Sughosh Madhav · Pardeep Singh · Vandana Mishra · Sirajuddin Ahmed · Pradeep Kumar Mishra *Editors*

Recent Trends in Wastewater Treatment

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Chapter 1
Water Quality Characterization of Industrial and Municipal Wastewater, Issues, Challenges, Health Effects, and Control Techniques

Nusrat Khanam, Aditya Abha Singh, Anil Kumar Singh, and M. K. Hamidi

Abstract Water is vital, renewable resource, and crucial for supporting all life forms. Water quality is important concerning both environmental and economic aspects. Rapid urbanization, industrialization, agriculture practices increase the water pollution. Water pollution refers to the changes in any water body's chemical, physical, and biological condition owing to the input, substitution, or removal of organic, inorganic, biological, or radioactive substances, etc. Point source includes industrial and municipal wastewater in which pollutant travels directly from source to water; while non-point source includes urban and agricultural run-off which make their way into the aquatic ecosystems. Various types of industrial wastewater include suspended solids, chemicals, and toxic compounds, metals, non-metals, organic, inorganic pollutants, solvents, and solid–liquid waste. While the composition of municipal wastewater varies, but chiefly comprises substances like food matter, beverages, inorganic and organic solids, and pharmaceutical wastes, etc. There are wastewater-related challenges and issues both in developed and developing countries. While major problems are being faced by developing countries like lack of access to clean water, sanitation, effective wastewater management causing multiple diseases across the population, besides, the lack of sufficient funds. Humans face health problems that are associated with water-related infectious diseases like diarrhoea, hepatitis, cholera, dysentery, dermatophytosis, malaria, yellow fever, dengue fever, filariasis, and other disorders. Pollution prevention is the key that reduces the load of pollutants discharged into the water bodies. Pollution control strategies seek the management of pollutants by stern actions, legislation and regulations, public awareness for sustainable use of resources, and recycling and treatment of industrial and municipal wastewater. Recent technologies such as UV led-induced advanced oxidation processes, peracetic acid-based advanced oxidation processes, membrane bioreactor, electrochemical advanced oxidation processes are

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employed for removing pollutants from the wastewater, United Nations, World Health Organization, World Wide Fund for Nature, United Nation Environment Programme, are the few international organizations that work for water quality and its conservation. Moreover, in India steps undertaken for water-related issues includes Swachh Bharat Mission, Ganga action plan, the National water mission, and water quality monitoring and regulation by Central Pollution Control Board. Furthermore, we need to improve the current status of water bodies through water resource management and also need proper strategies for solving wastewater-related problems throughout the world.

Keywords Human health · Industrial wastewater · Municipal wastewater · Organization · Pollution · Water quality

1.1 Introduction

The most essential element and a unique gift for human life is water, and irreplaceable for many of its uses in supporting nonliving and living things (Singh and Singh 2021). It is one of the life-supporting elements of the ecosystem and is a symbol of social equity and justice, which provides energy to all organisms of the earth and maintains the equilibrium of the ecosystem (Li et al. 2005; Chakraborty et al. 2021). For our existence, appropriate water quality is necessary on Earth. Approximately 70% of the human body is composed of water, and a majority of the earth's fauna and flora thrive in water (Smol 2009). We require adequate clear water to decimate our thirst, agriculture field irrigation, and assist all forms of life such as plants and animals, and micro-organisms in the ecosystem. We as humans require fresh and clean water in our locality, community, industries, businesses, as well as in natural environment. Since ages, water has aided into trade, commerce, progress, and innovation (Lufkin 2017). However, these commercial advances have had environmental costs and impacts (Goyes and South 2017).

The need for clean water is essential today and is everlasting (Vigil 2003). However, it is polluted or wasted, unsafe, and unhygienic due to anthropogenic activities and pollution (Faroque and South 2021). When the physical, chemical, or biological property of any water body gets altered due to the different kinds of pollutants, it is called as water pollution (Goel 2006). Pollution of water is also a violation of access to clean water under human rights (Barlow 2010). Both groundwater and surface water are being contaminated owing to the rapid urbanization, industrialization, and agriculture practices. Different pollution and industrial waste substances affect the potability of this precious natural resource (Faroque and South 2021). Nevertheless, abundantly supplied with water, planet earth faces numerous immediate water crises due to demographic changes, overuse, and overconsumption, pollution, climate change, and poor wastewater management (Brisman et al. 2018; Leahy 2018; García Ruiz et al. 2020). Water pollution has been the main focus for scientists and government protecting our aquatic ecosystem, and its quality is important because of the serious condition of water pollution and global insufficiency of water resources (Fig. 1.1).

There are chiefly two forms of water pollution sources: point and non-point source. The emissions from point sources are the chief source of pollution in water. It includes industrial wastewater besides the municipal wastewater. Industrial wastes and sewage releases contribute a significant load of pollutants to water bodies, since they increase BOD and nutrient content, promoting destabilized ecosystem (DWAF and WRC 1995; Murray et al. 2000). Non-point sources runoff, like pesticides and fertilizers, make their way into an aquatic ecosystem. Once water is contaminated, it becomes tremendously tedious and expensive to make it clean again, which renders it unusable (Denchak 2018). The rapid increase of population doubled the gap between demand and supply of resources (Matta 2010; Juma et al. 2014). Physiochemical characteristics of water can also influence the biodiversity of the aquatic system and later can lead to an impact on the water quality (Soja and Wiejaczka 2014). Turbidity, electrical conductivity, pH, and temperature are the physical characteristics of water bodies. DO, BOD, and COD are appropriate pollution indicators that have negative impacts on water quality (Hassan and Mahmood 2018).

