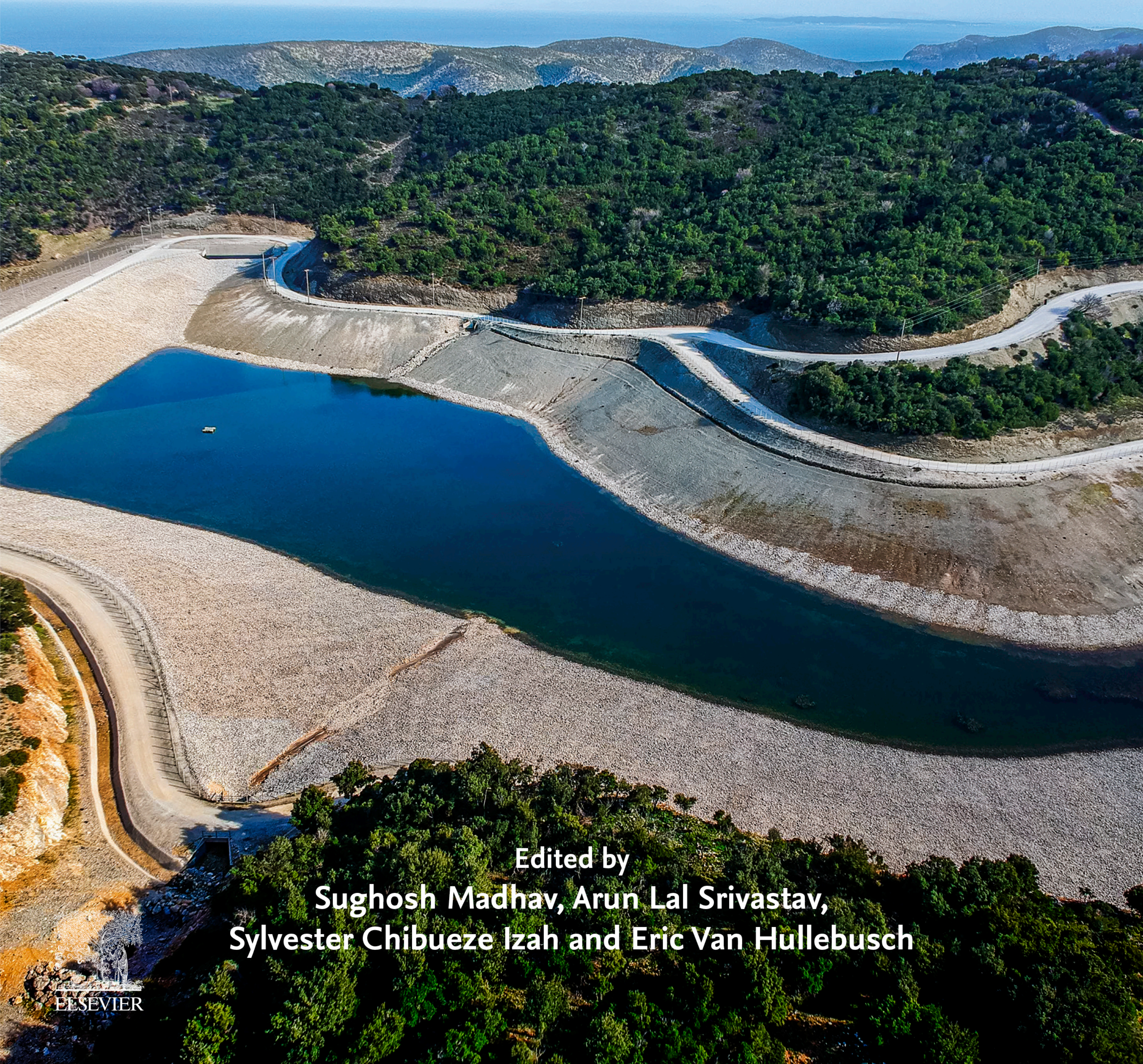
WATER RESOURCES MANAGEMENT FOR RURAL DEVELOPMENT

Challenges and Mitigation



Edited by

Sughosh Madhav, Arun Lal Srivastav, Sylvester Chibueze Izah and Eric Van Hullebusch

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Water Resources Management for Rural Development

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Section 1

Challenges in rural water management

Chapter 1

Water pollution: Primary sources and associated human health hazards with special emphasis on rural areas

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1.1 Introduction

Despite making up nearly 71% of the earth's surface, water is one of the scarcest commodities in the world. Only 2.5% of the world's total water resources are fresh water, and the remaining 97.5% of water consists of saline water. Out of that, around 87% of freshwater resources are stored in ice sheets, glaciers, and snow, followed by about 13% in the surface and sub-surface water (Hoogesteger & Wester, 2015). This 13% freshwater is only accessible for human consumption and economic needs (agricultural, domestic, and industrial) and sustains the freshwater aquatic ecosystem. Water has many uses, including drinking, domestic, agricultural, industrial, commercial, hydroelectric power, transportation, and recreational services (Igwe et al., 2017). Water resources are essential for supporting life and economic development, especially in rural areas. Water quality and quantity of an area are controlled by several factors, including precipitation, vegetation, climate, geology, soil type, flow conditions, and anthropogenic activities (Chaudhry et al., 2017). The quantity of water resources is important; at the same time, the quality is equally relevant and plays a significant role in sustainable water resource management. Globally, water scarcity is not only caused by physical shortage; a decline in water quality also leads to a substantial reduction in available safe water resources (Borah & Bera, 2004; Mateo-Sagasta et al., 2017).

Water pollution is a global concern as they pose a threat to humans, other organisms, and the climate and has the potential to alter the ecosystem dynamics. Water pollution is a qualitative term representing the condition when the levels of pollutants impede the desired use (Walker et al., 2019). Contamination of any water resources is considered water pollution, i.e., rivers, oceans, streams, lakes, and groundwater aquifers. Any changes in the chemical, physical, or biological properties of water resources lead to water pollution. Once a water resource is contaminated to a certain extent, water quality restoration becomes difficult and expensive. Water pollution has drastically increased in developed and developing nations, impacting billions of people's physical and environmental health and economic development. Water resources are contaminated by natural and anthropogenic activities that bring different organic and inorganic contaminants into the water system. Organic pollutants are majorly introduced by anthropogenic activities, which include agrochemicals, industrial effluents, domestic sewage, etc. Also, anthropogenic activities introduce emerging contaminants into the water system, such as pharmaceuticals, personal care products (PPCP), detergents, polyfluorinated compounds, micro-plastics, etc., which impose a high risk to human health (Ajith & Rajamani, 2021). Inorganic pollutants are introduced by natural as well as anthropogenic sources, including geogenic processes; weathering, erosion, runoff, and other activities such as atmospheric deposition, biological contaminants, etc. (Ahamad et al., 2020). Global reports indicate that about 80% of municipal wastewater discharged into the water bodies is not treated. Additionally, industries dump millions of tons of toxic sludge, heavy metals, solvents, and other waste materials into the water bodies each year (United Nations, 2017).

The demand for water resources and water pollution has increased over time due to increasing population and related exploitation. Excess water resources have been used for agriculture, energy production, industrialization, urbanization, and improving living standards. Around 35% of the world's renewable freshwater resources are used for domestic,

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industrial, and agricultural purposes (Schwarzenbach et al., 2006). Global data reveals that approximately one-third of the global population lives in countries with moderate to high water scarcity. In addition, about 20% of the population worldwide lacks appropriate access to clean and safe water, and around 40% experience the effects of appalling sanitary conditions (UNESCO, 2003). Between the years 1900 to 1995, global freshwater consumption increased six folds, which is more than twice the rate of human population increase (Postel, 1997; UNEP, 2002). Hence, the coinciding of limited water resources with a growing population results in water scarcity in many parts of the globe. Constant use or exposure to polluted water can cause mild to severe health impacts in humans, ranging from carcinogenic to non-carcinogenic effects. Globally, about 14,000 people die every day due to water contamination and related diseases (Chaudhry et al., 2017). In addition, water-related diseases claim the lives of 1.5 million children under the age of five every year globally.

India has 2.4% of the global land, 18% of the global population, and only 4% of the global water resources. As India is one of the world's fastest-growing economies, there is a high demand for water supply and tremendous pressure on natural resources (water, soil, and air). India has one of the largest water resource systems in the Indo-Gangetic plain and Brahmaputra alluvial plain, which have high-yield aquifers (Mukherjee et al., 2015). The precipitation recharges the sub-surface water resource in different parts of India due to the southwest and northwest monsoon. Irrigation accounts for about 87% of freshwater resource use in the country, followed by domestic and industrial purposes (Mukherjee et al., 2015). Even though abundant water resources are available in the country, over-extraction and mismanaged water consumption lead to scarcity and drinking water shortage. The groundwater table in the country is shifting downward with time due to exceeding withdrawal rates than the recharge rates (Gleeson et al., 2012). In India, more than 70% of the freshwater resources are unfit for consumption (Dwivedi, 2017). Lack of adequate amount of water, poor sanitization, and hygiene lead to the loss of 400,000 lives per year in India.

Studies have revealed that urban civilization requires more water resources than rural areas, and the quality of water discharged in the urban regions worsens and is chemically more toxic (Bandy, 1984). However, water pollution in rural areas is in primary concern worldwide due to a lack of monitoring and studies. In rural areas, agriculture is the major profession of local communities and a source of income. Hence, water resources are highly contaminated due to excessive water abstraction for irrigation and the addition of agrochemicals. Globally, 70% of the water is abstracted for agriculture, which substantially leads to water contamination (Mateo-Sagasta et al., 2017). Agricultural farms discharge huge amounts of agrochemicals, drug residues, organic substances, sediments, and saline drainage into water bodies. Groundwater resources are overexploited in rural areas for irrigation, substantially reducing groundwater tables and introducing geogenic contaminants. Leaching and infiltration from the agricultural field introduce various agrochemicals such as pesticides and fertilizers into the aquifers. Similarly, the agricultural field's erosion and runoff add agrochemicals to the surface water bodies. Also, increased livestock farming and aquaculture in rural water bodies are increasing the rate of water pollution in rural areas. However, small-scale industries, domestic wastes, waste dumping, sewages, etc., also lead to considerable water pollution in rural areas. The availability of clean and safe water in sufficient amounts and quality is a basic need; sustainable development will be impossible without that. The 2030 agenda for sustainable development acknowledges the significance of improving the water quality, drinking water, sanitation, and hygiene, and includes a specific water quality target in the sustainable development goal (SDG). To achieve the sustainable development goal for a better future, health, and safe water resources, there is an urgent need for proper monitoring, management, and protection of water resources in rural areas. This article intends to briefly discuss rural water pollution, investigate its primary sources, and major health impacts on rural communities, and elaborated on the key contaminants of concern in rural water health hazards. Such studies are necessary to address rural water pollution and related health issues as limited studies have only taken place in rural settings.

