various aspects of river water, and possible causes and sources of river pollution in developing nation like India.
- Point sources like industrials and municipal wastewaters, and non-point source like agricultural runoff are the primary source of river pollution in India.
- Multivariate statistical approaches and water quality indexes are promising tools for river water quality assessment.
- Periodic monitoring of river water quality status by analyses inorganic and organic contaminants and efficient and continuous treatments of wastewater by adopting ETPs and STPs are suggested.

13.2 Introduction

Water is a principal constituent and key resource requisite to sustain life on the earth. It is recognized as a fundamental individual right worldwide, thus a necessity to be handled effectively and efficiently to secure worldwide requirements. Water distribution across the globe is uneven, and water scarcity is now a primary global concern. The significant water utilizes in agricultural, industrial (comprises industrial actions, energy, and mining, etc.), and recreational, domestic/municipal, as well as ecological water application which has a significant effect on the availability of water via physical water abstraction and deterioration of water (Plessis et al. 2017). Human activities are mainly responsible for threatened freshwater ecosystems and stand to be further influenced by climate change. Presently, water scarcity is affecting one-fifth of the global populace, and a quarter of the global public faces a lack of technology to restore freshwater from ponds and rivers (Xiao-jun et al. 2014). Therefore, a framework to investigate the significant threats to water safety at a range of geographical scales from local to worldwide is urgently required (Vörösmarty et al. 2010).

The entire freshwater resources on the planet are evaluated to be 43,750 km^3 year^{-1}. The demand for agricultural freshwater is increasing at an alarming rate due to the continuous increase in the human population and urbanization. The global assessment shows that freshwater's requirement is affected by industrial development, agricultural production, and population expansion in addition to climate change. Globally, freshwater extraction is predicted at 3800 km^3, out of which 70% is for agricultural irrigation with significant fluctuation among and the nations. As the equilibrium between water requirement and availability has arrived at a critical level in various parts of the planet and increasing need for water and agricultural production is probable in the forthcoming, a sustainable way of water resource management is become important (Ayyam et al. 2019).

India is the second-most populated and the seventh-biggest country on the planet, with an entire geographical area of 32,87,590 km^2 (Garg 2012). It is located in the northern part of the Indo-Australian plate as well as north of the equator at 8°4′

and 37°6′ N and 68°7′ and 97°25′ E. India is home to nearly 18% of the world's populace and has approximately 4% of the world's freshwater resources. The rapid population growth has drive pressure on water resources in the country. Rivers and groundwater are significant sources of freshwater provide to the nation. India received approximately 75% of the annual precipitation, 48% mean surface water during monsoons. Overall, the country received <4,000,000 MCM (million cubic meters) of precipitation every year, which also comprises snowfall (Poddar et al. 2014). Besides rapid population growth, climate change also generates extra pressure on the hydrological cycle and changes the aquatic resources structures. According to Central Water Commission (CWC 2013–2014), the potential of water resources in India is predicted to be 1,869,000 MCM given both grounds and surface water (Manju and Sagar 2017).

About 329 million hectares of land in India consists of numerous small and big rivers, some of which are among the world's largest rivers (CWC 2005). Because of limitations in water resources, per capita, water availability (PCWA) also decreases (5177 to 1140 m^3/year) with an increasing populace (361 to 1640 million) from 1951 to 2050 (Fig. 13.1). The country's situation may be classified as water-stressed, when water availability is <700 m^3/capita/year, and water-scarce when water availability is <1000 m^3/capita/year (MoWR 2008; Manju and Sagar 2017). Among the world's 17 'extremely water-stressed nations, India has 13th ranked and is under extremely high levels of baseline water stress (WRI 2019).

Rivers are amongst the essential natural resources of water for humans and other living beings. Rivers aid human development as they meet water demands for irrigation, household use, industrial use, and aquaculture and sustain roles for different fauna and flora. They have founded reservoirs of ecological diversity,
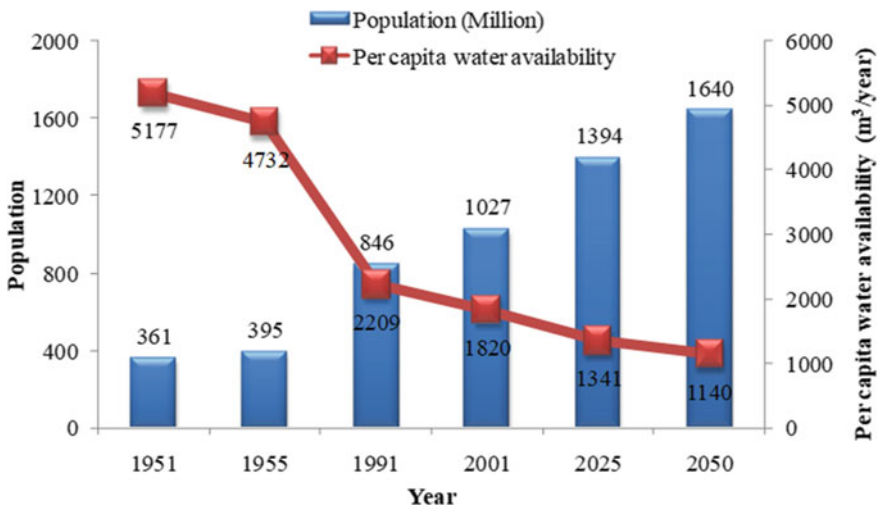

Fig. 13.1 Per capita water availability in India

provide adequate services to the public, and economic benefits. These rivers played a vital role in the development of Indian culture, religious and spiritual life. Most ancient civilizations grew along the river's banks. Even today, millions of people live in the cities developed along the bank of rivers and depend on them for their survival. India is bestowed with an extensive river network and blessed with high rainfall due to the southwestern monsoon, accounting for 75% of the yearly precipitation (Ghosh and Mistri 2015).