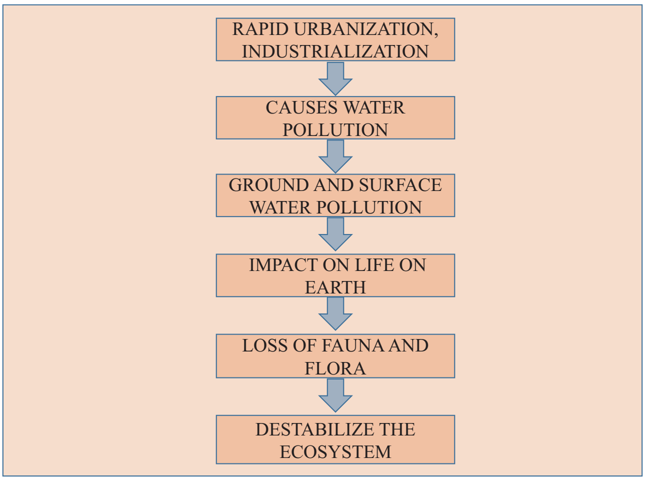

Fig. 1.1 shows that unsustainable human activities lead to water pollution, which causes negative implications on flora, fauna, and ecosystem. (It has been referred from DWAF and WRC 1995; Murray et al. 2000; Faroque and South 2021; Smol 2009)

1.2 Industrial Wastewater: Sources and Composition

Water pollution in which pollutants are discharged from industries such as mining, steel industries, petroleum industry, chemical plants, pharmaceutical industry, food processing, and paper and textile mills is among the major problems encountered by India and other countries in the world (Papirio et al. 2013; Doushanov 2015; Gadipelly et al. 2018; Li et al. 2019; Singh and Chandra 2019; Varjani et al. 2020). Different industries release a variety of pollutants, including chemical compounds, toxic substances, volatile compounds, heavy metals, and radioactive substances that change the physico-chemical status of water bodies, directly and indirectly affecting all types of living organisms (Ekpo et al. 2008; Rahman et al. 2009; Verma and Dwivedi 2013). The industrial sector consumes a big quantity of water and eventually produces a huge volume of wastewater discharge that contains inorganic and organic pollutants and solid and liquid waste (Paul et al. 2012; Crini et al. 2018; Hasan et al. 2019). Microbes biodegrade the organic pollutants and modify them into a simple form that benefits the aquatic ecosystem. However, inorganic pollutants like Arsenic (As), chromium (Cr), cadmium (Cd), nickel (Ni), mercury (Hg), cobalt (Co), vanadium (V), etc. are poisonous and cannot be removed easily by microbiota. Some minerals are required at a low level for human health; however, they are toxic at higher dosages and fall into toxic inorganic pollutants type (Verma and Dwivedi 2013).

Over 700 emerging toxic waste, their metabolites, and transformed products have been listed in the European aquatic system. Some naturally occurring chemical and inorganic pollutants were identified, whose environmental impact is severe and has a more adverse impact on human health (Dulio and Slobodnik 2009; Geissen et al. 2015). These contaminations cause skin cancer, eye irritation, digestion-related disease, lung infection, and other infectious diseases. Most of the inorganic pollutants are non-biodegradable hence they persist for a long period in both fresh and saline water and accumulate in the food chain (Kesari et al. 2021). Moreover, several pharmaceutical products contain toxic compounds that disrupt the endocrine gland and their secretion in the human body (Bolong et al. 2009). Chemical industries linked with the aluminium production release a bulk of fluoride through their discharge to water bodies. Ammonia is released from different fertilizer industries, while a huge quantity of cyanide is generated from the steel plant. Chromium salts are used in the industrial process to produce chromium containing compounds and sodium dichromate. Textile industries discharge a large volume of dark-coloured pollutants that contain a high concentration of sulphate, sulphide, chloride, magnesium, and calcium (Paul et al. 2012; Madhav et al. 2018, 2021). Moreover, different hazardous inorganic chemicals are immensely used during textile wet processing and remain with processed water, which is very challenging to eliminate (Madhav et al. 2018). Mining industries require a large amount of water for operational methods such as hydrometallurgical extraction, coal washing, mineral processing, and discharge wastewater containing acidic and toxic substances (Kesieme et al. 2012). The iron and steel industry are the major industry that contributes inorganic effluent such as cyanide, sulphides, oxides of copper, chromium, cadmium and mercury, sulphate, ammonia, thiocyanate, thiosulfate, fluorides (Verma and Dwivedi 2013; Doushanov 2015; Singh and Gupta 2016). These are finally released into water bodies as emissions being harmful to human health and the aquatic life. The food processing industry includes the vegetable industry, fruit industry, dairy industry, meat and fish processing industry. These industries discharge dissolved material, suspended solids, carbohydrate, starch, pectin, fat, protein, and sugar into the environment (Kroyer 1995). Moreover, the nuclear and electric power plants, petroleum refineries, steel industries, boilers from industries eject large amounts of heat to the aquatic ecosystem leading to modifications in the chemical, biological, and physical features of the receiving water systems (Singh and Gupta 2016).

1.3 Municipal Wastewater: Sources and Composition

Municipal wastewater or the domestic discharge is the wastewater generated principally by the people. This type of wastewater is predominantly discharged from households, hospitals, laundries, and other sources such as commercial market places, hotels, cattle, and poultry farms, etc. (Yetilmezsoy and Sapci-Zengin 2009; Otunyo et al. 2016; Lv et al. 2018; Khan et al. 2021; Tian et al. 2021; Gustavsson et al. 2022). Its constituent varies according to the geographical location and population of the area. Municipal wastewater is the major component of water pollution (CPCB 2021a). Continuous exploitation of water resources for quenching the human needs and socio-economic development results in the production of municipal wastewater (Teodosiu et al. 2016). The municipal wastewater chiefly contains all the substances utilized by the humans such as food, beverages, pharmaceuticals, oil, fatty acid, grease, dissolved salt, microplastic and nitrogen, inorganic phosphorus pollutant, household chemicals, and substances that are released into the sewer system (Morrison et al. 2001; Kroiss 2003; Pastore et al. 2015; Koch et al. 2016; Goswami et al. 2021; Madhav et al. 2021).