1.2 Types of water pollution

Natural waters are divided into groundwater and surface water. Groundwater exists beneath the earth's surface in the porous rock, whereas surface water exists above the surface in contact with the underlying terrestrial surface and atmosphere. Surface water includes rivers, lakes, streams, ponds, reservoirs, creeks, and oceans, each with unique characteristics. Hence the water resources are of different types, and the source of pollutants and the process involved also varies. The subsequent sections will discuss various sources, pathways, and mechanisms by which groundwater and surface water are being contaminated.

1.2.1 Groundwater pollution

Groundwater is the primary source of potable freshwater resources, which can be used for drinking, domestic, agricultural, and industrial activities. In 2003, groundwater contributed 50% of the drinking water supply, 40% to industrial, and 20% to irrigation (Foster et al., 2003). Globally, groundwater supplies 40% and 43% of the total water required for drinking and irrigation, respectively (Salman et al., 2018). One-third of the world's population uses groundwater for drinking (Pawari & Gawande, 2015). In rural areas, the ratio is higher; more than half of all drinking water is supplied from groundwater (Harter, 2003). Therefore, groundwater pollution is a major concern as most of the global population relies on groundwater for survival.

Deterioration in the adequate quality or introduction of any contaminants in groundwater is considered groundwater pollution. Groundwater pollution is a result of both anthropogenic and natural processes. Natural processes like geological weathering and aquifer characteristics primarily contribute to the inorganic constituents in groundwater, whereas anthropogenic activities also contribute significantly (Dixit et al., 2022). However, various anthropogenic activities mainly introduce organic pollutants into groundwater. Geogenic contaminants are the primary natural source of groundwater pollution in rural areas and were introduced due to the over-extraction of groundwater for irrigation purposes. Geogenic contaminants such as fluoride, nitrate, arsenic, iron, and other toxic metals are introduced into the groundwater by contacting the rocks, weathering, or during the percolation process (Madhav et al., 2021). The primary sources of anthropogenic contamination in rural groundwaters are the leaching and percolation of agrochemicals such as fertilizers and pesticides. Over-extraction of groundwater and groundwater pollution in rural areas can lead to poor drinking water quality, degrading surface water systems, high purification and alternative source cost, and potential health hazards. The global groundwater reserve is approximately 70,000 km^3, and the global annual demand for water resources is between 6000 km^3 and 7000 km^3 (Dwivedi, 2017). Overexploitation and limited rainfall lowered groundwater resources and the water table replenishment. Hence, groundwater, a life-sustaining resource is facing extremely vulnerable situations in most countries, and predictions have indicated its lesser availability in the future.

1.2.2 Surface water pollution

Surface waters such as rivers, lakes, and streams are the most available and accessible water sources for domestic purposes in developing countries. The human population benefits from a wide range of services provided by surface water sources, including drinking, irrigation, recreation, power generation, and habitat for fisheries with significant economic value. Surface waters are majorly contaminated with agricultural, industrial, and domestic wastes through direct dumping and runoff. Surface water and sediments substantially contribute to assimilating pollutants from agricultural runoff and municipal and industrial wastewater discharge. Rural aquaculture in surface water bodies has introduced an enormous amount of chemicals and organic contaminants into the water. This may lead to eutrophication and dying of water bodies. Seventy percent of the surface water in India is unsuitable for human consumption (Martin, 1998). It is estimated that about 40 million liters of wastewater in India are discharged into rivers and other surface water bodies. Only a small fraction is adequately treated before discharging (World Economic Forum, 2019). According to the World Bank report, such releases of pollutants upstream can lower the economic growth in the downstream area. It can cause a 16% reduction in downstream agricultural yield and a 9% decrease in agricultural revenue. Moreover, 351 river stretches across India are identified as polluted, among which Maharashtra has the highest number of polluted river stretches (CPCB, 2018).

Rural river pollution in India is primarily due to agricultural runoff and erosion, discharge of industrial effluents, partially or untreated treated sewage, and dumping of solid wastes (Singh et al., 2023). Despite the nation's sewage treatment capacity of 31,841 million liters per day (MLD), urban areas generate about 72,368 MLD of sewage (CPCB, 2021). Globally, many rural communities are identified to be in threat of polluted surface water resources. About 15% of the rural population in South Africa relies on contaminated river water for domestic purposes (Rapu, 2003). About 70% of the people in Sudan rely on a surface water supply, which is highly contaminated by agrochemicals and untreated industrial effluents (Khalil, 2005). Similarly, 40% of people in Nigeria rely on contaminated surface water or wells for their basic needs (Shuaib, 2007).

1.3 Primary sources

Water is a widely distributed natural substance and a constantly recharging resource on the earth. We think water resources are infinite and bountiful, but it is a finite resource. Any changes in its natural characteristics and distribution can have devastating environmental impacts. Under the preconceptions of natural properties of water to retain the quantity and quality for a longer period, tradition has arisen of a carefree attitude towards the usage of water resources. Water pollution may come from a point or non-point source; point sources are single identifiable sources such as discharge from an industry or a sewage plant, whereas non-point sources do not originate from a single source; instead, they may come from various sources. The primary source of water quality degradation can either be of natural or anthropogenic origin, directly impacting human health, agricultural output, and a country's economy (Raju et al., 2009). Each primary water pollution source is illustrated in Fig. 1.1 and discussed detailed in the below section.

1.3.1 Natural sources

1.3.1.1 Geogenic

In water bodies, the excess presence of naturally occurring elements can cause potential human health hazards are

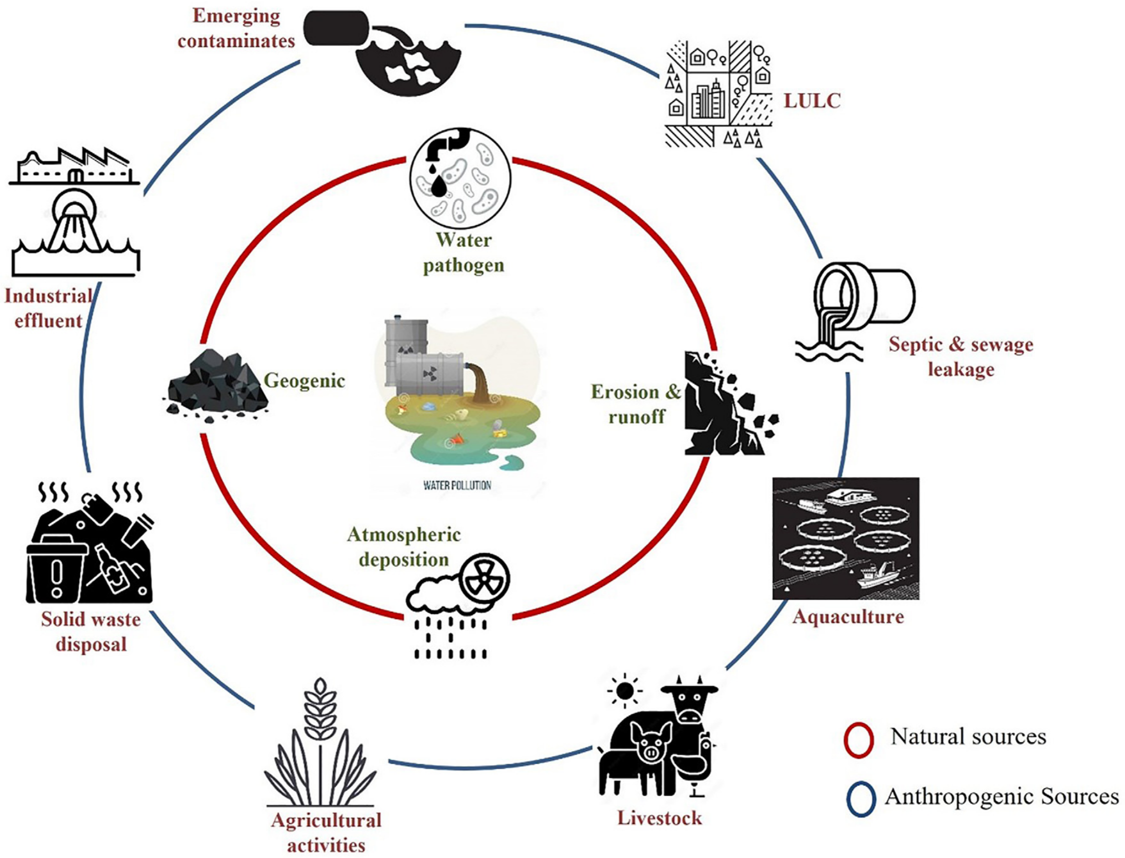

FIGURE 1.1 Figurative representation of major natural and anthropogenic sources of water pollution.

referred to as "*geogenic pollution*." Dissolution and weathering of minerals or rocks are dominant mechanisms responsible for adding geogenic contaminants into the water. Several parts of India are affected by the geogenic contamination of fluoride and arsenic, which is still a severe health issue and a continuing obstacle to providing clean safe drinking water. The background concentration of each element in the aquifer depends on the geological formation, climatic conditions, ion exchange processes, and past and present vegetation cover around the vicinity (Foster et al., 1999). High concentrations of elements, including salinity, iron, manganese, uranium, radon, and chromium, may also have geogenic origins in groundwater (Etikala et al., 2021). These pollutants may enter the surface waters due to subsurface recharge, erosion, and runoff.

1.3.1.2 Atmospheric deposition

Atmospheric deposition is a primary source of pollutants (gases, particulates, metals, nutrients, etc.) to the terrestrial and aquatic environments. Atmospheric deposition of pollutants can occur through dry and wet deposition. Via atmospheric deposition, pollutants can carry from longer distances and distribute into broad uncontaminated areas. Likewise, urban pollutants may be introduced to rural areas through atmospheric deposition. The health of people, animals, and the ecosystem can be adversely affected by the atmospheric deposition of pollutants. The deposition of sulfur and nutrients may contribute to the acidification and eutrophication of various water bodies (Shi et al., 2021). Once pollutants are deposited on the water's surface, they are assimilated in water and sediments for longer. Either these pollutants are directly ingested by biota, or in the case of acidifying pollutants, it accelerates the leaching of soil base cation, metals, and plant nutrients. Pollutants can also be moved from their original deposition sites through groundwater fluxes, surface runoff, and soil erosion. Pollutant uptake and toxicity in biota can be impacted by physical, chemical, and biological factors.

1.3.1.3 Erosion and runoff

Majorly, three processes; soil loosening, transport, and deposition are defined as soil erosion. The topsoil rich in organic matter, nutrients, and soil life is typically removed due to these activities. At the same time, these eroded materials may transport and deposit in some other regions, especially in surface water bodies (Shi et al., 2012). The mechanisms of soil erosion have an impact on how much water the soil can hold, how quickly water flows over the soil, and how quickly water travels below the surface. Rainfall is one of the leading causes of soil erosion because it erodes the soil, moves it from its natural position, and then washes it away as runoff. The impact of soil erosion can be very significant, not only in reducing soil productivity but also in depleting water quality. As a result of sediment buildup in lakes and rivers, light cannot easily pass through the water. So, aquatic plants that require sunlight for photosynthesis are impeded by this. Sediments are also a good source of nitrogen and phosphorus. These nutrients promote excessive algae growth and it can affect the natural processes occurring in water bodies. Plant growth, agricultural productivity, water quality, and recreation are all negatively impacted by soil erosion. Considering that it happens naturally in all areas, it is a significant factor in soil and water quality degradation (Posthumus et al., 2015).