India is affluent with 13 major river basins that cover 20,000 km^2 (82.4% of the total river basin of the country) and contributing 85% of the total surface flow and nearly 80% of the country's populace is dwelling in these basins (Dadhwal et al. 2014). Main river basins of the country include the Brahmaputra, Indus (including Satluj and Beas Sub Basin), Ganga (including Yamuna Sub Basin), Krishna, Godavari, Mahanadi, Cauvery, Narmada, Brahmini (including Baitarni Sub Basin), Mahi, Sabarmati, Pennar and Tapi, (CWC 2015).

Government of India (GoI) is focused to clean Ganga River comprise its tributaries for conservation and rejuvenation, which catchment basin covered almost northern India, by launching Namami Gange scheme under National Mission for Clean Ganga (NMCG), Ministry of Jal Shakti. Along with various government bodies like State Project Management Group (SPMG) in Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal, CPCB, CWC and affiliated agencies also working on rejuvenation of river water quality in holistic approaches i.e. cleaning of surface river, ghats, biodiversity conservation, afforestation and upgrading or establishment of STPs and ETPs. Hence, the objective of this review summarizes the literature of various sources and causes of river water pollution in India with respective of monitoring of various parameter and pollution status of Indian rivers. This review helps to intensive sympathetic for upcoming researchers, preservationists, and environmentalists in developing strategies to mitigate river water pollution and rejuvenation.

13.3　River Water Pollution

Degradation of surface water quality due to various human activities such as random urbanization and moderately treated or non-treated industrial effluent released, poor hygiene, inappropriately managed landfills, and other sources of pollution viz pesticides and fertilizers runoff from the farming sector is an area of serious concern (CGWB 2017). In India, just 62% of effluents from industries and 37% sewage from municipal sources are treated (MoEFCC 2019). Several districts have contaminated water sources, thus influencing human wellbeing on a broad scale (CGWB 2017).

Rivers are among the most diversified and vulnerable ecosphere on the globe. The ever-increasing anthropogenic pressure has severely altered these ecosystems. However, various protection and management approaches for rivers have been prepared and executed worldwide to counters this problem. Assessment of rivers' actual status or "health" has become imperative to all such strategies (Srivastava et al. 2017). Diminished river water quality (RWQ) upsets the balance of the aquatic

ecosystem and leads to fatal consequences both for humans and animals. It is an environmental concern and a socio-economic issue that needs to be immediately resolved (Pathak and Mishra 2020). It is recognized that elevated spatial–temporal fluctuations describe streams and rivers, and traditional investigative water quality evaluation techniques involving physicochemical parameters have been considered insufficient (Srivastava et al. 2017). Contamination level in any aquatic body is monitored by comprehensive observation of various physical and chemical variables, bacteriological/coliform, heavy metals, and computing water quality indexes. These parameters act as an indicator to find out the level of contamination. Excessive levels of contaminants through various anthropogenic reasons, which ultimately affect the biological system of aquatic flora and fauna and human beings, should be addressed first.

13.3.1   Major Causes and Sources of River Water Pollution

Numerous sources cause river water pollution on national and international levels. The contaminants include a broad spectrum of organic, inorganic, chemicals, and pathogens. Mainly, river water pollution is caused by point and non-point sources. When pollutants have come into the water body is from a detectable source like industrial effluents/effluent treatment plants (ETPs), major drains, as well as municipal waste/sewage treatment plants (STPs), is called point source (PS) pollution. However, the source of water pollution is not well-known, or pollutants that are not entered from a single disconnected source are called non-point source (NPS) pollution. NPS pollutions are the leading cause of water pollution on national and international scales (Jain et al. 1998; Schwarzenbach et al. 2010; Chaudhry and Malik 2017). As per the Centre for Science and Environment (CSE), about 75–80% of the river water pollution is caused by industrial runoff, municipal sewage, and other wastes are discharged into surface water bodies, including rivers, and it totals over 3000 million liters of wastes per day (Misra 2010; Gaur 2018). The remaining is disposed directly into water bodies, polluting three-fourths of our surface water resources. For example, in northern India, rivers such as the Yamuna are polluted due to numerous sources like agricultural, industrial, urban stormwater runoff, organic contaminants, nutrients, and pathogens (Fig. 13.2).

13.3.1.1   Agricultural Pollutants

Surface runoff from adjacent agricultural fields is a major NPS of pollution and is largely recognized as being more difficult to decrease than point sources. In past decades, organic nutrients have been mainly applied in the agriculture field that might cause eutrophication. But due to the high yield and modernization of agriculture practices after the green revolution (associated with agricultural production through

Fig. 13.2 Various sources and causes of Yamuna River pollution

the use of chemical fertilizers, pesticides, i.e., insecticides, fungicides and herbicides, and machinery), surface/river water pollution increase many times since last few decades (Lal et al. 2016; Chaudhry and Malik 2017; Wato et al. 2020). Chemical fertilizers, pesticides, and herbicides contain metals and metalloids, complex compounds that reach natural water bodies through runoff and may be hazardous to flora and fauna. Some of them are persistent, which takes time to degrade, are more harmful. Therefore, it contaminates water, soil, and irrigated plants and causes various health problems to aquatic flora and fauna, which ultimately affect human wellbeing through the food web (Anju, et al. 2010; Schwarzenbach et al. 2010; Chaudhry and Malik 2017).

13.3.1.2   Industrial Pollutants

Industrial units situated along or close by rivers frequently discharge their effluents and wastes indirectly or directly into the streams/rivers. Most of these manufacturing effluents are toxic to living beings that use contaminated river water. Effluents from electroplating, textile, diamond, chemical, and fertilizer industries, etc., are very chronic. India has numerous types of industrial sectors viz mining, thermal power plant, electroplating, distilleries, sugar, paper, and pulp mills, automobile manufacturing, oil refineries, chemical and pesticide production units, hydropower unit, and so

Table 13.1 Pollution index and category of the different industrial units

PI Score	Category	Approximate industries
60 and above	Red	60
41–59	Orange	83
21–40	Green	63
Upto 20	White*	36

Newly introduced White group have industrial segments which are non-contaminating

on adjacent to surface water body (Gaur 2018). Development/establishment of small and large industrial units are increasing day by day due to increasing population, demand, and upgrading living standards.