Wastewater treatment methods produce sewage sludge, which is a concentrated and bioactive filtrate of organic clay-sized particles (Fei-Baffoe et al. 2014). Those area faces problems of water pollution where the wastewater treatment systems are simple or not efficient (DWAF and WRC 1995; Murray et al. 2000). The proper management of solid waste is one of the major problems the human population is facing due to different lifestyles, habits, the latest technological and scientific advancement, and the consumption of new products (Miezah et al. 2015). These factors increase both the quantity and complexity of waste generation (Fei-Baffoe et al. 2014). In India, it is estimated that roughly one lakh people produce near about 16,662 million litres of wastewater daily. Furthermore, approximately 70% of the humans near river Ganga and Yamuna have access to sewerage facilities and generate around 33% of wastewater (Bhattacharya et al. 1997). In urban areas, due to sewer connection often common point source exists which discharge multiple pollutants in the river that severely impacts its water quality (Seitzinger et al. 2010;

Hofstra et al. 2013; Lebreton et al. 2017; van Wijnen et al. 2018; Font-Palma 2019; Van Puijenbroek et al. 2019). Organic and inorganic pollutants in municipal wastewater widely vary; organic pollutants can be subdivided into toxic, persistent, and bioaccumulative substances and more polar substances such as pharmaceutical products. While, inorganic pollutant includes nano particles, micro-plastics and metals (Geissen et al. 2015). According to UNEP (2016), ammonia is the common effluent in municipal wastewater that is toxic to water biodiversity. Hospitals are an important source of pollutants due to diagnosis, research and development actions, and medicine excretion by patients, including the active component of drugs, radioactive markers, etc. especially those without appropriate treatment (Wang et al. 2020). Presently the COVID-19 pandemic is the chief and one of the biggest issues around the world. The novel SARS-CoV-2 has been expanded all over the world. It's secondary transmission via sewage is a major problem that can be increased by the faeces of patients (Teymoorian et al. 2021) (Table 1.1).

Table 1.1 A list of pollutant types released from different sources which compose the industrial and municipal waste

Type of industries	Organic pollutant	References	Inorganic pollutant	References
Industrial waste				
Pulp and paper industry	Lignocellulosic waste, cellulose, lignin, phenols, tannins, resins, and fatty acid	Singh and Chandra (2019)	Ferrous, magnesium, zinc, copper, nickel	Singh and Chandra (2019)
Textile industries	Organic matter	Tüfekci et al. (2007)	Sulphate, sulphide, chloride, calcium, magnesium	Paul et al. (2012), Madhav et al. (2018)
Food processing	Organic matter (protein, carbohydrate, lipid)	Parnaudeau et al. (2006), Kroyer (1995)	Nitrogen, phosphorous, potassium	Kroyer (1995), Qasim and Mane (2013)
	Organic carbon	Ji et al. (2015)	Calcium, iron, aluminium	Ji et al. (2015)
	Pathogen	Manasa and Mehta (2020)		
	Suspended oil, grease	Kroyer (1995)		
Mining	Organic matter	Papirio et al. (2013)	Hydrochloric acid	Cui et al. (2016)
			Hydrogen sulphide	Kesieme et al. (2012)
	Organic carbon	Cravotta III and Brady (2015)	Suspended solids, metals (lead, thallium, nickel, mercury, arsenic, arsenite, cadmium)	Pan (2009), Kumar et al. (2013), Uetani (2007)

(continued)

Table 1.1 (continued)

Type of industries	Organic pollutant	References	Inorganic pollutant	References
Petroleum industry and chemical plants	Oil, phenol, Neptha	Allen (2008)	Lead compounds, cyanide, sulphate, mercury, nickel, Zinc	Borah et al. (2020)
	Mercaptans, grease	Varjani et al. (2020)		
	Benzene	Jephcote and Mah (2019)		
	Chlorinated dibenzo-*p*-dioxins and dibenzofurans	Dyke and Amendola (2007)		
Pharmaceutical industry	Endocrine-disrupting compounds, steroids, vitamins	Gadipelly et al. (2014)	Cyanide, halides, arsenite, metals, nitrates	Gadipelly et al. (2014)
	Acetone	Wang et al. (2019a, b)		
	Hydralazine hydrochloride	Patil et al. (2019)		
	Drugs and antibiotics	Bolong et al. (2009), Bielen et al. (2017)		
Iron and steel industry	Organic matter, oil, benzene, phenol	Doushanov (2015)	Cyanide	Singh and Gupta (2016)
			Sulphate, ammonia, thiocynate, thiosulphate, fluorides	Doushanov (2015)
			Sulphides, oxides of copper, chromium, cadmium, mercury	Verma and Dwivedi (2013)
Municipal waste				
Household discharge (including the pharmaceutical discharge)	Food waste	Koch et al. (2016)	Microplastics	Nguyen et al. (2021)
	Oil, fatty acids, grease	Pastore et al. (2015)		
	1,4-dioxane	Karges et al. (2020)		
	Dissolved salt (organic)	Morrison et al. (2001)	Ammonium and phosphate	Goswami et al. (2021)
	Bisphenol A	Dos Santos et al. (2021)		
	Poly-fluoroalkyl substances	Banks and Tatlow (2013)		
	Ibuprofen	Slack et al. (2007)	Lead, Chromium, Mercury, and other inorganic pollutants	Slack et al. (2007)
	Acetaminophen, caffeine, cotinine, carbamazepine	Costa et al. (2019)		
	Antibiotics, hormones	Hinkle et al. (2005)		

(continued)

Table 1.1 (continued)

Type of industries	Organic pollutant	References	Inorganic pollutant	References
Hospital pollutant	Endocrine-disrupting substance	Sarkar et al. (2022)	Mercury and other inorganic hazardous substances	Rana et al. (2019)
	Pathogen	Shahzad et al. (2021)		
	Ibuprofen, diclofenac	Vieira et al. (2021)		
	N-nitrosodimethylamine	Sarizadeh et al. (2021)		
Laundry discharge	Detergent	Mohamed et al. (2018)	Microplastic, microfibre	Galvão et al. (2020)
	Organic carbon, pathogen	Sidin and Mohamed (2021)		