The surplus liquid travels across the surface of the land before draining into nearby creeks, streams, or ponds. Runoff can result from human actions as well as natural phenomena. Additionally, runoff happens naturally as soil erodes and is moved to different bodies of water. Even harmful substances are carried into streams by natural events like volcanic eruptions. Volcanic gases eventually make their way back into the water or land as precipitation.

1.3.1.4 Water pathogens

Pathogen contamination is present in all forms of ambient water bodies, and it is crucial to recognize and comprehend this problem (USEPA, 2012). Water pathogens primarily enter the water bodies through a lack of sanitization, hygiene, and infrastructure in rural areas. Especially through open defecation, leakage of sewers and septic systems, open dumping, and introduction of animal wastes. Worldwide, a major water quality concern is the contamination of ambient water bodies with waterborne pathogens and their associated diseases. Numerous outbreaks have been driven by waterborne illnesses such as diarrhea, vomiting, nausea, and gastrointestinal disorders by different waterborne bacteria, viruses, and protozoa (Craun et al., 2006).

1.3.2 Anthropogenic sources

Expanding human population increased the demand for food supply, leading to an expansion in the irrigated agricultural area, increased demand for water supply, and the use of chemical fertilizers and pesticides. Maintaining the demand can increase the probability of contaminating water resources rapidly. Other than agricultural sources, small-scale industries, domestic wastes, sewage, open dumping, solid wastes, mining, etc., lead to considerable water contamination in rural areas (Ahamad et al., 2020). Water basins can get naturally revived either by rainfall or sub-surface recharge, but the processes are slow compared to the extraction rates. If the extraction rate exceeds the revival rate from a particular groundwater basin, the aquifer is said to be mined, which can lead to disastrous consequences. Anthropogenically induced chemicals, hazardous wastes, effluents, and treated/untreated waste discharged into the aquatic system degrade the ecosystem and cause potential human health impacts.

1.3.2.1 Agricultural activities

Pollution in the ground and surface water has increased steadily due to extensive agricultural activities worldwide (Kumazawa, 2002; Parween et al., 2021). In rural areas, agriculture is the primary source of income as well as the major source of water contamination. The use of chemical fertilizers and pesticides has extremely increased to enhance production and meet the food demand. Since 1970, the world population has increased by 78%, and fertilizer use raised to 120% (Galloway et al., 2008). It anticipates that one billion hectares of natural habitat, primarily in developing countries, will need to be converted for agricultural production to maintain the demand and supply in the future. As a result, the amount of nitrogen and phosphate inputs may double or triple, the amount of water required may increase by two-fold, and the amount of pesticides used may be threefold (Hole et al., 2005). As the population increases, the excess demand for food and energy continues, and the amount of reactive nitrogen created, and the magnitude of the consequences will also be increased. India consumes around 14 million tons of fertilizers per annum, of which more than 75% are nitrogenous fertilizers (Pathak, 1999). Consumption of nutrient fertilizers ($N + P_2O_5 + K_2O$) worldwide was estimated to reach 186.9 million in 2014, up by 2% over 2013. World demand for nutrient fertilizers was calculated to increase by 1.8% per annum from 2014 to 2018 (Gutiérrez et al., 2018), and it was expected to reach 200.5 million by the end of 2018. During this period, the demand for nitrogen, potassium, and potash was estimated to grow annually by 1.4%, 2.2%, and 2.6%, respectively. The researcher also finds that the global capacity of fertilizer products, intermediates, and raw materials will increase in the upcoming years. The overall increased demand for nitrogen fertilizer was 630 million between 2014 to 2018, with 58% from Asia (mainly China 18% and India 17%), 22% from America (a major portion coming from Latin America 18%), 11% from Europe (mainly east Europe and Central Asia 9%), 8% is from Africa, and 1% from Oceanic. The intensive use of fertilizers causes the depletion of resources and the environment (FAO, 2018). Pesticide accumulation in the water system and the food chain has a detrimental effect on humans and animals, which prompted the global ban on persistent pesticides like DDT and organophosphates. However, some such pesticide is still in use in poor countries and cause acute and chronic health effects. Such pollution leads to health risks for infants to adults, global acidification, and stratospheric ozone loss. The pace at which pollutants and nutrients are released into the aquatic environment has grown due to the overuse of agrochemicals. Increased nutrient levels in the aquatic system may cause eutrophication, increased water turbidity, oxygen depletion, coral reef destruction, and high marine life susceptibility (Kalff, 2002; Nazneen et al., 2022).

1.3.2.1.1 Livestock

Livestock farming and raising animals is a common practice of livelihood around the world. Domesticated animals rose to produce commodities such as meat, milk, egg, fur, leather, and wool. It is common in rural and suburban areas in developing nations to do animal husbandry for consumption or commercialization. The livestock population in only Rajasthan's rural areas is 1.62 million (Suthar et al., 2009). Somasundaram et al. (1993) and Tellam (1993) studied the pollution status in the watersheds of Madras, India, and observed that animal farming (several oxen, cows, and buffaloes) is the primary source of water pollution. Dung, excreta, and urine of animals are rich sources of contaminants such as nitrate, potassium, and pathogens (Sankararamakrishnan et al., 2008). They reach the aquifers through stormwater channels or river recharge basins. The improper management of manure and animal waste results in the leaching and infiltration of contaminates from the soil to streams and aquifers. In the last 10 years, veterinary drugs have become a brand-new agricultural pollutant class (antibiotics, vaccines, and growth promoters).

1.3.2.1.2 Aquaculture

Aquaculture has been a fast-growing industry because of the sharp rises in global demand for fish and seafood, and it is experiencing rapid growth. Compared to other animal culture industry segments, it is expanding more quickly (Gang et al., 2005). Aquaculture is more prominent in rural water bodies like ponds, lakes, wetlands, etc., and inland aquaculture using artificial ponds is also booming in rural areas. The usage of antibiotics, fungicides, and antifouling chemicals has also increased in aquaculture, leading to pollution in downstream ecosystems. Aquaculture wastes contaminate and potentially threaten the water system and the surrounding aquatic ecology. Aquaculture may worsen the environment, but ironically, it still depends on the availability of clean waterways. Aquaculture production is dominated by traditional farming approaches in many rural regions (such as extensive pond farming), although these are now gradually being displaced by intense western-oriented techniques. An intensive mariculture system's rapid scale expansion is frequently associated with adverse environmental effects. As throughput-based systems, intensive fish and shrimp aquaculture have a constant or intermittent release of nutrients that contributes to eutrophication (Troell et al., 1999). These contaminants may leach into the nearby aquifers and contaminate the groundwater.

1.3.2.2 Other sources

1.3.2.2.1 Leakage from septic tanks and sewer lines

Many regions worldwide face water contamination problems related to damaged sewer lines, septic tanks, and cesspits. In rural areas, such amenities are still missing, especially sewer lines and septic tanks, and are disposed of openly. They are the main source of sulfate, chloride, and nitrogen contamination in various water systems in rural areas (Eiswirth & Hötzl, 1997). Leakage of sewer lines and water supply networks in urban areas around the world accounts for the biggest proportion of water recharge to aquifers (Yang et al., 1999). The leakage is due to improper installation of sewer lines and water supply systems, cracks, and joint defects. Underground sewer leaks naturally develop over time, and the leak-outs gradually enter the water system and deteriorate the water quality (Ly & Chui, 2012). Since many people lack access to clean water and sanitary conditions, sewage disposal is a serious issue in rural areas. One percent of the nation's useable aquifers are contaminated by septic tanks (USEPA, 1980). In freshwater environments, sewage pollution increases the concentration of pathogens, which are thought to be responsible for potential waterborne health hazards to humans annually. Additionally, sewage contamination makes heavy metal toxicity more common in humans and fish (Alves et al., 2014). Sewage discharge causes dangerously low oxygen levels in freshwater environments because of the use of available oxygen for breaking down organic matter.

1.3.2.2.2 Solid waste disposal

Solid waste management is a worldwide challenge, especially due to the growing population, waste generation, and unsustainable developmental activities. Proper solid waste management is lacking in many parts of the world, especially in rural areas. People still practice open dumping instead of appropriate solid waste management in rural areas. Lack of awareness and infrastructural development is the major cause in rural settings. Improper disposal of solid wastes can introduce various chemical contaminants into the environment, especially into the water systems, including lead, copper, cadmium, manganese, nitrate, phosphate, etc. These contaminants may leach into aquifers and contaminate the groundwater. Direct dumping of solid wastes in surface water bodies results in the accumulation of toxic substances in the food chains, especially toxic chemicals such as mercury, cyanides, and polychlorinated biphenyls (PCBs). Improper solid waste disposal can lead to the discharge of storm water into the aquatic system, and storm water is a great source of N and P in the aquatic environment (Odell, 1994). Poor solid waste management in rural areas could cause potential health hazards for humans and animals, which in turn causes losses in terms of economy, environmental health, and biological diversity in most developing countries. Another high-risk population includes individuals who live close to waste dumps as their water supply may get contaminated due to garbage dumping or landfill leaks. This may increase the risk of illness and infection in the community.

1.3.2.2.3 Land use and land cover (LULC)

The land is one of the primary natural resources. An area's development does not only depend on population density but is also measured by alteration in spatial dimensions. The conversion of land from one land type to another and the alteration of land cover have significantly impacted a sizable section of the earth's land surface. The natural process of land transformation cannot be stopped, but it can be regulated. Whether positive or negative, all land uses have an impact on the quality of the water. The majority of rainfall soaks into the soil rather than evaporating in forests and other vegetated places with little human disturbance, which also have constant stream flows and good water quality. In paved and built-up areas, little rainfall seeps into the soil, resulting in an excessive runoff, stream flow with high peaks and low flows in between, and decreased water quality. In rural areas, a large proportion of land is converted for agricultural and developing activities. Additionally, land-use changes brought on by industrialization, urbanization, and agriculture can influence the watershed's surface features, affecting the quantity and quality of runoff (Tu, 2011). Such activities demand massive deforestation and ultimately impact an area's water infiltration, erosion, runoff, and ecosystem dynamics.