In compliance with GoI acts and rules related to environment protection, Central Pollution Control Board (CPCB) has fixed and categorized the industrial sectors in 2016, based on having pollution index (PI) (Table 13.1). PI of the industrial segment is a number between 0–100, and the rising value of PI indicates the increasing amount of pollutants load generated from the industries. The CPCB also formulated and applied the effluent discharge limit for different categories of industries. But following the rules and monitoring of these compliances is very tough at ground levels.

13.3.1.3 Urban Storm Water Runoff

Among various anthropogenic activities, urban regions are accounted to impose the most consistent and ever-present effects on the RWQ, habitat modification, and decline in biodiversity attributed to both the considerable pollutants load from point and non-point sources. In peri-urban and urban regions, buildings cover and pavement lots of the land surface; hence, when there is precipitation or melting of snow, the water does not absorb/soak into the land. This runoff water brings contaminants such as lawn fertilizers, dirt, chemicals, and oil straight to streams and rivers, ultimately a source of water pollution (Letchinger 2000). In ordinary land, these contaminants are captured into soil's pores, and water is filtered. However, as water cannot absorb/penetrate the ground in metropolitan cities, it washes away all of these contaminants into surface water bodies (Chaudhry and Malik 2017). Walsh et al. (2005) formulated "urban stream syndrome" after studying the degradation of streams draining urban runoff. This term addresses problems like negative changes in flow regime, amplification of pollutant loads, riverbed morphology.

13.3.1.4 Sediment Pollution

Sedimentation because of runoff affects RWQ. It decreases the capacity of navigation channels, streams, ditches, and rivers and also reduces sunlight penetration into the water due to disturbed underwater flora. Therefore, the fishes and other

aquatic fauna nourishing on that vegetation were also disrupted, and the entire food web was disrupted. Contaminants such as phosphorus and pesticides are carried and collected because of sedimentation. Sediment particles also affix to fish gills and cause respiratory problems; ultimately, the death of fish may also occur. In addition, sediments bring hazardous chemicals, viz petroleum products, and pesticides, to surface reservoirs, consequently polluting them (Letchinger 2000; Chaudhry and Malik 2017).

13.3.1.5   Heavy Metals Pollution

"Heavy metals (HMs)" is a cluster of metals with an atomic weight >4 g/cm^3, or 5 times or more, higher than water (Hawkes 1997). HMs are of serious concern among the contaminants because of their accumulation characteristics through the food web and generate ecological troubles (Paul and Sinha 2015). Commonly, the majority of the HMs come in the river from different sources, which can be either natural by weathering and erosion or human activities (Kashyap et al. 2016; Paul 2017). HMs concentrations at high levels may form toxic complex compounds, which significantly affect the various biotic systems. The occurrence of HMs in industrial effluents is a possible threat to the ecological community. The occurrence of toxic metals in sediments is because of the precipitation of their hydroxides, sulfides and, carbonates, which set down and form the fraction of sediments. The industries which characteristic toxic metals in surface water are commonly metal industries, varnishes, pigment, paints, rayon, paper and pulp, distillery, rubber, tannery, steel plant, thermal power plant, mining industries, cotton textiles as well as random application of toxic metal-containing fertilizer and pesticides in farming fields (Suthar et al. 2009; Paul 2017). A concise summary of metal sources and possible harmful effects on human wellbeing has been presented in Table 13.2.

The most vital HMs concerning water contamination is arsenic (As), Cu, Cd, Ni, mercury (Hg), Cr, Pb, and Zn. Some metals (e.g. Zn, Mn, Fe and Cu) are essential as nutrients in trace quantities for plants and microbes' biological processes but become noxious at elevated concentrations. The Bureau of Indian Standards (BIS) and CPCB have fixed permissible limits of essential metals concentration in drinking water and discharge for a natural water body. Others like chromium, lead, and cadmium has no role in biotic activities but are toxic metal (Ghannam et al. 2015). These HMs are not easily degradable and bio-accumulates in the human and animal bodies to an excessive noxious quantity leading to abominable effects beyond an acceptable limit (Pandey and Madhuri 2014; Paul 2017). Lethal diseases like nephritis, nasal mucous membranes, eyelid edema, renal tumor, anuria, and pharynx congestion, headache, increment cardiovascular diseases, and blood pressure, cancer, osteoporosis, and impairment of various biological systems caused by toxic metals (Jaishankar et al. 2014; Vaishaly et al. 2015). They are also well-known to inhibit the hormone's metabolism and synthesis (Paul 2017).

India is a nation of intensive gala/ritual where a significant number of festivals are celebrated. Many persons take bathe in the river and discard behind worship

Table 13.2 Heavy metals sources and probable toxic effects on human wellbeing

Metals	Source of heavy metals	Toxic effects
Cadmium (Cd)	Batteries, fertilizer, electroplating, pesticides, nuclear fission plant, welding	Nausea, vomiting, diarrhea, and death
Iron (Fe)	Mining	Congestion of blood vessels, quick increase in respiration, pulse rate, hypertension and drowsiness, noxious for marine life
Chromium (Cr)	Cotton Textiles, electroplating, mining, tannery industries	Sensitization/ulceration of the skin, lung cancer,
Copper (Cu)	Electroplating, pesticides, mining	Sporadic fever, coma, hypertension, noxious for marine life, death
Lead (Pb)	Automobile emission, burning of coal, mining, paint, batteries, pesticides	Lead poisoning, death, anemia
Manganese (Mn)	Welding, fuel addition, Ferromanganese production	Fever, sexual impotence, central nervous system disorder, growth retardation, blindness and muscular fatigue
Nickel (Ni)	Electroplating, batteries industry, zinc base casting,	Lung and nasal cancer
Zinc (Zn)	Metal plating, brass manufacture, refineries, immersion of painted idols	Liver and kidney damage, headache, noxious for marine life

Sources Sundaray et al. (2012), Paul (2017)

goods, clay idols, plastic bags, account books, human excreta, and flower gifts in the river that raise the floating matters and contaminants in the river water. Additionally, several small towns and villages are situated all alongside the river, the most of them don't have satisfactory hygiene amenities. Thus, several persons utilize the river drainage field for excretion, a source of pathogenic and organic pollution in river water. Also, the public has the tradition of discarding the un-burnt dead bodies of humans and cattle into the river. As per superstition, the dead body has certain diseases (tuberculosis, asthma, snake bite, leprosy, poisoning, etc.), and infants, holy men, and unmarried persons are discarded into the river. People having meager incomes also abandon dead bodies into the river water to save the expensive wood incineration (Gaur 2018). Dumping garbage and solid waste is one more contaminating cause and contaminating activities by Indian people, whose appropriate supervision is inescapable in rivers.