1.4 Wastewater Related Issues and Challenges Worldwide

Both developed and developing countries encounter more or less water pollution-related problems. The United States is also a developed country, but wastewater infrastructure in the United States is more complex and expensive. Most of the waste is buried beneath the ground of cities and towns, therefore it is difficult and expensive to inspect (Tafuri and Selvakumar 2002). In the United States, pharmaceutical, organic wastewater contaminants and personal care products related contaminants create a rising concern for human health (Barnes et al. 2008; Spongberg and Witter 2008). Report on pharmaceuticals in wastewater was first published in the United States in 1970 (Daughton and Ternes 1999). Pharmaceutical compounds and human hormones are ubiquitous pollutants identified as endocrine-disrupting chemicals (EDCs) which affect or alter the thyroid functioning and causes cancer in humans, and obesity among youth (Kim et al. 2007; Alsen et al. 2021; Perng et al. 2021). In EU states, sewage waste is an important issue that is required to be handled according to the law (Cieślik et al. 2015). Member of EU discharge a million tonnes of dry mass of sewage sludge every year. Approximately 583,100 tonnes of dry matter of municipal waste Poland alone produced during municipal wastewater treatment (Kujawa et al. 2020). The Netherlands and Volga River of Russia also faces problems concerning different pollutants, including micro-pollutants (Vij et al. 2021; Lisina et al. 2021). In Ireland, Domestic Wastewater Treatment System (DWWTS) is a substantial source of nutrients and enteric pathogens, predominantly in the rural areas (Naughton and Hynds 2014). 1,4-dioxane is the cyclic ether which is identified as a carcinogen by the US-EPA, is widely distributed in the rivers of Germany (Karges et al. 2018). Polycyclic aromatic hydrocarbons (PAHs) are a type of pollutant found both naturally and anthropogenically (Pampanin 2017). Industrial and municipal waste, oil spills, incomplete burning are some reasons for the anthropogenic discharge of PAHs in the Volturno river of Italy (Montuori et al. 2020). Release of the insufficiently treated domestic wastewater pollutants through direct discharge leads to surplus nutrient enrichment that results in eutrophication and algal blooms (Gill et al. 2009; Palmer-Felgate et al. 2010; Withers et al. 2012). The integrated water resource management concept application and attainment of the objectives of the Water Framework Directive (WFD) needs to be solved in a unified way to issues linked to the water use cycle (Teodosiu et al. 2012, 2015; Lemos et al. 2013). The Seine River is one of the most important rivers of France, but due to anthropogenic activities large quantity of metals, chemicals, and pathogens have been accumulated in the river (Le Gall et al. 2018). In developed country wastewater collection and treatment have common practices, and its reuse is practiced with proper attention of environmental protection and health attention (Jimenez and Asano 2008). Poly-fluoroalkyl substances (PFAS) are synthetic and inert compounds that are frequently used since the 1950s in industries and consumer products (Banks and Tatlow 2013). In Australia PFAS are used for firefighting action in Defence Force bases from the 1970s and also used for industrial purposes, that leads to their accumulation in environment which causes many health-related issues (Banwell et al. 2021).

In developing countries, effective wastewater management is not well established in comparison to a developed country. People of these countries lack access to water and sanitation, causing multiple diseases across the population (Libhaber and Orozco-Jaramillo 2012). Water-related diseases affect approximately 2.3 billion people around the globe most of which are the citizens of India and Pakistan (Jalan and Ravallion 2003; Azizullah et al. 2011). In the two-third of rivers of Asia, Africa, and Latin America, the concentration of disease-causing bacteria has increased between 1990 and 2010. In Africa, water-borne diseases infect millions of people (Fenwick 2006). In Latin America, organic pollutants affect about one of every seven kilometres of all river stretch. Due to the lack of effective measures, the eutrophication problem is more severe in Latin American and African countries than in North America and Europe. The global freshwater quality Database (GEMStat) in developing countries is low in density compared to developed countries (UNEP 2016).

Wastewater treatment plants (WWTP) consume more energy for processing waste, associated with higher carbon emissions (Wang et al. 2016). Because of discharging a large amount of wastewater and its productive use in irrigation, it ultimately affects health (Qadir et al. 2010). All over the world, China is the most populated developing country which faces major challenges of accessibility and water quality, including the magnitude and diversity of the country and its rivers (Zhu et al. 2018). Constantly large amounts of pollutants are released into the river and cause eutrophication (Qu and Fan 2010).

Moreover, unplanned urban development has prioritized water services and sewerage, leading to a disparity amid existing water resources and water excellence security, so wastewater treatment and solid waste removal has lagged (Moscoso et al. 2002). Energy consumption in the water sector of Latin America and Caribbean is likely to grow due to the enhancement in the number of treatment facilities required for recovering the present treatment coverage (Noyola et al. 2012). According to United Nations (UN) World Water Development Report (UN WWDR 2021) poor regulation, management, and lack of investment are major obstacles in providing hygienic water to all. Bangladesh, India, Sri Lanka, Nepal are the South Asian countries having water-rich regions, but they show spatial variability, and there has also been great disparity in the strictness of monitoring and enforcement of regulations (Helmer and Hespanhol 1997). Every day, approximately 10.5 million gallons of wastewater are discharged into the water resource (Hirani and Dimble 2019). In India, there are many rivers, but Ganga and Yamuna are the most polluted rivers (Sarker et al. 2021) being the lifeline of indo-Gangetic plain. Thus, there is an immediate concern for the prevention of inadequate and unchecked discharge of industrial and municipal wastewater into the water bodies for pollution prevention.