1.4 Potential health hazards

Water pollution has severe impacts on human health. According to the UNESCO (2021), over 829,000 people die each year from diarrhea led by poor hand hygiene, sanitation, and drinking water. Among them, about 300,000 are children under the age group of five, representing 5.3% of total death. In many nations around the world, groundwater is the main supply of water for household, agricultural, and industrial uses (Naik et al., 2008; UNESCO, 2004). Due to its widespread distribution, affordable construction costs, and high quality, groundwater is a primary source of drinking water for most rural residents. Yet anthropogenic activities have considerably deteriorated the quality and availability of groundwater. Except for groundwater, rural communities worldwide are exposed to a higher level of water pollution due to the consumption of untreated surface water. Discharge of large amounts of untreated domestic sewage into the river, hazardous substances, solid waste, plastic litter, runoff from agricultural fields, and bacteria are the primary source of waterborne illnesses (Haseena et al., 2017). Population growth has increased waste generation and its discharge into the rivers and other water bodies in rural areas, which is harmful to human health.

Heavy metals are the elements naturally present in the earth's crust and are a major concern for human health as they contaminate the groundwater, surface water, and soil (Ajith et al., 2020). The heavy metals are introduced into the water environment naturally by weathering and decomposition of rocks or via human-made activities (Jafari et al., 2018). The major heavy metals found in the water environment are arsenic (As), chromium (Cr), lead (Pb), cadmium (Cd), molybdenum (Mo), copper (Cu), zinc (Zn), nickel (Ni), and barium (Ba). Similarly, in rural areas, the primary health hazard is due to agrochemical contamination, especially chemical fertilizers and pesticides. Agrochemicals are widely identified in rural waters, groundwater due to leaching, and surface waters due to runoff and erosion from the agricultural field. The major pesticides identified in rural waters are organochlorine (OCPs) and organophosphate (OPPs) compounds, especially DDT, HCH, endosulfan, drins, atrazine, etc. Once these contaminants are entered the water environment, they reach the human body through various pathways like inhalation through the nose and mouth, direct ingestion, and dermal contact (Sardar et al., 2013). Long-term consumption of polluted water could cause potential health risks to humans. It can cause extensive damage to human health due to its toxicity, bioaccumulation, and poor biodegradability. In addition, it can accumulate in human body tissue over time owing to exposure, posing significant health risks to the brain, kidneys, liver, and bones (Kamunda et al., 2016). Health risk assessment is a method followed by researchers to estimate the exposure of these contaminants to the human body and evaluate the probable health impacts of the water environment (Sharma et al., 2022). According to studies, drinking water pollution is to blame for 70% of all diseases and 20% of all cancer cases worldwide (WHO, 2020). Carcinogens are the agents or compound that causes cancer. There are several metals and other cancer-causing pollutants, and prolonged exposure to these can cause cancer and even death. Major contaminants in concern to rural water health hazards have been discussed below.

1.4.1 Chemical contaminants

1.4.1.1 Nitrate

In the subsurface, nitrate is one of the most prevalent contaminants because it easily percolates through soil (Chen et al., 2016). In rural areas, high nitrate contamination in groundwater is reported due to the excess use of nitrogen-bearing fertilizers in agricultural fields (Singh et al., 2006). Drinking water with a higher nitrate concentration can cause various human health disorders, namely hypertension, birth malformations, and even gastric cancer (Majumdar & Gupta, 2000). Long-term consumption of high levels of nitrate-contaminated water reduces the oxygen-carrying capacity leading to methemoglobinemia, i.e., Blue Baby Syndrome, seen particularly in infants below 6 months of age. Additionally, long-term consumption of nitrate-contaminated water has been linked to thyroid, colorectal, breast, and neural tube abnormalities. Nitrate consumption results in the endogenous synthesis of N-nitroso compounds (NOC), which have the potential to cause cancer. Studies also have reported that early life exposure to nitrogen-related pollution leads to low birth weight, shorter height in adulthood, and even infant mortality. Low birth weight can lead to coronary heart disease, decreased glucose tolerance, and an increased mortality rate. According to a recent study (Ahada & Suthar, 2018), chronic toxicity is more likely to affect 93.42% of adults and 100% of children in Malwa (a rural area in the Punjab district) as a result of excessive NO_3 intake.

1.4.1.2 *Fertilizers and pesticides*

Pesticides cause severe health impacts due to their rapid fat solubility and tend to bioaccumulate. It has been reported that even small concentrations of pesticides can have various adverse consequences at biochemical, molecular, and behavioral levels (Anju et al., 2010). Over the past 20 years, there has been a sharp increase in the use of nitrogen-containing herbicides and fertilizers in rural regions, which has contaminated the nearby surface and groundwater. Consumption of these contaminants creates various health hazards to the rural community ranging from chronic neurotoxicity to lung damage and infant methemoglobinemia. In addition to these different types of cancers, especially hematopoietic cancer, immunological disorder, and adverse reproductive and developmental disorders have been reported (Sankhla et al., 2018). According to studies, drinking water tainted with herbicides has increased the incidence of breast cancer in Kentucky (Kettles et al., 1997) and low birth weight infants born as a result of water tainted with herbicides. Furthermore, due to pesticide contamination in drinking water, males in rural areas had lower sperm counts than those in metropolitan areas (Sankhla et al., 2018). In general effects of pesticides on human health can be linked to immune system deficiencies, pulmonary and hematological morbidity, and levels of oncological disease due to contaminated water ingestion (WHO, 2010).

1.4.1.3 *Arsenic (As)*

The earth's crust naturally contains arsenic, which is also extensively found in the air, water, and soil. Arsenic in its inorganic form is considered to be extremely toxic. The inorganic form of arsenic is exposed to humans through consuming contaminated water and food (Raju, 2022). Arsenic poisoning can become chronic if consumed over an extended period. Skin disease and even skin cancer are the common health impacts of arsenic contamination. Exposure to arsenic during early childhood negatively impacts cognitive development and is the primary cause of increased death in young adults. Bangladesh, India, China, Argentina, Chile, the United States of America, and Mexico are among the nations where high levels of arsenic have been found in groundwater. The main sources of arsenic exposure in these nations are drinking water, food made using arsenic-affected water, and crops grown using contaminated water. Besides contaminated groundwater, fish, dairy products, meat, and poultry can also be the source of arsenic but are comparably low. The early symptoms of arsenic poising are vomiting, abdominal pain, and diarrhea. If not diagnosed, it leads to numbness, muscle cramps, and even death in extreme cases. Long-term exposure to high levels of arsenic causes skin changes in pigmentation and hard patches on the palms and soles of the feet (Hyperkeratosis), which can progress to skin cancer. Long-term exposure to arsenic can also result in bladder and lung cancer. Arsenic in drinking water has been classified by the International Agency for Research on Cancer (IARC) as human carcinogenic. Besides cancer, long-term consumption of arsenic also causes cardiovascular disease, pulmonary disease, and diabetes. "Blackfoot disease" is a severe case of blood vessels leading to gangrene reported in China due to arsenic contamination. Arsenic contamination is also associated with young adult infant mortality and lung diseases. Additionally, it has been claimed that consuming excessive amounts of arsenic from groundwater over time causes bronchiectasis, skin cancer, bladder cancer, and arsenicosis. Additionally, 230 million people worldwide and 180 million in Asia are at high risk of developing arsenic poisoning, with South Asian countries being the most afflicted (Shaji et al., 2021). In India, rural areas of West Bengal, Bihar, Jharkhand, Uttar Pradesh, Chhattisgarh, Manipur, and Assam are the worst affected states by arsenic contamination, which cause potential health hazard risk to humans.

1.4.1.4 *Fluoride (F^-)*

Fluoride is naturally occurring in the water bodies as a result of weathering and runoff from fluoride-bearing rocks. Similarly, atmospheric deposition of fluoride-containing emissions from coal-fired power plants, small-scale industries, and agrochemicals introduce fluoride into rural water bodies. Fluoride is an essential compound for human health, but when exposed to higher concentrations, it leads to a severe disease called fluorosis, categorized as skeletal and dental fluorosis. In addition, it also impacts the human organs/systems like the cardiovascular, endocrine, renal, gastrointestinal, brain, and reproductive systems . Additionally, it has been observed that fluoride contamination in drinking water can cause infertility, hypertension, arthritis, and liver, kidney, and lung tissue damage, as well as hypertension. In a rural community with limited access to safe drinking water, prolonged consumption of fluoride-contaminated water can affect the teeth, bones, and joints, including knees, hips, back, and neck, and may lead to reduced mobility. Further, the bones become stiffer, causing severe pain and may lead to permanent disability (Del Bello., 2020). Countries like the United States, China, Saudi Arabia, India, Australia, Pakistan, South Korea, Indonesia, Sri Lanka, Iran, Turkey, Mexico, and Canada are worst affected by fluoride contamination in groundwater (Solanki et al., 2022). Fluoride pollution has been documented in 230 districts across 20 states in India.

1.4.2 Microbial contaminants

The World Health Organization (WHO) states that pathogenic bacteria cannot be found in drinking water (Gorchev & Ozolins, 2011). However, in a rural area where a large population depends on groundwater for daily activities, the water source is susceptible to contamination from micro-bacterial sources (Bogena, 2015). Especially in rural areas, these contaminations cause many water contamination-related illnesses like cholera, dysentery, and typhoid fever. Most micro-bacterial contaminants are produced by the fecal source/gastrointestinal wall of warm-blooded animals, including humans. The presence of *Escherichia coli* and salmonella are typically signs of fecal contamination (Odonkor & Ampofo, 2013). Many rural areas in developing countries lack access to sewerage systems and efficient municipal waste disposal, which severely pollutes their surroundings and causes microbial contamination. Some people may be aware that wastewater can include a variety of toxins, while others may not be aware that untreated wastewater serves as an ideal habitat for various human infections (Raja et al., 2015). However, multiple studies show that untreated urban wastewater contains dangerous microbes; if they get into surface and groundwater sources, they could cause disease outbreaks (Pandey et al., 2014; Rivera-Jaimes et al., 2018).

Conclusion

The importance of groundwater is ever-increasing all around the globe, especially in countries like India where agriculture is practiced extensively. Groundwater supply is immensely important in both the urban and rural areas of developing nations. Each organism depends on the presence of water resources to survive. From the human perspective, water resources are vital for their existence and economic development. The lack of accessible freshwater and water scarcity is prominent around the world. Global water scarcity results from a physical shortage of resources and a decline in quality. Water resources have widely deteriorated and been polluted all around the world. Irrespective of water resource types, groundwater and surface water has been highly polluted to an extent where water quality cannot reinstate. Both natural and artificial sources cause water contamination, but the degree of anthropogenic pollution is exceptionally severe and intolerable. Water pollution in rural areas has been increasing over the past few decades, but very few studies have been conducted on rural water pollution. People residing in rural areas are mainly dependent on natural water resources, so it is important to have clean water. The availability of safe and potable water in the rural region continues to be a distant dream for the rural population, mainly in developing nations. In rural areas, the origin of water pollution includes, run-off from agricultural land containing substances including pest control products, animal medicines, slurry, sewage sludge, and manure. Excessive groundwater abstraction for irrigation and agrochemicals used for farming are considered primary sources of water pollution in rural areas. It is recommended that regular monitoring is important for sustainable groundwater management and long-term protection of water quality from depletion.