13.4   Reviews on River Water Pollution in India

About 70% of rivers in India are polluted due to rapid industrialization and urbanization (Jindal and Sharma 2011). In developing nations, the majority of the rivers

nearby urban cities are the primary sinks for wastes released from industries (Suthar et al. 2009). The release of urban wastewater into river drainage basins is a significant problem in sustaining RWQ. These effluents and urban sewage negatively influence public well-being through various processes/routes of the food chain (Gomez-Baggethun et al. 2013). Regarding progress plans in India, cleaning up of rivers is often not optimally prioritized; hence, continuous evaluation of the status of pollution of the rivers by human activities is needed.

CPCB monitored 445 rivers throughout the country, of which 302 river stretches were identified polluted. These polluted river stretches were further classified under different priority classes (CPCB 2015). Accordingly, CPCB has assessed present sewage generation based on India's urban population and projecting the population for 2020, considering the growth rate for the year 2001 to 2011. The rate of sewage generation is taken as 80% of the water supply. Total sewage generation and treatment capacity in India is presented in Fig. 13.3. Out of this, Uttar Pradesh (UP) generates 8263 MLD (million liters per day), with 3374 MLD (41%) installed capacity. Out of total sewage generation, 2510 MLD (30%) is treated (CPCB 2021).

Girija et al. (2007) have evaluated the water quality of Bharalu tributary's (Brahmaputra River, Assam) in different seasons. They reported 'poor' water quality, with significant spatial and seasonal fluctuation. Urban runoff was found to have the leading role in hardness, alkalinity, and BOD, and the catchment region has a noticeable influence on chloride concentration and conductivity. Sulfate (SO_4^{2-}) content showed noticeable seasonal fluctuation, influenced by dilution and occurrence of
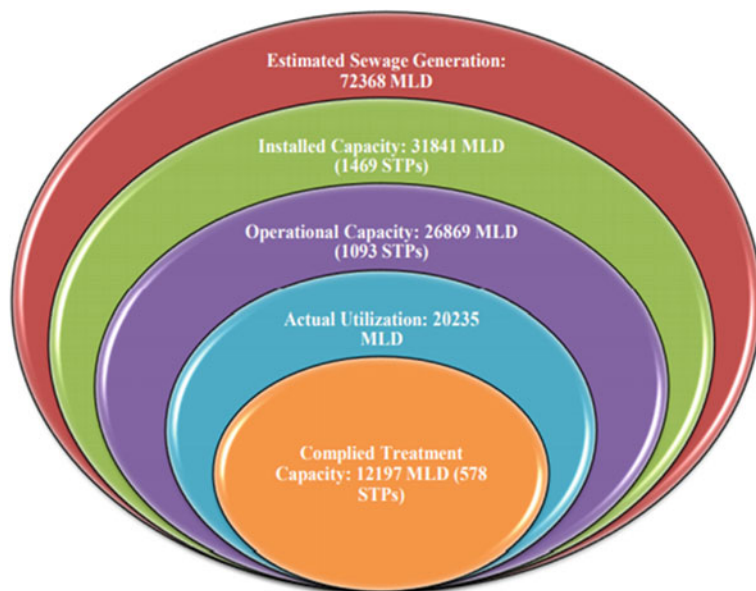
Fig. 13.3 Venn diagram depicting sewage generation, installed treatment capacity, operational capacity, actual utilization, and complied treatment capacity (*Sources* CPCB 2021)

bacteria, iron, and phosphorus was high in all the sites promoting extreme growth of weeds and inducing more stress on dissolved oxygen (DO) of the water channel. Chatterjee et al. (2010) evaluated environmental and bacteriological variables of Damodar River (West Bengal) at a point source location following chemometric methods from 2004 to 2007. The results show that contamination of metals, coliform counts, and organic pollutants at beyond the acceptable limits for domestic uses. Besides different industrial's effluents near the sampling location, the random inclusion of domestic sewage may be contributed to the increment of the pollutants.

Mandal et al. (2010) investigated the spatial and seasonal fluctuation of Yamuna RWQ in Delhi during 2000–2005. The result reveals that the release of partially treated and non-treated wastewater is the leading cause of Yamuna River pollution. The seasonal fluctuation and interrelationship of the chosen variables may be helpful to in the regular examination of RWQ. Banerjee and Gupta (2013) characterized the industrial effluents discharged from different industries and heavy metals distribution in effluent releases channel and their impact on Damodar River. The results of enrichment factors (EF) and the pollution load index (PLI) (1.305) confirm that effluent channels have deteriorated from important heavy metal pollution following urbanization and industrialization. Compared to baseline data, the surface sediment layers explain high enrichment across the channel and at its release point. Factor analysis (FA) also explains three factors i.e., surface runoff inputs, industrial sources, and background lithogenic factors, which clarify the observed variance of the environmental parameters.

Further, Haldar et al. (2014) assessed the water quality of the Sabarmati River (Gujarat) using physicochemical variables, microbiological (total and chosen bacterial count), and biological (phytoplankton). The results showed that the river stretch from Ahmedabad -Vasana barrage to Vataman was extremely contaminated due to continuous waste releases primarily from industries and municipal drainage. The study also showed moderate to poor Sabarmati RWQ concerning physicochemical and biological contaminants. The river has significantly lost self-purification capacity among Ahmedabad to Vataman due to a lack of minimum flow. Numerous small and medium-scale industries situated along the river water body are causing river water pollution.