1.5 Health Concerns Due to Water Pollution

WHO defines health as “a state of complete physical, mental and social wellbeing” (Brinkel et al. 2009), and individual health should be sound for proper growth and development. Water is essential and precious, but many people don’t have right to use to clean drinking water, and die due to water-borne bacterial, viral, and fungal infections (Cabral 2010). More than 3 billion people have been at risk and lack adequate access to hand hygiene facilities (UN WWDR 2021). Moreover, women are at risk due to the consistent water use from different water resources such as rivers or lakes for washing cloth and storing water for household purposes (UNEP 2021).

Worldwide, more than 80% of wastewater is neither collected nor treated, and is discharged directly into the environment devoid of appropriate handling (UN WWDR 2020). Few trace elements are essential for the human body (Camur et al. 2021). However, if their concentration exceeds the permissible limit, it affects living organisms (Izah et al. 2016). There are 12 heavy metals which are poisonous when found above the permissible concentration including arsenic, mercury, chromium, nickel, cadmium, cobalt causing disease in humans. These toxic metals are five times denser than water and are not easily removed from the water bodies (Ekpo et al. 2008). Arsenic is ubiquitous and both natural and anthropogenic activity causes its contamination (Ng et al. 2003). Water contamination by natural phenomenon is influenced by hydrological and geological properties of the allied aquatic source (Singh et al. 2021). Consumption of arsenic contaminated drinking water for a longer duration causes toxicity and is detrimental to human (Spallholz et al. 2004; Khan et al. 2007). Furthermore, it shows carcinogenic activity. Arsenicals (a chemical compound that contains arsenic) causes lung, skin, and bladder cancer, but clinical indicators of chronic arsenicosis (accumulation of arsenic in the body due to long-term exposure from drinking water) in people accounts non-cancerous effects like keratosis, hyper or hypopigmentation, cardiovascular ailments, hypertension, and diabetes (Ng et al. 2003; Kapaj et al. 2006; Sun et al. 2016). It is estimated that approximately 60–100 million people in India and Bangladesh face the risk of consuming arsenic-contaminated water (Ahmad 2001; Chakraborti et al. 2001).

Mercury is another toxic metal that causes health-related issues (Budnik and Casteleyn 2019). Mercury exists in various conformation, such as elemental, inorganic and organic mercury compounds. Mercury is released in the environment both naturally and by anthropogenic means. Natural means include volcanic activity, weathering of rocks that contribute to water resources. Anthropogenic sources include mercury and gold mining, cement manufacture, industrial leaks, dentistry, etc. (WHO 2007). The most common disease caused due to mercury is Minamata (methyl mercury poisoning) caused by methyl mercury-contaminated pollutant (Yorifuji et al. 2013; Takaoka et al. 2018). Methyl mercury leads to a form of food poisoning which shows the symptoms like sensitivity disorders, cerebellar ataxia, mental retardation, visual and hearing disorders, deformed or functionally weakened limbs, paralysis, coma, and sometimes even death (Yorifuji et al. 2013). Moreover, the disease-causing methyl mercury is also transported through the placenta to wreak the development of unborn children, which often cause stern mental and physical problems lately in their life (Harada 1978; Harada et al. 2005). Mercury-induced immune toxicity causes risk for infectious diseases, such as malarial infection (Silbergeld et al. 2005).

Fluoride is an essential element for human health in lower amount (Yadav et al. 2019). However, beyond 1.3 mg/l which is a limit set by WHO, it is harmful to human health. In excess dose it causes severe gastroenteritis, restlessness, anorexia, muscle weakness, stiffness, dyspnoea, ventricular abnormalities, and tachycardia (Sahu et al. 2017), bone abnormalities, reproductive organs impairment, muscle and nerve degeneration and particularly the disease fluorosis. Fluorosis can be dental or skeletal fluorosis (Yadav et al. 2019). Due to the uptake of excess fluoride containing drinking water during the tooth development, dental fluorosis or hypoplasia occurs, in which teeth become hard and frangible, leads to mottling, discoloration, and pit formation in enamel (Yadav et al. 2019). Decline in bone mass, joint pain, and hardening of joints are some of the other symptoms of this disease. Asian countries especially India, face fluoride contamination in water resources. It is observed that fluoride concentration is higher in India than in other Asian countries (Yadav et al. 2019). Fluorosis is endemic in at least 25 countries throughout the Asian continent (Fawell et al. 2006). In India, fluorosis is very severe in Andhra Pradesh, Gujarat, and North Rajasthan. Punjab, Haryana, Madhya Pradesh, and Maharashtra are affected slightly, whereas Assam, Bihar, Tamil Nadu, Uttar Pradesh, and West Bengal, are affected the least (Arlappa et al. 2013).

Cadmium is classified as a pollutant in water, that has been reported from all around the world, causing considerable death annually (Fatima et al. 2019). According to WHO guideline, adequate cadmium concentration should be 3 μg/l, while above this concentration, Cd can accumulate in the human body and affect human health (Segawa et al. 2021). Cd causes osteoporosis, renal tubular dysfunction and also causes Itai-Itai disease which leads to severe bone pain (Kasuya et al. 1992). Copper is an essential nutrient, but its higher concentration in drinking water causes anaemia, liver cirrhosis, and kidney damage (Akpor et al. 2014). Likewise, many pharmaceutical pollutants are carcinogenic (Bonefeld-Jorgensen et al. 2011). A compound PFCs (Perfluorinated compound) is a pharmaceutical pollutant which is a severe health hazard causing pre-eclampsia, congenital disabilities, reduced human fertility (Webster 2010), immune-toxicity (Seyoum et al. 2020), and neurotoxicity (Lee and Viberg 2013).