- The poor water quality zone in rural areas must be properly treated before being subjected to drinking and other purposes.
- Due to the lack of proper education and awareness related to water quality, the probability of potential human health hazards increases immensely in rural areas. Awareness programs should be conducted mainly in rural areas to aware the local community regarding water pollution and water quality.
- Unauthorized extraction of groundwater should be prohibited for irrigation and commercial uses.
- The increasing population led to an enormous rise in waste generation, it has to be controlled and properly disposed of.
- It is vital to optimize the use of agrochemicals and reduce the dependency on chemical pesticides. And there is a need to implement an eco-friendly agricultural model and develop agroecological practices in rural settings.
- Rainwater harvesting and water recycling practices should be adopted to mitigate the effects of scarcity. It can be a good alternative source for irrigation and domestic purposes.

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Chapter 2

Water pollution in rural areas: Primary sources, associated health issues, and remedies

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2.1 Introduction

Water pollution in rural areas is the most predominant issue from an Indian perspective. Extensive pollution in water bodies adversely affects the groundwater and water bodies in rural areas due to agricultural runoff, domestic and industrial discharge. It impacts on potability index of water and induces drought and pathogenic outbreaks in rural communities. In a nutshell, it generates enormous danger to the natural bio-geo-chemical cycle in the rural environment and health hazards (InyinborAdejumoke et al., 2018).

The current review aims to discuss the wide variety of sources of pollutants to the water bodies and sources, the impact of these pollutants on the mortality rates of populations in rural areas which are greatly affected by the unavailability of potable water, the destruction of the biodiversity as a result of the contaminants in water and its ramifications on the food chain in nature. The various health hazards and diseases that are disseminated due to the contaminants in the water sources and the microbial pathogens involved have also been talked about. The review also focuses on the policies that have been implemented in India and the United Kingdom for ascertaining the availability of potable drinking water to the population with a comparative analysis using statistical insights and data on water pollution. A paradigm shift is an utmost necessity to identify diverse sources of water pollution and classify a broad spectrum of pollutants and their impacts in the first phase for minimizing rural water pollution and its ill influences on community health and environmental eco-dynamics for finding out possible solutions to combat these issues in grass-root level. Thus, we conclude by discussing many of the remedial measures that have been implemented for the safer treatment of water and making it available to rural and urban areas.

2.1.1 Sources of water pollution

There can be different sources of pollutants that can contaminate bodies of water. The contamination hence caused to water bodies is referred to as point source pollution when the origin of the pollutant is known or the specific contaminants that are introduced to the water flow are of origin that is identifiable like sewage treatment plants, ditch, storm drains, industries, etc. (Ahamad et al., 2018; Kumar et al., 2017). Non-point source pollution refers to water pollution in which the source is unknown or the pollutants present in the water body are of varying origins and not from a single distinct source. The sources may include fertilizers, chemicals, and pesticides in the form of agricultural pollutants or industrial wastes, making it really difficult to control. Some of the types of pollutants for bodies of water are discussed herein (Abera Mitiku, 2020).

2.1.1.1 Agricultural pollutants

The population in urban and developing areas when compared to the population of rural areas is lower. The majority of the contaminants in rural areas include fertilizers and pesticides, and eroded soil which reach the bodies of water through runoffs following rain, floods, and more. The runoff from the fields of agriculture causes eutrophication of the water bodies. A majority of the lakes and ponds in India are eutrophic (Moss, 2008). The chief contributor to eutrophication is the high concentration of phosphates which promote the growth of Cyanobacteria and algae which use up the oxygen available in the water body, ultimately causing a considerable reduction in the quantity of dissolved oxygen. The cyanobacterial blooms that form in the water bodies produce several harmful toxins which upon being

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introduced into the food web, get accumulated in the various trophic levels causing biomagnifications of these toxins (Rastogi et al., 2015). The fertilizers used in agricultural fields are rich in nitrogen compounds. These nitrogen-rich fertilizers on reaching the water bodies cause a deficiency in the dissolved oxygen in the lakes, rivers, and other water bodies, causing disastrous consequences for the fauna found in these water bodies. The nitrogen-containing fertilizers have high solubility in water and an increased rate of runoff and leaching which further results in groundwater pollution. Another pollutant that contaminates the water reservoirs is selenium. Selenium, which is a heavy metal, is found naturally occurring in soil but irrigation results in the heavy metal to accumulate in the soil. This accumulated metal ultimately reaches the reservoirs of water and is found to be significantly toxic for not only animals but also humans (Ahamad et al., 2018; George & John, 2015; Haygarth, 2005; Parashar, 2016). Pesticides which include fungicides, herbicides, insecticides, and more happen to be all used widely by industries and public authorities and in agricultural fields. These pesticides are potentially hazardous to health as they are toxic and persistent in the environment and accumulate in the food web in the environment at various trophic levels. These pesticides and herbicides are utilized in controlling weeds and pests. Pesticides, similar to fertilizers, leach into groundwater. Moreover, the pesticides which are readily soluble in water leach more and faster. A number of factors influence the leaching of these pesticides and herbicides into groundwater including soil texture, irrigation and the quantity of precipitation, and properties of the pesticides. Sandy soil promotes a faster and greater amount of leaching. Furthermore, the greater the solubility of the pesticide, the greater and faster the leaching. A similar process results in the reaching of these pesticides and herbicides to natural bodies of water via runoffs. The residues of pesticides and herbicides disturb the flora and fauna in these natural water bodies. A greater cause of concern posed by pesticides is that they do not degrade readily and require a long period making them more hazardous (Abera Mitiku, 2020; Ahamad et al., 2018).

2.1.1.2 Atmospheric pollutants

Tons of carbon dioxide, carbon monoxide, ash, methane, and other sulfur compounds are pumped into the atmosphere by underground coal fires in rural areas which consume millions of tons of coal yearly. The burning of coal results in the formation of thick and smoggy smoke with the coal containing a high amount of sulfur being extremely nasty producing a rotten egg smell (Gadde et al., 2009). Estimation states that over 22,000 kilotons of surplus rice straw are produced in India and out of these, each year around 14,000 kilotons are burnt in the field. Open field burning has been a major contributor to the emission of carbon dioxide, methane, carbon monoxide, nitrous oxide, sulfur dioxide, and a large amount of particulates with two states namely Punjab and Haryana contributing 48% of the total open field burning (Gadde et al., 2009). The tiny particulate pollutants present in the atmosphere are another source of pollutants for water bodies that enter the water via rain. The atmospheric pollutants include carbon dioxide which is produced in large amounts by burning fossil fuels and the quantity of carbon dioxide is ever-increasing with urbanization, industrialization, and globalization. The carbon dioxide is found to be merged with bodies of water forming carbonic acid. Volcanic eruptions and industrial gaseous wastes produce sulfur dioxide which upon mixing with water molecules, forms sulfuric acid. However, the combustion of products of petroleum and coal produces sulfur dioxide. Another atmospheric pollutant that adds to the pollutants in water bodies is nitrogen dioxide which on entering the water bodies reacts with water bodies to produce nitric acid (Thakur et al., 2020; Tord et al., 2006).

2.1.1.3 Microbiological pollutants

Contamination of the groundwater by microbiological contaminants is derived from sewages, either from animals or from humans. Pathogen refers to the microorganisms that happen to be the causative agents of various diseases. Majorities of the bacteria found in nature are beneficial and nonpathogenic, but a few which are pathogenic, pollute drinking water. The wide spectrums of pathogens that are found in sewage waters include bacterial pathogens, viruses, and protozoans (Gwimbi et al., 2019). This presence of microbial contaminants in the supply of water poses a grave threat to public health. The leaky sewers, septic tanks, leaking cesspits soak ways, landfills, mineshafts used as a route for disposal, and horn sewage that is applied to the agricultural lands as fertilizers can be a source for these microbial contaminants resulting in the microbiological contaminants enter the sub-surface environment. The sewers, septic tanks, and soak ways result in contamination of groundwater from the discharged wastewater or direct contamination by sewage (Gupta et al., 2018). The contaminants from sewage are related to the wastewater containment structure and the operation of systems associated with wastewater treatment and local hydrogeology. The potentiality for imparting infectious diseases by the presence of microbiological contaminants in the contaminated water on the ground has been widely studied and reported in several areas around the globe (Jung et al., 2014). For the purpose of identification of purity or potability of water for safe drinking, coliform bacteria are put to use as indicator species. The microbes which cause water pollution and diseases include *Giardia lamblia, Burkholderia pseudomallei, Cryptosporidium parvum, Salmonella sp., Schistosoma sp.,* and *Norovirus* which is a parasitic worm (Jung et al., 2014; Some et al., 2021). The rural microbial contamination in water sources finds its origin in fecal discharge by humans and animals and several open water sewages with overflow. Diffuse slurry on the other hand which includes slurry, sludge, and manure may also be considered a source of microbial contaminants (Jung et al., 2014).

2.1.1.4 Chemical pollutants from rural-based industries

Chemical pollutants come from chemical factories and other activities that produce a large amount of harmful chemical wastes which may remain to be a by-product of the process of the manufacturing process (Swathi, 2021). The characteristic properties of these pollutants which make them hazardous are ignitability, corrosiveness, reactivity, and toxicity. The chemical wastes from industries need to be treated by specific treatments in specialized waste treatment plants. Chemical pollutants may enter water bodies either from a point or a non-point source. For example, as mentioned earlier about agricultural pollutants, water from rain or irrigation over agricultural fields may pick up pollutants such as fertilizers, pesticides, herbicides, and insecticides and carry them to nearby water bodies including lakes, reservoirs, rivers, groundwater, or coastal waters. Rural-based industries like sugar industries and handloom industries discharge their effluents into the nearby water bodies. The effluents generated by the sugar mills cause several environmental problems concerned with land and water pollution. The sugar mills generate wastewater that infiltrates the subsoil layers and gets leached into the groundwater resulting in disturbance of the quality of groundwater by changing the chemical composition. It has also resulted in the development of several diseases in livestock and has impacted aquatic life considerably (Qureshi et al., 2015). The effluents discharged by the textile industries also pose a serious threat to aquatic ecology. Synthetic dyes, used as a part of the processing in textile industries for the addition of color to the raw materials or to the products, are a part of the effluents released by the textile factories mainly in rural areas. These dyes contain many heavy metals including chromium, cadmium, lead, and copper (Madhav et al., 2018; Sanyal et al., 2015).