Sharma et al. (2014) assessed the Hindon RWQ of various point sources contributing to a river in pre-and post-monsoon seasons in 2012. The high amount of BOD and COD content noticed in the drains showed a high level of organic contamination represented the water inappropriately even for bathing purposes. Almost sampling locations of the u/s and m/s of Hindon River, DO content was found to be 0 mg/L due to huge organic load. BOD content varied between 3.3–65 mg/L, and COD content is varied between 28–338 mg/L in pre-monsoon. However, during post-monsoon BOD varied between 0–139 mg/L, and COD varied between 24–388 mg/L. Further, RWQ has been evaluated using WQI and water quality was found to be 'bad' at each sampling location. Results showed that point sources have a huge organic pollution load that degrades overall Hindon RWQ. Moreover, pollution risk estimation based on QUAL2E-UNCAS simulations of Hindon and its tributary Kali flowing through Uttar Pradesh shows the imperceptible concentration of DO with

higher levels of BOD equal to 56.7 mg/L in Kali and 86.5 mg/L in Hindon eluci-dated the effect of slightly treated to non-treated waste releases into both rivers. The simulations of water quality were conducted and the study indicated that both rivers are in pollution stress and, particularly Hindon River is not able to recover even in winter seasons when it is generally expected that the high absorptive capability of rivers (Babbar 2014).

Gurjar and Tare (2019) evaluated the RWQ and natural absorptive capacity of Ramganga River, which confluence with Ganga River. Despite the huge organic load in midstream (m/s) of Ramganga, the recorded values of DO were >4 mg/L at approximately every location on the main stem, even in a lean flow time of a year. Assessment of Ramganga before and after the confluence with Ganga, RWQ for lean flow period declared that Ramganga is not considerably contributed to the deteriora-tion in Ganga RWQ concerning variables like heavy metals and DO. RWQ at 12 sites were classified as good, 9 sites as satisfactory and 2 sites as poor according to irriga-tion criteria described by CPCB (2011). Pathak and Mishra (2020) also investigated Ganga RWQ at 6 urban centers (Anupshahar, Kannauj, Kanpur, Prayagraj, Mirzapur, and Varanasi) of UP. Four RWQ [DO, BOD, Fecal Coliform (FC), and Total Coliform (TC)] monitoring data of the UP-Pollution Control Board were used for the analysis. Anupshahar and Kannauj were less polluted centers with downstream values slightly higher than the upstream values that signified a slight accumulation of pollutants. The maximum differences in the BOD level and pathogenic concentration between the u/s and d/s sides were observed at Kanpur and Varanasi, signifying massive inter-ference of human activities in the river ecosystem in Kanpur and Varanasi. Prayagraj showed a continuous decline in pollution, signifying improving water quality. The decreasing trend of pollution levels in the Ganga River water stream showed that the efforts from the government sector and participation from the general community are in the right direction.

The current situation of HMs (Cu, Fe, Co, Cd, Cr, Hg, Mn, Zn, Ni, and Pb) pollution in the Ganga River was reviewed by Paul (2017). Numerous researches of HMs contamination confirm that the concentration of different toxic metals in Ganga River water and sediment is beyond the permissible limits. HMs at elevated levels in the river ecosystem shows a chronic risk to human wellbeing. HMs exposure is associated with various cancers, developmental retardation, kidney damage, and yet death is the occurrence of excessive exposure. Therefore, the step must be taken to reduce the effluent load in river Ganga. They recorded different sources of HMs in sediment and river water that need to be strongly supervised to the enhancement of the environment, and domestic sewage discharge and industrial effluent should be reduced.

In this continuation, few studies on physicochemical variables and heavy metals concentration in Indian RWQs are presented in Tables 13.3 and 13.4, respectively.

Table 13.3 Overall mean/range of numerous physiochemical variables in different rivers of India

Rivers	Location	pH	EC	TDS	DO	BOD	COD	NO_3^-	Cl^-	SO_2^{4-}	HCO_3^-	Turb	TA	TH	PO_4^{3-}	References
Chambal	Madhya Pradesh	6.95–8.96	222–854	200–550	5.54–9.02	0.12–18.08	2.0–68.35	0.35–7.35	–	–	–	0.11–126.33	–	–	–	Srivastava et al. (2017)
Damodar	West Bengal	7.93	384.44	253.86	–	–	–	0.98	8.18	26.84	109.33	–	–	–	0.29	Banerjee and Gupta (2013)
Hindon	Uttar Pradesh	7.40–7.89	83–504	222.2–2426.3	3.10–4.03	27–51	85.0–337.4	106–245	201–1326	36.4–162.4	–	28.7–109.3	347.0–596.3	235.1–459.9	–	Suthar et al. (2010)
Ganga	Uttarakhand	7.17	192.04	413.39	10.26	1.84	9.86	0.05	6.72	–	–	3.31	60.12	81.74	–	Bhutiani et al. (2016)
Ganga	Uttarakhand	9.4	85.2	38.6	10.0	4.3	–	–	22.1	–	18.8	–	70.4	101.2	4.2	Haritash et al. (2016)
Kali	Uttar Pradesh	7.13	1281.2	655.6	–	24.3	110.8	31.1	69.2	29.6	277	7.7	301.8	185.9	3.50	Singh et al. (2020)
Ghaghara	Uttar Pradesh	8.083	323.367	226.5	7.76	2.802	11.683	0.4291	7.4816	16.541	–	–	140.3	–	0.0682	Singh et al. (2017)
Gandak	Bihar	8.179	241.1	170.9	7.322	2.277	12.459	0.2387	4.838	22.158	–	–	112.547	–	0.0642	Singh et al. (2017)
Mahanadi	Orissa	7.39	4,665.2	2,461.3	–	–	–	–	1572.2	56.43	–	–	87.9	592.38	–	Sundaray et al. (2009)
Tapi	Gujarat	8.27	290	–	4.95	5.45	79.5	0.53	36.08	–	–	23.8	77.67	137.67	0.67	Gaur, (2018)