Water-related infectious diseases are classified into four categories: water-borne disease, water-washed disease, water-based disease, and water-related insect disease (Manetu and Karanja 2021). Water resource contamination by water-borne pathogens and the linked diseases are a major problem worldwide (Pandey et al. 2014). Water-borne diseases are threat caused by bacteria, viruses, protozoa and transmitted via ingestion of contaminated drinking water or animal faeces or urine containing pathogens such as cholera, diarrhoeal disease, typhoid, infectious hepatitis, etc. (Woodall 2009; Collier et al. 2021). Various bacterial, viral, and protozoan pathogens excreted in faeces can initiate water-borne infection (Leclerc et al. 2002). Passive carriers of the infectious agent of gastrointestinal illness are different microbes and germs that cause diseases showing symptoms like diarrhoea, nausea, vomiting, fever, and abdominal pain (Arnone and Perdek Walling 2007). *Adenovirus, Cryptosporidium*, *E. coli, Giardia, Shigella spp, Leptospira, Naegleria fowleri, Salmonella, and Vibrio cholera* are the agents responsible for many outbreaks (Craun et al. 2006). In any developing country, majority of people get affected by the diarrhoeal disease due to lack of proper water management and the unhygienic condition and the diseases are easily transmitted from people to people. The people in countries of Asia and Africa are mostly infected by microbial diseases spread through the use or consumption of contaminated water (Seas et al. 2000).

Water-washed diseases are infectious diseases that are transferred by unhygienic lifestyles or lack of water for hand washing and bathing, such as dermatophytosis disease caused by *Trichophyton,* trachoma, Ophthalmia Neonatorum, etc. (Webber 2009; Sobsey 2015). Water-based diseases are infectious diseases that are spread through aquatic host organisms that carry parasitic pathogens such as flat worms schistosomes (Schistosomiasis) and guinea worm Dracunculus (Dracunculiasis). Malaria, yellow fever, dengue fever, filariasis, are an example of water-related diseases caused by an insect that breeds in water (Greenaway 2004; UNICEF 2008) (Fig. 1.2).

1.6 Control and Treatment Technologies for Water Pollution

The pollution load and quality control are critical for proper water quality maintenance and for sustainable development of water resources, continuous endeavours are required to lower the water pollution and improve its quality (Singh and Singh 2021). Pollution prevention is an essential and predominant factor that reduces or minimizes the pollutant generated from a point source (Weng et al. 2012). The strategy of pollution control seeks management of pollutants and reduction of their effect on the environment. The best way to control pollution is to prevent it from

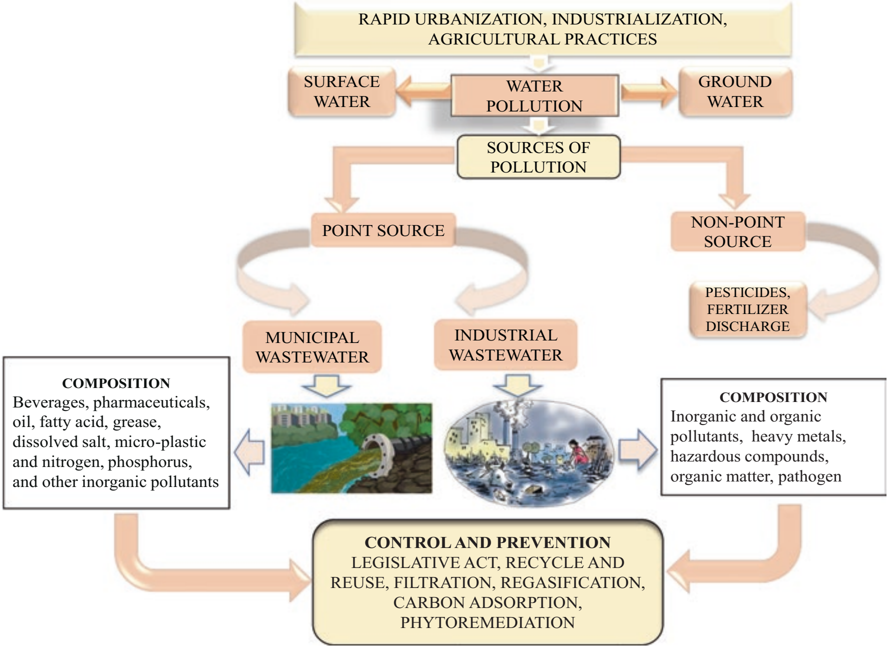

Fig. 1.2 Sources of water pollution, composition of the municipal and industrial wastewater and control and prevention of water pollution

being created in the first place. This demands the development of new technologies that are environment friendly, efficient, and produce least quantity of pollutants. Furthermore, the sustainable use of natural resources is significant to achieve the goal. Generally, there are two important policies for controlling environmental pollution, which includes the obligatory means and economic incentive. Developed and developing nations both have taken the mandatory means for permitting licenses and implementing the environmental rules (Wang 2006). Legislative acts and regulations are an important tool for controlling water pollution. The instrument of enforcement includes administrative and judiciary means of control. Administrative pressure, warning, amendment, financial damage, fines, and imprisonment are some administrative and judiciary regulations by which we can control the pollution (Warmer and Dokkum 2001). Population control, recycle, and reuse of different industrial products are methods to reduce water pollution (Warmer and Dokkum 2001).

It is important to identify the characteristics of the origin of pollutants. Integrated long short-term memory networks (LSTM) and the Internet of Things are utilized in identifying the characteristics of water pollutants (Wang et al. 2019a, b). Biodegradation, chemical oxidation, enzymatic methods, adsorption, membrane filtration, cementation are some methods used for the removal of industrial effluents (Singh and Singh 2002; Mantzavinos and Psillakis 2004; Noorjahan 2014;

Al-Saydeh et al. 2017; Singh et al. 2018). Common effluent treatment plants (CETPs) are one of the feasible wastewater treatment solutions (Devda et al. 2021). Other methods such as water reclamation, biosorption, and electrochemical technique are also used for this purpose (Volesky 1990; Vo et al. 2014; Devda et al. 2021). For removing heavy metals, and organic and inorganic pollutants from the wastewater system, green and biosynthesized nano-catalyst are used (Eskandarinezhad et al. 2021). Phycoremediation is a cost-effective, environment friendly method used to treat wastewater of food processing industry. Both microalgae and macro-algae are used in the process of phycoremediation (Olguín 2003; Munoz and Guieysse 2006; Gani et al. 2016). Global Freshwater Monitoring Station (GEMStat) should be established all over the country for better analysis of water quality. Awareness about the cause and effects of industrial wastewater should be spread all over the country through NGOs, government, strong institutions, and educated people (Srivastava et al. 2016).