Stormwater is another example of a non-point source that floods roads and ultimately flows to rivers or lakes (Kumar et al., 2017). The suburban and urban areas have much of the open land covered with pavements and the rest with buildings, due to which the water from rain or storms does not get soaked into the ground. The stormwater that remains carries a variety of pollutants be it dirt, resemble oils, chemical fertilizers used in lawns, and various chemicals into the streams and rivers, causing pollution of these water bodies. Furthermore, these storm waters flow at a high velocity, eroding more sediment from the embankments of the bodies of water. Sedimentations from the runoff affect the water quality, decreasing the capacity of these streams, rivers, and navigation channels. It has quite a prominent impact on the light penetrating these water bodies resulting in disturbance of the resident flora. This result impacts the fauna in the bodies of water that feed upon this flora. Thus, the entire associated food web is unsettled. The particles in the sediment may also get attached to the gills of fish making it difficult for the fish to respire and eventually leading to the death of the fish (Subramanian, 2016). Among the point sources of chemical pollutants, industries are the major contributors. A large volume of water is consumed by paper and pulp mills and they discharge solid and liquid products into the environment. The biological oxygen demand of the liquid waste discharged is very high and contains a high number of suspended solids and dioxins along with other chlorinated organic compounds. Solid wastes such as wastewater treatment sludge and lime sludge along with ash are transported to the water bodies contaminating the surface waters. Sugar mills release effluents which too have a high biological demand and contain solids suspended, with the effluent having a high content of ammonium. Along with these, the rinse liquid from sugarcane might contain residues of pesticides. Disinfection of water with the utilization of chemical disinfectants is another source of water pollution caused due to use of chemicals. The most widely practiced and economical method currently being used for the disinfection of water supplies for a large community is chlorination. Although chlorination has been shown to successfully disinfect water supplies having a crucial contribution when it comes to reducing the transmission of several water-borne diseases, it also has its shortcomings. Several disinfection by-products are formed due to chlorine reacting with organic matter naturally occurring in bodies of water. These by-products are found to be potentially toxic chemical compounds. Several other industries and human activities like mining add to the harm caused to various water bodies (Edokpayi et al., 2017; Hrušková et al., 2018; Tsitsifli & Kanakoudis, 2018).

2.2 Effect of water pollution in rural areas

Water is called the elixir of life; its scarcity and unavailability can be the cause of major concern. Water pollution has now globally been deemed a major issue for its various ill effects ranging from the environment to the people and the economy as a whole. According to the World Health Organization (WHO), around 2.2 billion individuals across the world do not have access to safe drinking water and water management services to maintain the potability of the water. Over 3 billion exist at risk of health hazards due to the poor water quality of rivers, lakes, and groundwater worldwide. Whereas 2.3 billion people live in countries deemed as "water-stressed," including 721 million in regions with "critical" water situations according to the most recent research carried out by the United Nations Environment Program (UNEP) and partners. When it comes to India**,** around 37.7 million Indians are affected by waterborne diseases annually its estimated that 1.5 million children die due to diarrhea alone, and many more are lost to waterborne diseases each year. The causes of water pollution are many as are its effects and in India, about 195,813 people happen to be affected by poor water quality specifically degraded by chemical pollutants. The major pollutants as fluoride and arsenic are of great concern. Iron is also proving to be emerging as yet another significant problem in many regions (Khurana & Sen, 2022). Water pollution-related issues are increasing as a result of several human practices including discharge through sewage, industrial-based discharge; the uneven distribution of rainfall with run-off from agriculture fields, floods and droughts, and many more. Further aggravation arises from a lack of education and awareness among the general mass.

There is an interplay of a plethora of factors that determine the cause and effect of water pollution, some commonly known effects of the pollution of water in rural areas include the following:

- **Destruction of regional biodiversity:** Water pollution causes a depletion in the quality of water which in turn harms the water ecosystems resulting in harm and triggers unchecked proliferation of the population of phytoplankton in water bodies such as lakes. This phenomenon is termed as eutrophication. This affects the biological oxygen demand (BOD) and the chemical oxygen demand (COD).
- **Impact on the food chain:** The aquatic life in the water bodies gets affected, the depletion or unbridled proliferation of organisms at any level of the food chain negatively impacts the others, besides which the use of this water for the purpose of agriculture and livestock farming further introduces toxic elements into the crop and produce which prove to be quite harmful to one's health when consumed (Khurana & Sen, 2022).
- **Scarcity of potable water:** Water, when contaminated, becomes unsuitable for purposes such as drinking, and in regions that lack access to sufficient supply of fresh water, contamination can have a huge negative effect on the resident population of humans besides the flora and fauna. The UN states has reported that even today several regions across the globe and their population to lack accessibility to safe and clean water for the purpose of consumption and sanitation and has stated that it is a major issue in rural areas.
- **Risk to health:** Contamination of any kind to basic requirements as water can have a widespread effect on individuals living in a region, thus pollution possesses as major hazard to health for contaminated water can be the cause of spread various diseases as cholera, diarrhea typhoid, dysentery, hepatitis A and more (Khurana & Sen, 2022). Based upon collected data, World Health Organization has estimated that around 2 billion people do not have the option but to consume excrement contaminated water exposing to cholera, hepatitis A and dysentery.
- **Effect on mortality:** Contaminated water results in widespread loss of lives on a regular basis due to the health hazards incurred from its consumption or use in regions that lack proper access to potable water, but face consequences for the increasing pollution (Khurana & Sen, 2022). Data from the UN shows that diarrheal diseases caused due to unhygienic practices led to the loss of the lives of around 1000 children globally on a daily basis.
- **Effects on agriculture:** Contaminated water disrupts the production of crops and goods associated with it, which are essential for the survival of the population as food crops, and associated products. The rural parts of India have above 700 million residents of which 1.42 million people are distributed over 15 ecologically diverse regions of the country. Meeting the basic drinking water requirements of such a huge population can prove to be quite a daunting task (Udmale et al., 2016).

2.3 Health hazards

Water pollution is the root of the spread of various diseases around the globe. Contaminated water is linked to the transmission of diseases such as cholera, diarrhea, hepatitis A, dysentery, typhoid, and polio. In the rural region, it has a greater impact because of the further lack of basic necessities. Around 37.7 million residents in India are annually affected by waterborne diseases, 1.5 million of this population is estimated to be children who die because of diarrhea and 66 million Indian lives happen to be at risk, as a result of excess fluoride present in water as 10 million due to excess arsenic present in the groundwater. Almost 200,000 habitations around the nation have been impacted by significantly substandard water quality. Some of the diseases caused due to water pollution that greatly impact people around the world are:

2.3.1 Bacterial diseases

The fecal contamination of drinking water, improper treatment, insufficient wastewater processing, and improper disposal of liquid waste happens to be the prevalent causes of bacterial diseases. The most common among these are:

Cholera is caused by *Vibrio cholerae*, this disease significantly affects the digestive tract and includes watery diarrhea as one of its symptoms, it can lead to dehydration and renal failure in the most serious of cases when left untreated, and can potentially be prove to be fatal (Harris et al., 2012). The outbreaks of the disease are commonly caused by the consumption of contaminated food or water and affect both adults and children. Its spread can be endemic or epidemic and even seasonal or sporadic.

Diarrhea happens to be one of the most common symptoms of a variety of diseases caused by the consumption of contaminated water. Abdominal pains, nausea, fever, and headaches are the most common symptoms of diarrhea, which affects both children as well as adults (Lakshminarayanan & Jayalakshmy, 2015). Salmonellosis caused by *Salmonella*, includes symptoms such as diarrhea, fever, stomach cramps, and inflammation in the intestinal tract, salmonella can prove to be quite fatal if not treated appropriately (Xiang et al., 2020). Shigellosis is an intestinal bacterial infection caused by the family *Shigella*. The main sign of shigellosis is bloody diarrhea; it can significantly damage the intestinal lining and result in stomach cramps, as well as vomiting (Rogawski McQuade et al., 2020).

2.3.2 Viral diseases

Contaminated water sources provide the perfect ground for virus transmission and consequent multiplication. Some viral diseases transmitted via contaminated water are:

Hepatitis A is caused by the hepatitis A virus, it manifests itself in the symptoms as loss of appetite, fatigue, fever, extreme discomfort, and jaundice; it might result in premature death since it affects one's liver's ability to function (Lin et al., 2017). Encephalitis can supposedly be caused by the West Nile virus (WNV), herpes simplex, enterovirus, and other causative agents, usually transmitted by the Culex mosquito which lays its eggs in polluted water, encephalitis is often symptomless but can cause paralysis and even come in susceptible individuals (Narain et al., 2022). Poliomyelitis is caused by the poliovirus. Sore throat, constipation or diarrhea, and fever are its common symptoms, it can result in a coma state in severe cases, and significantly affects children under the age of five years (Mehndiratta et al., 2014). Gastroenteritis falls under the family of diseases caused by adenoviruses, rotaviruses, and caliciviruses with symptoms including headaches, nausea, and vomiting. It can prove to be deadly in infants and young children (Al Jassas et al., 2018)

2.3.3 Parasitic diseases

Parasitic diseases are transmitted by parasites through contaminated water. The most common diseases that affect humans include:

Cryptosporidiosis is caused by the cryptosporidium parasite, this disease results in stomach cramps, diarrhea, and vomiting, and is prevalent globally (Leitch & He, 2012). Amoeba-associated diseases affect the stomach lining, the galloping amoeba has both, a cystic and non-cystic form. Its symptoms include precipitating chills, fever, and diarrhea (Kantor et al., 2018). Giardiasis is caused by Giardia, it is sometimes known as the traveler's disease, the disease manifests itself in symptoms such as bloatedness, weight loss, diarrhea, and flatulence (Li et al., 2017). Schistosomiasis is caused by a small parasitic worm that thrives in water; it can remain dormant for years and significantly damages the host's internal organs all the while (Klohe et al., 2021).

2.4 Water rights and laws for availability of clean water for drinking

Water contamination and pollution are progressively turning into significant issues worldwide. To regulate and check water contamination and pollution so that people have enough access to clean, fresh water to drink and use for other home tasks, there are unquestionably a number of measures, including legal actions. This section explains how the rules are applied to regulate and control water pollution and contamination in India and worldwide. (Nkosi, 2014). In India, contamination of bodies of water is more extreme closer to the metropolitan stretches because of a significant contamination load released by urban activities. "The water bodies in India experience the ill effects of extreme contamination nowadays inadequate sewerage, lack of units on location sterilization, and wastewater treatment offices, and absence of successful contamination control measures are the significant reasons for the rampant discharge of toxic elements in the ocean and other water bodies" (Harada & Karn, 2001).

2.4.1 Legislation adopted in India to prevent water pollution and maintain water quality

According to Ramakrishna (1985), India holds the distinction of being the first nation in the entire world to write environmental protection and improvement into its constitution and then put those provisions into effect. A fundamental right to water is not recognized in the Constitution of India, but Article 21 (which reads, in part, "Water is the fundamental requirement for people to survive and is important for the right to life and common liberties as enshrined in the Constitution of India") has been interpreted by the courts as suggesting such a right. Some other laws and norms have also been implemented Article 48-A, which is part of the constitution's chapter IV on "Principles of the State Policy" (Singh & Singh Kohli, 2012), mandates that every state implement policies to preserve its wildlife and forests and ensure their continued viability. According to Reddy and Char (2006), protecting and expanding India's natural habitat and environment—including its forests, rivers, and wildlife—is a vital responsibility of every Indian citizen.