All values in mg/L except pH, EC (µs/cm), Turb (NTU)

Table 13.4 Comparison of average heavy metals concentrations (mg/L) in different rivers of India

S. N	Rivers	Regions	Cd	Cu	Cr	Fe	Ni	Pb	Mn	Zn	References
1	Hindon	Uttar Pradesh	–	0.006	0.015	0.226	0.024	0.037	0.129	0.058	Jain and Sharma (2006)
2	Achankovil	Kerala	0.006	0.224	–	11.85	–	0.072	0.699	0.415	Prasad et al. (2006)
3	Koel (Brahmani)	Orissa	–	0.006	0.010	0.481	0.024	0.001	0.030	0.031	Sundaray (2010)
4	Ganga River	West Bengal	0.01	0.01	–	0.8	0.14	0.12	0.26	0.06	Aktar et al. (2010)
5	Damodar		0.30	3.95	11.55	0.480	–	–	–	–	Chatterjee et al. (2010)
6	Kabini	Karnataka	–	27.44	21.79	63.55	–	–	21.70	53.95	Hejabi et al. (2011)
7	Brahmani	Orissa	0.001	0.001	–	0.020	0.015	0.012	0.024	0.015	Reza and Singh (2010)
8	Mahanadi		0.0009	0.0083	0.0036	0.1893	0.0101	0.008	0.0198	0.0292	Sundaray et al. (2012)
9	Subarnarekha	Jharkhand	bdl–0.02	0.01–0.03	0.01–0.023	–	bdl–0.03	bdl–0.38	–	0.07–0.49	Banerjee et al. (2016)
10	Yamuna	Delhi NCR	0.02	0.11	0.05	–	0.05	0.1	–	0.69	Bhattacharya et al. (2015)
11	Yamuna		0.0476	2.1518	0.1471	10.488	0.3755	0.1164	–	1.5007	Bhardwaj et al. (2017)

(continued)

Table 13.4 (continued)

S. N	Rivers	Regions	Cd	Cu	Cr	Fe	Ni	Pb	Mn	Zn	References
12	Kali (East)	Uttar Pradesh	0.06	–	0.06	1.53	–	0.13	–	24.71	Mishra et al. (2018)
13	Kali		0.0774	0.1987	0.1338	0.5316	0.2515	0.3134	0.2524	0.2377	Singh et al. (2020)
14	Ganga	Uttar Pradesh	0.020–0.080	0.020–0.080	0.030–0.090	0.590–0.680	0.220–0.305	0.060–0.190	–	0.200–0.270	Niveshika et al. (2016)
15	Ganga	Uttarakhand-Uttar Pradesh	0.60–13.10	bdl-36.0	–	–	–	2.40–26.90		bdl-106.30	Goswami and Sanjay (2014)

not recorded, bdl below detection limit

13.5 Approaches of River Water Quality Evaluation

13.5.1 Water Quality Index

Water quality indexes (WQIs) are internationally accepted statistical approaches to determine the pollution status by categorizing quality classes (excellent, good, poor, inferior, and unfit for human use). WQI is the most reliable measure of surface and groundwater pollution and can be used effectively to execute water quality updating programmers. The WQI transforms multifaceted water quality information into secure data that is intelligible and useable by people. Water quality lists facilitate the assessment of the water quality profile of a river over its entire stretch and recognize the zones where the difference between the required and current water quality is sufficiently large to necessitate critical pollution control measures (Srivastava et al. 2017; Kumar et al. 2021). This index accounts for a general assessment of water quality on numerous levels that affect the capacity of a stream to sustain life. Numerous studies have been conducted on WQI in India by different researchers (Table 13.5).

Table 13.5 List of different WQIs for monitoring of various rivers in India

Area	Rivers	WQI	References
Tamil Nadu	Cauvery	Tiwari and Mishra	Kalavathy et al. (2011)
Madhya Pradesh	Chambal	NSFWQI	Srivastava et al. (2017)
South Bengal	Damodar	CCMEWQI	Haldar et al. (2016)
Entire river	Godavari	NSFWQI	Chavan et al. (2009)
Uttar Pradesh	Hindon	CPI	Mishra et al. (2016)
Entire river	Hindon	Tiwari and Mishra	Sharma et al. (2014)
Ujjain	Kshipra	NSFWQI	Gupta et al. (2012)
Madhya Pradesh	Narmada	CCMEWQI, NSFWQI, Weighted arithmetic	Gupta et al. (2017)
Gujarat	Sabarmati	Weighted arithmetic mean	Shah and Joshi (2017)
Gujarat	Sabarmati	NSFWQI	Haldar et al. (2014)
Himachal Pradesh	Swan	NSFWQI, OIP	Sharda et al. (2017)
Delhi NCT	Yamuna	OIP	Katyal et al. (2012)
Entire river	Yamuna	Customized NSFWQI	Sharma et al. (2008)
Uttar Pradesh	Kali River	Weighted arithmetic mean	Singh et al. (2020)
Uttarakhand	Ganga	CPI	Kumar et al. (2020)
Uttarakhand	Ganga	CCMEWQI, NSFWQI	Kumar et al. (2021)

NSFWQI: National Sanitation Foundation Water Quality Index; OIP: Overall Index of Pollution; CCMEWQI: Canadian Council of Ministers for Environment Water Quality Index; CPI: Comprehensive pollution index

Jindal and Sharma (2011) studied Sutlej RWQ at Ludhiana (Punjab) in different seasons during 2006–2007. For the calculation of water quality rating and WQI, nine variables were measured. The average values of each variable were compared with ICMR, BIS, and WHO norms. The WQI was found 32.84, 51.01, and 132.66 at sites S1, S2, and S3, respectively. This showed that the river water was unsafe for human use at sites S2 and S3 and might be used only for irrigation, aquaculture, and industrial application. Sharma and Kansal (2011) studied the river Yamuna using WQI to explain the contamination level in the river for 10 years period (2000–2009). They also determine the significant contaminants influencing the RWQ during its course through the city. The range of water quality is found "good to marginal" class at Palla and "poor" class at all other sites. The RWQ at different sites is mainly affected by wastewater release produced from the National Capital Territory (NCR, Delhi), entering the Yamuna River through numerous drains.