Emerging contaminants threaten the aqueous environment because their persistent occurrence adversely affects all forms of living organisms (Parida et al. 2021). We can reduce the toxicity of municipal wastewater by following different methods. The legislative Act is the most important and regulating method to control pollutant discharge. In India, the water (prevention and control of pollution) Act 1974 was enforced by parliament for solving the problem related to the environment and safety of flora and fauna (CPCB 2021b). Ganga action plan and national river plan address the task of trapping, redirection, and municipal wastewater treatment. Usually, many of the country's wastewater from domestic sources is rarely treated owing to the inadequate sanitation facilities. The use of wastewater in agriculture is an ideal method of irrigation instead of freshwater (Contreras et al. 2017). Domestic and treated water have phosphorous, nitrogen, potassium, and sulphur. These nutrients are accumulated by the plants easily, therefore they are widely used for irrigation (Mara 2009; Drechsel and Evans 2010; Sengupta et al. 2015; Poustie et al. 2020). Nutrient-rich wastewater reduces the use of fertilizers, increases the productivity of crop, can improve the soil fertility, and reduce the cost of production. (Chen et al. 2013; Jeong et al. 2016).

Most of the water pollutants can be removed by both conventional and non-conventional processes. For instance, to avoid nitrate contamination in drinking water and its adverse effect, conventional decontamination technologies are used all over the world (Ahamad et al. 2018). The most common methods are filtration, degasification, sedimentation, adsorption, reverse osmosis, precipitation, and flocculation. Adsorption and membrane separation methods are applied to control the municipal wastewater pollution and are more effective than conventional techniques and well-known recovery processes. These methods have the notable power of removing wastewater pollutants (Saravanan et al. 2021). Pre-coat filtration, slow sand filtration, granular high-rate filtration are some methods that are used to eliminate different microbes such as viruses, bacteria, protozoa, etc. (WHO 2017). Awareness of solid-liquid waste management (SLWM), sustainable use of resources, sustainable urban design are the methods through which municipal pollutants discharge can be reduced. Moreover, treated municipal wastewater can be used as a water source for sustainable aquaculture (Zaibel et al. 2021).

Water-related emerging contaminants are the most challenging issue currently all over the world. For solving this problem various treatment technologies are used frequently. Ultraviolet light-emitting diodes is a modern technique utilized for removing organic pollutants through an advanced oxidation process (Matafonova and Batoev 2018). Electrochemical advanced oxidation process methods eliminate majority of pollutants from wastewater (Monteil et al. 2019). Porous carbonaceous material, i.e., biochar is obtained through the thermochemical decomposition of biomass feedstock used in biochar technologies for wastewater treatment (Xiang et al. 2020). Metal-organic framework (MOFs), peracetic acid-based advanced oxidation processes, three-dimensional graphene-based hybrid material are other methods practiced for the water treatment (Wang et al. 2019a, b; Li et al. 2020; Ao et al. 2021). Ferrates is an iron-based technique used for removing contamination from water which is the tetraoxy iron, eco-friendly, used as a disinfectant for deactivating micro-organisms (Sharma et al. 2015). Membrane bioreactor and hybrid reactor systems are used for removing micropollutants from wastewater. In a Hybrid reactor system, combination of techniques is applied for treatment purposes (Goswami et al. 2018). Besides these technologies, some nanoparticle-based materials such as green-synthesized nanocatalysts, nano adsorbents, and nano metals, are frequently used for eliminating and degrading variant types of hazardous pollutants. Sol-gel based copper–ceria adsorbent is a technique used for removing cadmium from the environment (Pal et al. 2021). Remediation of pharmaceutical hazardous substances, especially antibiotics that affects human health is carried out by biogenic nanomaterials (Nasrollahzadeh et al. 2021; Ojha et al. 2021). The synthetic pollutants such as chlorinated phenolic compounds, inorganic metals, polycyclic aromatic hydrocarbons, absorbable organic halides, phthalates, etc. released in the environment can be degraded by microbial engineering (Schwarzenbach et al. 2006; Kurwadkar 2019; Bhatt et al. 2020, 2021).

1.7 Major Action Taken by Various Organizations

According to the United Nations (UN), clean water is necessary for human health, socio-economic advancement, and the ecosystem. However, due to the excess population, nature and its resources are being depleted and degraded. It has been becoming a challenge to ensure a sufficient and safe water supply for each individual. The only remedy for it is to discharge less pollution and improve the wastewater treatment method. On March 22, world water day is celebrated by the UN since 1993. The UN world water report was published on March 21, 2021, as “valuing water.” The 2021 edition of the United Nations World Development Report (UN WWDR 2021) is divided into five interrelated perspectives valuing water source, ecosystem and in situ water resources, valuing water infrastructure, valuing water service, valuing water as an input to production and socio-economic activity. Today we need to improve the current status of water bodies through water resource management for achieving sustainable goal no. 6 i.e., clean water and sanitation of the United Nations 2030 Agenda for sustainable development (UN WWDR 2021).

Global programme for protecting the marine environment from land-based activity focuses on regulating and reducing wastewater, marine litter, and excess nutrients. A program of UNEP is GEMS/water programme (Global Environment Monitoring System for Water) which supports all countries for monitoring and reporting on water quality. In 1978 GEMS/water programme was established, which mainly works to collect global inland water quality data and promote nature-based solutions for water management. Currently, GEMStat (Global Environment Monitoring Station) has data from more than hundred countries (UNEP 2016).