Chapter V of the Prevention and Control of Pollution Act of 1974 (Bhullar, 2013) addresses water and air quality. In an effort to stop and reduce water pollution and restore its quality, this law was passed. It gives the water board the authority to establish standards and regulations for the prevention and management of pollution. A Water Quality Monitoring Network has been established across India by the Central Pollution Control Board, and the Ministry of Environment and Forests (Jain et al., 2007). This network consists of 1429 observing stations located in 27 states and 6 Union Territories on various rivers and bodies of water. The Central Board's recent action to categorize river waters according to their highest and best use follows a systematic and rational framework. Based on the Ganga Action Plan (GAP), the primary fundamental report was developed. The main objective of the GAP was to prevent and reroute metropolitan settlements away from river banks. The plan detailed land use patterns, homegrown and modern contamination loads, compost and pesticide use, hydrological perspectives, and river classification. It was the initial phase in the quality of river water administration. Its command was restricted to speedy and powerful, yet supportable intercession to contain the harm. The current legitimate system concerning water is supplemented by a common liberties aspect (Roy Basu, 2017).

Statutory water regulation additionally incorporates various pre-and post-independence establishments across different regions, including the norms and regulations for river banks, drinking water supply systems, flood management, water protection, water contamination level, and restoration of evacuees and uprooted people, fisheries, and ships. In an effort to regulate the flow of water throughout the region, the Northern India Canal and waste Act of 1873 was passed. Amongst the drawn-out ramifications of this Act is the right of the public authority's presentation to utilize and establish control over water of all streams and waterways be it regular channels or lakes for public purposes ("allocating the common heritage-debates over water rights and governance structures in india", 2022; Dellapenna & Gupta, 2011; Maria Saleth, 1994; "The Canal and Drainage Act 1873", 2022). In spite of these, India lacks a strong framework to regulate pollution of all dimensions. Legislation in India is based on colonial-era regulatory norms and water system acts, as well as more recent guidelines for water quality and the formal recognition of a human right to water (Bhullar, 2013). Understanding the complex web of water regulations is difficult because different issues have been addressed in different permits.

2.4.2 Laws implemented UK for the prevention of water pollution and maintenance of water quality

The British way to deal with water contamination control has generally been established on central trait goals for getting water considering which fluctuating emanation norms are set exclusively, that states: An individual should regard conditions listed in the emission guidelines (Ekins & Simon, 2003; Gaba, 2007; Harrison, 2013).

Additionally, they must avoid introducing any contaminating materials into the restricted waters. Failure to comply with emission principles or other water contamination regulations is a criminal offense (Heyes, 1998).

The norms are as follows:

- Water Resources Act 2003 (WRA) December 1991.
- Water Industry Act 1991.
- Land Drainage Act 1991.
- Statutory Water Act 1991.
- Water Consequential Provisions Act 1991 (Potter, 2012).

These Acts were created with the intention of integrating the more than twenty different elements of regulation that made up the existing water regulation. By outlining the Environment Agency's functions, the WRA manages the quantity and quality of water. It outlines water-related offenses, emission consents, and viable defenses against the violations. The Water Act of 2003, Part (III) which is about protecting regulated stream waters, is the most important regulation to amend this Act. It covers key regional or territorial waters, seaside, inland freshwaters (including lakes and lakes), and ground waters.

2.4.3 Comparative analysis of the regulations of India and abroad

Regulation in the India and UK makes offenses and punishments for water contamination in various manners. Water polluters are rebuffed by fines, detainment, or both. Medicinal orders might be made to forestall or control the effects of water contamination or to reestablish water to its past circumstances (Jordan, 1993; Priyadarshini & Gupta, 2003). Strategy proclamations in regard to water contamination control can be found inside the authoritative structure of these nations. Government rules and documents frequently incorporate sections about ecological arrangements and policies. The security and protection of natural assets are critical particularly water which holds an essential part in not only financial advancement but also in social upliftment. The United Kingdom (Water Resources Act, section 161-1) regulation enforces a commitment on the proprietor, occupier, or regulator of the land to maintain all possible measures to prevent the occurrence, continuation, or repetition of water pollution considering that the authority might do whatever it may take to solve the situation in case they neglect or fail to execute their duties (Braden, 1982; Kuruc, 1985). In these two nations, rules state that in case of the release of waste or trade effluent into a water body by any particular organization, the discharger should have a grant or permit and conform to its limitations, except if the action falls under the exemptions. Infringement of the permit is a criminal offense and a court might take steps against the blamed in favor of the individual who experienced misfortune because of the offense or to solve the situation (Gaba, 2007; OECD, 2000; Rajaram & Das, 2008). Ecological rules generally state that where a company has committed an offense under the regulation, then chiefs and different directors of the organization are appraised to be at legitimate fault for a similar offense. Ecological regulation does not permit corporate officials to take cover behind a legitimate design of the company (Blumstein et al., 2005; Gill, 2008). An individual might get away from obligation assuming the person demonstrates to the court that the individual was not in the position of mind to impact the lead of the organization according to the offense (Welks, 1991), or assuming that the person in question in such position utilized all expected level of effort to forestall the conduct by the enterprise (Peters, 1991). The vicarious obligation is utilized to rebuff enterprises for the demonstrations or exclusion of their workers that cause pollution of waters, regardless of whether they practice the coordinating body or will of the organization except if some outsider interferes with the chain of causation (Winiger et al., 2007). Despite the fact that India has rolled out huge improvements in its natural difficulties, much work actually should be finished. As reported by the World Bank, the nation has made quite possibly the quickest advancement in upgrading its ecological issues between the years 1995 and 2010. Despite the fact that India has updated its National Water Policy in 2002 to empower local area investment and decentralize water executives, there are still many more goals to achieve in this concern. Obligation regarding overseeing water issues is divided among various services and offices practically without any coordination. The public authority organization and state-run project division have neglected to take care of the issue, in spite of having spent numerous years and $140 million on this venture (Agrawal et al., 2010).

2.5 Statistical insights on the rate of pollution in India

There is a lack of proof about the viability of ecological guidelines in emerging nations which has forced a significant increase in the cost of wellbeing due to the high concentrations of pollutants which also results in the shortening of lives (Chen et al., 2013). Along these lines, understanding the most effective methods for diminishing contamination could altogether further develop prosperity in developing nations. India gives a convincing setting to investigate the adequacy of natural guidelines in an emerging nation because of multiple factors. India is encountering fast financial development of around 6.4% yearly throughout the course of recent years, which is putting a huge strain on the climate (Bandyopadhyay & Shafik, 1992; Grossman & Krueger, 1995; Selden & Song, 1994) referring to the stage of economic development that raises concerns regarding environmental. Subsequently, considering the stats, it could be sensible to expect that the majority of the ecological arrangements carried out to date have been inadequate. India has a moderately broad arrangement of guidelines intended to further develop water quality as expressed before in the segment. Its natural strategies have their underlying foundations in the Water Act of 1974 and the Air Act of 1981. These demonstrations made the Central Pollution Control Board (CPCB) and the State Pollution Control Boards (SPCBs), which are answerable for information assortment and strategy authorization, and furthermore created detailed methodology for ecological consistency. The Ministry of Environment and Forests (MoEF), created its primary structure in 1980, which was laid out generally to set the general approaches that the control boards were to implement (Copeland & Taylor, 2004; Stern & Common, 2001).

2.6 Remedies to combat water pollution in various water bodies

Water being a significant constituent of our daily activities, it is very important to emphasize the need for its preservation. Three-fourth of body fluid in humans is comprised of water, forming the vital medium for all reactions of the biochemical nature that occur within the body. Although pure water is a significant commodity, essential for the well-being of organisms of all kinds, regrettably freshwater is not readily available in all parts across the world and is quite unevenly distributed and is significantly threatened where it is available (Khatun, 2017). The threat to water availability is attributed to all the sources of pollutants mentioned along with climate changes and inefficient management of water. The efficacious management and treatment of contaminated water have been found to be essential in protecting the bodies of water with a target of effective and cheap methods which are easily accessible for the treatment of wastewater. There are several other methodologies which include forward and reverse osmosis precipitations, filtration, and coagulation systems along with advanced oxidation processes for the purification of water that have been reported (Inyinbor Adejumoke et al., 2018). Another important aspect associated with the pollution of water and wastewater management has been the introduction of environmental policies that stipulate the protocols for discharge. However, these policies have not been executed effectively due to the industries considering these policies to be damaging to their business (Singh et al., 2013). In this current section, various ways to remediate the damage caused to water bodies due to human activities and various sources of pollutants are discussed.

2.6.1 Conventional methods used in rural areas

The lack of skills and economic status in rural areas, household water treatment still prevails as the primary way of attaining potable drinking water. Drinking water may contain fluorides, and a conventional defluoridation method can normally help in accomplishing by adsorptive and precipitation process, to safer water to drink. In rural areas, bone charcoal and calcined clay were found useful as the low-cost methodology for effective water treatment at a smaller scale for domestic use. Certain studies found the use of cake alum as defluoridator. These methodologies can be utilized effectively in rural areas for reducing the concentration levels of fluoride. For the reduction of microbes, physical met groundwater hoods are used for the treatment of water in the households of rural communities including storage and settlement and boiling and filtration. Other methods that have been proposed to use in rural areas are the use of home bleach, and other compounds of chlorine, the use of a home filter which is usually followed by disinfection, exposure to sunlight and also the use of coagulants (Ahmed & Ismail, 2018; Chaurasia & Tiwari, 2016; Odiyo & Makungo, 2012).

2.6.2 Removal of microbiological contaminants in the supply of water

Water supplied for consumption is usually from underground sources, rivers, or water springs. Routinely, treatments of some form are conducted for the assurance of the potability of the supplied water making it fir for consumption. Although some sources like the deep wells are relatively free from contaminating pathogens or other microbes and are clean (Smith, 2001). In several developing countries, a single water source can have several functions like washing, bathing, drinking, etc. Sewage may also be channeled into the bodies of water via the same vein which as mentioned earlier may consist of a wide variety of chemicals, microbes, and other debris which can potentially be hazardous to the health of the consumers or users of water from these sources. This is the reason why the water is treated in three sequential stages. The primary stage is the separation of larger matter from the water source, followed by the second stage which is focused on removing more toxic contaminants. The complete purification of water by chemical disinfectants is carried out in the tertiary stage. A very efficient method is the usage of bioreactors, specifically, membrane bioreactors for removing contaminants from water sources. These bioreactors work in a combination of communities and membranes that have a high efficiency in removing contaminants (Narayanan & Narayan, 2019). Microorganisms find a significant role in stage two of water treatment and are involved in carrying out biodegradation of the organic components on the aqueous part obtained from the first stage of the treatment. Exposure of water to the soil, air, and other effluents can result in attaining contaminants as saprophytic microbes and can also gain pathogenic microbes such as *Campylobacter sp., Shigella sp., Cryptosporidium sp., Salmonella sp.,* etc. Monitoring water for these pathogenic microbes individually is not possible, so a simpler method of spotting contamination in water, and the presence of fecal matter is detected. In the case of the presence of high fecal contaminants, it is believed that pathogens are present in the water and making it unsafe for drinking. Thus, specific organisms are used as indicators making them an essential tool for the detection of fecal contamination. These indicator organisms are usually the inhabitants of the gut of birds and mammals and are identified using commonly used laboratory identification procedures. Some of the commonly used indicators of the kind, in water, are fecal coliform, total coliform bacteria, *Escherichia coli, Clostridium perfringens,* fecal *Streptococci* sp. or *Enterococci* sp., and Coliphage (Da'ana et al., 2021).