Prasad et al. (2013) developed a web-based system to express the surface water quality in the imprecise condition of observed data. Eight variables were examined in surface water, in which four variables i.e. pH, DO, BOD, and FC were applied for the WQI computation following Maharashtra Pollution Control Board (MPCB) water quality norms of category A-II for the best-designated application. The investigation explained that river points in a specific year were in a very bad class with 0–38% certainty level, which is not suitable for drinking uses. Samples in the "bad" and "medium to good" classes had certainty levels between 38–50% and 50–100%, respectively. The remaining sample was a "good to excellent" class, appropriate for drinking uses, with certainty levels between 63–100%. This web system is helpful for the concerned authorities and policymakers that allowing them to obtain the expected output in a shorter time.

Mishra et al. (2015) assessed the heavy metal contamination (Cd, Pb, Fe, Cr, and Zn) in Kali River apply Nemerow pollution index (NPI), in pre-and post-monsoon seasons in 2014. NPI computed for drinking water quality norms and found 5.04 in pre-monsoon and 7.08 in post-monsoon, whereas regarding inland water quality norms established as 4.37 in pre-monsoon and 3.62 in post-monsoon. Heavy metals analysis results revealed that Zn and Pb are the major variables accountable for river water pollution. Comprehensively NPI showed that river water was extremely polluted (i.e. NPI > 3) in pre-and post-monsoon seasons, due to surface runoff, dredging, other associated human activities, and the release of urban/industrial effluents into Kali River. Further, Mishra et al. (2018) also evaluated the effect of heavy metal contamination (Zn, Cr, Fe, Cd, and Pb) using the heavy metal pollution index (HPI) in the Kali River at seven locations in pre-monsoon and post-monsoon in 2014. HPI was established to be 6.79 in pre-monsoon and 4.98 in post-monsoon season, which is higher than the crucial value (HPI >> 1). The study explained that the Kali river stretch was extremely polluted concerning heavy metals, and recommended that the wastewater produces from industrial units must be treated before release into the river.

Bhutiani et al. (2016) assessed the river Ganga environs at Uttarakhand and calculated WQI by investigating 16 physicochemical variables based on NSFWQI to

evaluate the appropriateness of water for irrigational, drinking, and other applications. Application of NSFWQI to evaluate the RWQ over 11 years displays small fluctuations in water quality. Results also showed that solid and liquid waste pollutants, sewerage, or organic nature are the major causes of pollution. Mishra et al. (2016) estimated Hindon RWQ at 28 sampling locations of western Uttar Pradesh (WUP) applying the CPI, considering the eleven environmental variables in 2013–14. The results of CPI showed that the Hindon River was extremely polluted (CPI = 2.68–7.12).

Jaiswal et al. (2019) studies characterized the extensive evaluation of physical and chemical conditions in RWQ of the entire Yamuna stretch (India). Computed WQI was "excellent" to "good" in the upper region, with BOD average values of 2.1 mg/L in rainy and 2.4 mg/L in the non-rainy season. While, WQI was "poor" to "marginal' in the middle region, with BOD mean values of 13.1 and 32.3 mg/L in rainy and non-rainy seasons, respectively. Additionally, WQI values better to "good," and "excellent' class in lower region and BOD reduced to 1.9 and 1.8 mg/L in rainy and non-rainy seasons, respectively.

The globally accepted coherent approach of WQIs and multivariate statistical models (PCA and CA) were utilized in the dataset to assess the spatial–temporal fluctuation and contamination source recognition and apportionment river Ganga in Uttarakhand (Kumar et al. 2021). Total 22 hydro-chemical variables were analyzed by collecting the samples from 20 different vertically elevated monitoring locations for different seasons. The seasonal variation in RWQ by the CCMEWQI showed the quality class at a marginal level in summer (62.16), monsoon (59.96), and post-monsoon (60.20) season, whereas in winters (71.18), water quality was in fair condition. The present observations contribute to the usefulness of these statistical methodologies to interpret and understand large datasets and also provide reliable information to reduce the tediousness and cost of water quality monitoring and assessment programs.

13.5.2 Multivariate Statistical Approach to Monitoring the River Water Quality

The multivariate statistical analysis involves concurrent evaluation of more than two variables of water quality. All statistical systems concerned with the instantaneous breakdown of numerous measurements on several diverse variables comprise the multivariate analysis (Manoj and Padhy 2014). Some commonly used multivariate statistical models (or environmetrics) for environmental data analysis are factor analysis (FA), cluster analysis (CA), and discriminant analysis (DA). FA, which consists of principal component analysis (PCA), is a statistical method utilized to reduce the dimensionality of a dataset comprising a considerable number of inter-related variables (Singh et al. 2004). This reduction method includes a conversion of the dataset into a new dataset of variables, i.e., termed principal components (PCs).

These PCs are organized in reducing an array of significance and are orthogonal, i.e., non-correlated (Panda et al. 2006). Some of the advantages of PCA are:

1. PCA gives information on the major consequential variables, which explain the entire data set providing data reducing with the least loss of original data.
2. PCA helps the recognition of contamination sources based on shortened variables, like spatial (contamination originate from human activities) and temporal (climatic and seasonal) (Razmkhah et al. 2010; Rizvi et al. 2016).

CA is a technique for establishing a large quantity of data into convenient very important heaps. It is an information-reducing tool that makes sub-clusters which are convenient than a single dataset. Like FA, it examines the inter-association among the variables. This method also aids in assume the data on the contamination sources and inter-relationship among different contamination sources. Hierarchical agglomerative cluster analysis (HACA) is a technique that shows perceptive resemblance associations among any individual sample and the total data set and is usually displayed as a tree diagram, i.e., dendrogram (Panda et al. 2006; Rizvi et al. 2016). The Euclidean metric usually details the uniformity among two samples. A Euclidean metric can be expressed by the variation among investigative data from both samples (Zheng et al. 2015).