Moreover, World Bank provides financial assistance to the country for improving water quality for both fresh water and the ocean. It focuses on remediation of contamination sites (World Bank 2020). World Wide Fund for Nature (WWF) is the most important and world largest independent conservation organization. This organization works to conserve the planet's natural environment and aim for a future in which humans live in congruence with the nature practicing sustainable use of natural resources. According to the freshwater living planet index, freshwater biodiversity is rapidly declining compared to oceans or forests. Approximately 90% of the global wetlands have been lost, due to anthropogenic activity and have impacted millions of rivers (WWF 2020).

For public health, the World health organization (WHO) released their fourth edition guideline (2017) for drinking water safety. This document consists of all water quality data such as different chemical discharge, microbial contamination (bacteria, virus, fungi, etc.), radioactive pollutant, water-borne diseases, and managing their risk. It also deals with public health according to local and national authorities and water safety plan (Table 1.2).

Table 1.2 Guideline for chemicals from industrial source and sewage that are of health significance in drinking water (WHO 2017)

Guideline values for naturally occurring chemicals	mg/L
Inorganic chemicals	
Fluoride	1.5
Arsenic	0.01
Barium	1.3
Chromium	0.05
Guideline value for chemical released from industries and municipal water	
Inorganic chemicals	
Mercury	0.006
Cadmium	0.003
Organic chemicals	
Benzene	0.01
Toluene	0.7
Tetrachloroethene	0.04
Nitrilotriacetic acid	0.2

The Water (Prevention and Control of Pollution) Act was enacted in 1974 to reduce and prevent water pollution and restore good quality of water in the country. This Act was further revised in 1988 and then in 2003. Cess Act was enacted in 1977 on the person/organization who consumes water for operating different industries. Collected cess is used to increase the State Board's and Central Board's resources to control and prevent the pollution of water constituted under the Water (Prevention and Control of Pollution) Act, 1974 (CPCB 2021b).

The flagship Programme Namami Gange was launched by Union Government in June 2014 costed a budget of Rs. 20,000 crores to achieve protection and rejuvenation of the River Ganga integrated Programme. The Namami Gange Programme has eight pillars, viz. river surface cleaning, river-front development, sewerage treatment infrastructure, afforestation, biodiversity, industrial effluent monitoring, public awareness, and Ganga Gram. In Indian states (Uttar Pradesh, Uttarakhand, Jharkhand, Bihar, and West Bengal), 63 sewerage management schemes are under implementation to create a sewerage capacity of 1187.33 million litres per day (NMCG 2021). Campaigns such as workshops, conferences, events, seminars, and various Information, Education, and Communication (IEC) activities were planned to make public aware of their involvement in the programme. Numerous awareness events/activities were organized through campaigns, rallies, exhibitions, cleanliness and plantation drive, competitions, development, and resource distribution. For widespread publicity, mass media such as television/Radio, media advertisements, featured articles, were published (NMCG 2021). Around 1674 gram panchayat near river Ganga was identified as gram Ganga and funded by the Ministry of Drinking Water and Sanitation (MoDWS) in five states which are Uttar Pradesh, Uttarakhand, Jharkhand, Bihar, and West Bengal for construction of toilet. Out of the targeted 1,527,105 units approximately 853,397 toilets were constructed (NMCG 2021).

Prime Minister of India launched Swachh Bharat Mission with two Sub-Missions, the Swachh Bharat Mission (Gramin) and the Swachh Bharat Mission (Urban), on October 2, 2014 to achieve and accelerate universal sanitation coverage. This mission allows village, panchayat, district, union territories and states, in India to declare themselves “open-defecation free” (ODF) by October 2, 2019, by building over 100 million toilets in rural India. The second segment of the Swachh Bharat Mission (Grameen) has been also launched to drive the facilities to ensure the liquid and solid waste management, i.e., ODF-Plus which will reinforce ODF behaviours and focus on providing interventions for the safe management of liquid and solid waste in the villages (SBMG 2021).

1.8 Conclusion

After reviewing the scenario of water pollution, we conclude that there is an urgent requirement for in-depth analysis (i.e., proper monitoring, assessment, collecting data, and strong institution) and planning to protect the earth and achieve UN sustainable goals for our better life in the present and future. Our understanding suggests that the government's policies for regulating the economy, technology, and environment determine the course of water conservation. The current situation demands the treatment of anthropogenic industrial and municipal waste before they are discharged into the water resources. The majority of the developing nations are devoid of advanced wastewater management infrastructure, and therefore, the industries lack the equipment to carry out waste management. Intensive investment in research and innovation will help us discover innovative and efficient strategies to tackle water pollution, ultimately having immense health benefits. Serious efforts are required to make drinking water as safe as possible. Further, modifying national economy policies from extensive to intensive mode causes a reduction in water consumption and paves the way for investment in water-saving technologies and affordable policy. Additionally, to ensure safe drinking water to the public, it is required to carry the regular microbiological analysis of drinking water by assaying the presence of different microbes by culture media. The government should invest financial resources to understand better the ecology and behaviour of human and animal faecal bacteria in environmental waters. Further, subsidies from the government are required for the enhancement of water infrastructure in developing nations. Applying economic strategies for water resource allocation is suitable and offers a simple tool for developing water services more efficiently. Yet, the same should not be followed for water use for domestic needs, specifically for individuals living in extreme poverty. More research, analysis, discussion, and pledges are desirable in deciding whether water is a common or economic good. Understanding the future water quality parameters can pave the way for designing efficient and accurate monitoring programmes for the assessment and prevention of water pollution. Adoption of clever strategies such as using treated tailwater for construction purposes such as road construction. Further, the issue of heavy metal contamination can be tackled by adopting environmental sustainability and various biological treatment processes, mainly microbial and phytoremediation. Additionally, terrestrial vegetation plays a crucial role in the recycling of various toxic inorganic heavy metal waste.

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