Since RWQ evaluation demands working with large datasets, numerous advanced statistical tools were practiced. Environmetrics like PCA and CA have been used to identify possible sources that can influence aquatic bodies to improve the perception of water quality and the actual status of the study region. These techniques have been mainly dependable in providing a new and unique sympathetic of the association between a range of different contaminants (Wang et al. 2013; Barakat et al. 2016). These techniques are crucial for trustworthy monitoring of river water resources and quickly finding solutions to deterioration problems in river water. Numerous studies on the application of multivariate techniques/environmetrics to assess the RWQ have been carried out nationwide by various researchers (Table 13.6).

Singh et al. (2004) reported various environmetrics to evaluate spatial–temporal fluctuations and interpret a substantial complex RWQ dataset collected in examining the river Gomti River in UP, India. The multifaceted data matrix (17,790 measured data) was analyzed with various environmetrics like CA, FA/PCA, and DA. CA displayed good outcomes rendition 3 dissimilar clusters of resemblance among the sampling locations indicating the various RWQ variables. PCA recognized six factors, i.e. liable for the data framework describing 71% of the entire variance of a dataset and permitted to cluster the chosen variables as per general characteristics and assess each cluster's frequency on the comprehensive fluctuation in RWQ. DA displayed the best outcomes for reducing data and pattern recognition in a spatial–temporal investigation. DA presented five variables managing over 88% right rendezvous in a temporal investigation, whereas nine variables to manage 91% right rendezvous in a geographical investigation of 3 dissimilar areas in the catchment. Hence, DA permitted a decrease in the spatiality of the huge dataset, defining few indicator variables accountable for huge fluctuations in RWQ. This research shows the need and effectiveness of environmetrics for the monitoring and analyzing

Table 13.6 Application of multivariate techniques for monitoring of RWQs in India

Region	Rivers	Multivariate statistics/environmetrics	References
Uttarakhand	Ganga	PCA, CA	Kumar et al. (2021)
Uttarakhand	Ganga	PCA, HCA	Kumar et al. (2020)
Uttar Pradesh	Hindon	PCA, HCA	Mishra et al. (2016)
Madhya Pradesh	Chambal	PCA, DCA, CCA	Srivastava et al. (2017)
Gujarat	Sabarmati	PCA	Haldar et al. (2014)
Uttar Pradesh	Kali	PCA, HCA	Singh et al. (2020)
Uttar Pradesh	Hindon	PCA, HACA	Rizvi et al. (2016)
Uttar Pradesh	Ramganga	DA, HCA	Gurjar and Tare (2019)
West Bengal	Damodar	PCA	Banerjee and Gupta (2013)
Delhi	Yamuna	PCA	Bhardwaj et al. (2017)

Detrended correspondence analysis (DCA); Canonical correspondence analysis (CCA)

huge datasets to obtain the best information regarding the RWQ and plan of observing networks for efficient water resources supervision.

Kumar et al. (2020) attempted to evaluate the long-term (1989–2016) hydro-chemical parameters of Ganga RWQ at five u/s sites of Uttarakhand i.e. Uttarkashi, Tehri, Rudraprayag, Devprayag, and Rishikesh, applying a CPI and multivariate statistical method (PCA and CA). These techniques were applied to classify, sum up expensive datasets and clustering similar contaminated region along the river stretches. PCA established the input source of nutrients in the river from both human and natural sources. Additionally, the u/s RWQ evaluated was established to be good in comparison to the extremely polluted d/s area.

13.6   Conclusions

This comprehensively reviewed the importance of water and various characteristics of RWQ on a national scale and concluded that the majority of Indian rivers are degrading day by day through different anthropogenic reasons, causes, and sources. Hence, in current scenarios, meticulous monitoring of RWQ concerning physico-chemical, heavy metal, and bacteriological parameters is necessary. Simultaneously, the application of multivariate statistical approach and computing WQI, CPI is also important to find out the actual status of RWQ. Because, rivers have reservoir of ecological diversity and provide important services to communities. River and other surface water qualities is mainly affected by various anthropogenic activities such as fast industrialization, urbanization, improperly managed landfills, landscape change, pollutants (chemical fertilizers and pesticides), runoff from agricultural fields, cities

runoff, municipal drainage mixing, dumping solid of semi-solid wastes in river catchments, which need to be examined and control by adopting following remediation techniques:

- Efficient working of ETPs for industrial effluents, STPs for municipal wastewaters. Upgrading or establishment of advance ETP and STP technologies and ensure complete treatments (primary, secondary and tertiary stage)
- The present ETPs and STPs need to be tested for its efficiency, reliability and technological parameters by self-reliant departments (tech-efficiency-reliability verification).
- Based on effluents/wastewater characteristics, following advance remediation/treatment techniques could be adopted inside the industrial/municipal regions, which is addressed by numerous reviewers:

    - Bioremediation/phytoremediation technique (by using microbes, algae, exotic and aquatic plants species)
    - Advanced oxidation processes (Fenton's Reagent, Peroxonation, Sonolysis, Ozonation, Ultraviolet Radiation-Based AOP, Photo-Fenton Process, Heterogeneous Photocatalysts, using catalytic nanomaterials)
    - Chitosan-based magnetic adsorbents (for toxic metals)
    - Photoelectro-Fenton process as efficient electrochemical advanced oxidation.
    - Treatment with UV light, sunlight, and coupling with conventional and other photo-assisted advanced technologies

- Identify major drain in urban and peri-urban region; treat their water before release or confluence with surface water body.
- Need to strict implication of numerous rules and regulations followed by national agencies at ground level for improvement of all surface water qualities
- Preventive measure viz stops discarding of solid waste/garbage in its catchment areas as well as creating awareness among community.
- Precise application of chemical fertilizers and pesticide in agricultural field.
- Besides that, monitoring of RWQs at specific intervals is important for find out major causative factors.
- Minimum generation of wastewaters, recycling and reuse is also a significant optional method.

Competing Interests

The authors declare that they do not have any personal or financial conflict of interests.

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