The prevention of waterborne diseases is essential and for it controlling the pathogens contaminating the water is important. This is achieved by utilizing the effective barrier approach. The microbial aids in the removal of nutrients like organic compounds and inorganic compounds. It includes nitrates and phosphates that are easily degradable besides the possible toxins and managing the change of pH in the wastewater. Thus, microbial treatment of wastewater goes further beyond the traditionally used wastewater treatment done by municipalities. The bioreactor utilized for this cause requires a more advanced design considering various factors and conditions including the addition of nutrients, the oxygen supply, and other donors of the electron, biomass yield, and pH control including the kinetics or biotransformation. Some of the treatments that are noteworthy are the lagoon treatment in which an anaerobic condition is prepared to make use of a highly loaded lake and is utilized in pretreating the poultry and meat processing wastewaters in turn considerably reducing the biological oxygen demand. Another treatment involves a method that employs two layers; an aerobic surface layer followed by an anaerobic bottom in facultative ponds. The aerobic layer on the top allows the treatment of matter, organic in nature, in the dissolved form along with other odorous compounds. This treatment particularly finds application in the paper and pulp industries. The activated sludge treatment involves an aeration basin where the equipment for aeration not only provides oxygen but also mixes the wastewater adequately allowing the maintenance uniformity of the mixed liquor suspended solids (MLSS). The clarifier succeeds the basin that employs gravity for a liquid-solid separation; as a result, eventually, the residue that settles at the bottom is reused and again added to the activated basin of sludge. Apart from the mentioned treatments, the use of anaerobic bioreactors has been determined to be very beneficial owing to the factor of cost-effectiveness and its applicability in the treatment of wastewaters with high strength along with lower sludge formation and production of products such as methane and other gases which are beneficial as biogas. It also has a low nutrient requirement and demands a lesser amount of energy relative to aerobic treatment. The most recent and advanced wastewater treatment is the utilization of membranes along with bioreactors. These membranes act as a surface to allow the attachment of organisms for their growth and allow the permeation of the biofilm with oxygen. The membrane may also be utilized in the form of a selective barrier allowing only organic compounds to pass through but inhibiting the ions to be transported into the bioreactors. These membranes might be utilized for the separation of biomass replacing the clarifier after the activated sludge treatment producing a high quality of effluent with a lesser amount of sludge (ElSayed Abdel-Raouf et al., 2019; Ezugbe & Rathilal, 2020).

2.6.3 Herbal methods of disinfection of water

A number of methodologies utilized in current times for the purification of water have been adopted and embraced well by society. In spite of the advances made in this direction, rural areas still lack the affordability of these modern treatment methodologies and still face water pollution posing a major challenge to the provision of safe drinking water. Herbal disinfection methods have been studied and are being encouraged by researchers keeping in mind the disinfection by-products that remain in the water after treatment. A Point to be noted is that not a majority of researchers would apply the antimicrobial fractions or extracts in the water treatment directly. An example of the utilization of extracts from plants in water treatment is the use of alcoholic, aqueous, or fresh *Azadirachta indica* (neem) and *Ocimum sanctum* (tulsi) against *Salmonella* sp. *in vitro* as the indicator organism. It was found that the aqueous extract was best suited for lake waters, whereas, the alcoholic extract showed the best results for well water. In effect of the discovery that neem, amla, and tulsi could be utilized for the treatment of microbial infections with no side effects, similar studies were conducted comparing the efficacy of these herbs in the purification of water with *E. coli* as the indicator organism. An observation that was noteworthy was the determination that a 1% concentration mixture of each of the herbs was not as efficacious as the synergic combined use of the mentioned three herbs. The application of these herbs in the synthesis of nanoparticles for water purification is an indirect application, which on being applied to water has the capability to remove contaminants. The surface-associated properties of the nanoparticles synthesized are influenced by these herbs extracts and thus, they dictate the significantly unique characteristics of the particles. Hence, considering the benefits of utilizing natural disinfection methods prompts a greater drive toward research on natural products for the purification of water. This approach will greatly reduce the cost and help the rural dwellers have been led to a healthier kind of life in the availability of pure water (Gowri, 2017; Nirichan Kunchiraman Bharati Vidyapeeth et al., 2013; Wankhade, 2016).

2.6.4 pH control in waste waters

The cleaning strategy involved in wastewater treatment significantly determines its pH. Coagulation processes work efficiently only in specific pH and conditions and thus, the pH of wastewater needs to be altered first. For controlling the pH in the acidic range Na_2CO_3, NaOH, $Ca(OH)_2$, or $CaCO_3$ is used and for the wastes in the alkali range, HCl and H_2SO_4 are used (Abera Mitiku, 2020).

2.6.5 Coagulation using inorganic and organic coagulants

The collection of small particles dispersed in a liquid to form larger aggregates or form flocs by the addition of specific chemicals or natural coagulants during coagulation allows these flocs to absorb the organic matter dissolved in the wastewater. The size distribution of the aggregates is an important parameter for the design and control of coagulation-flocculation. The solid-liquid separation processes like sedimentation are greatly dependent on the way size is distributed, the aggregation size along with the density and structure of the aggregates. The overall process of coagulation results in the reduction of turbidity and the dissolved chemicals in the liquid. The process of coagulation is the most prevalently used physiochemical technique in use for water treatment owing to its efficiency as well as simplicity of operation which can be achieved by chemical as well as electrical means. The coagulants may include hydrolyzing metallic salts such as ferric chloride, alum, and ferric sulfate, and synthetic cationic polymers such as amino methyl polyacrylamide, and polyalkylene polyamine. Organic coagulants of plant origin are preferred over animal-based coagulants (Abera Mitiku, 2020).

2.6.6 Removal of heavy metals through adsorption on naturally obtained wastes and microbes

The efficacy of the adsorption technology makes it the most preferred method for the decontamination of water bodies as it is economical and eco-friendly. The technique works on the principle of mass transfer of the metal ions, dependent on the interaction between the metal ions present in the solution with the sorbent surface via physical and chemical interactions. A number of wastes obtained from agricultural

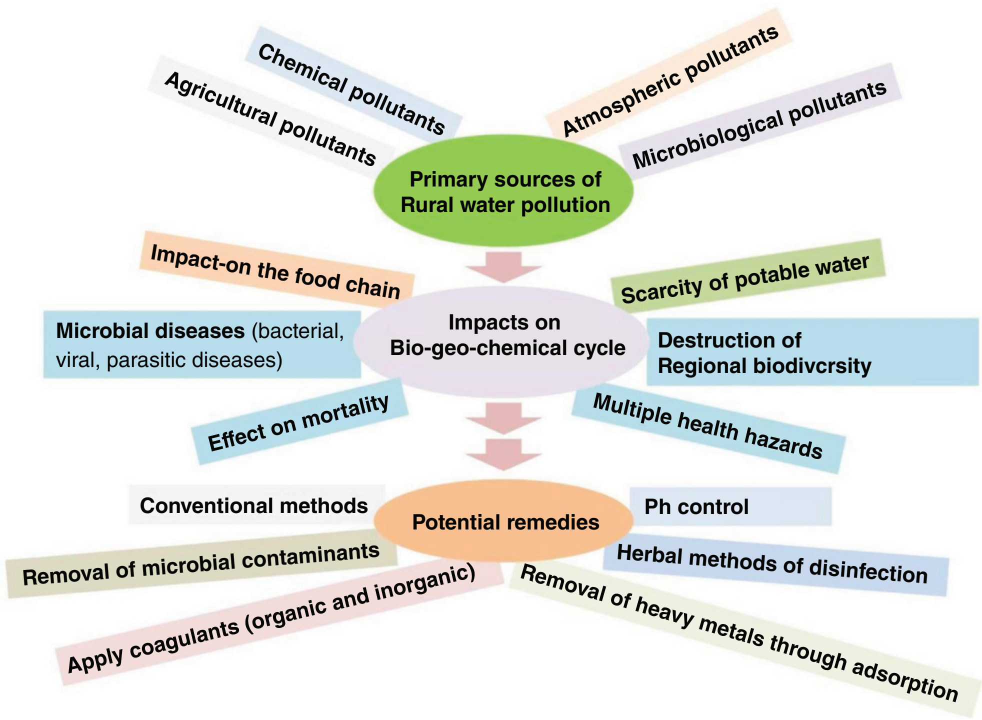

FIGURE 2.1 Over all scenario on primary sources of rural water pollution, impact on rural bio-geo-chemical cycle and potential remedies.

sources such as rice, wool, coconut husks, straw, exhausted coffee, peat moss, waste tea, cork biomass, rice hulls, coconut shells, seeds of *Ocimum basilicum*, cottonseed hulls and soybean hulls, untreated coffee dust, sawdust of walnut, peanut hulls, papaya wood, citrus peel have acted as sorbent surface for removal of metals from water. Encouraging results have also been obtained when using yeasts, molds, seaweeds, and bacteria for the biosorption of metals (ElSayed Abdel-Raouf et al., 2019; Farhadi et al., 2021).

Hence, it has been clearly comprehended that the various activities of humans have significantly impacted the availability of water in rural areas and several measures are hence being put in place to remedy the damage that has been caused and to combat the scarcity that is arising (Fig. 2.1).

2.7 Conclusion

The presence of water is a prerequisite for the continuation of all forms of life. It is of the utmost importance for both the continuation of human civilization and the appropriate maintenance of ecological equilibrium that various water sources are preserved, and that water be made available in a manner that is environmentally responsible. This is because the preservation of water sources is essential to the proper upkeep of ecological equilibrium. The various human activities that lead to the production of pollutants, whether it be of inorganic origin, industrial origin, rural origin, or microbial origin, pose a significant risk to the availability of clean and potable water. The impact of pollution on the ecosystem is quite evident in the way that it causes degradation and deterioration of biodiversity, causes climatic change, affects crop production, disrupts natural food webs, and a great deal more; the severity of this damage cannot be overemphasized. The treatment of wastewater that is discharged into water bodies in the form of industrial effluents in an untreated form is the subject of a number of methods that are currently being researched, including those that were discussed above, including the establishment of various treatment plants and industries for the purpose of treating this wastewater. Therefore, the successful implementation of policies for the protection of the environment and compliance drives will play a significant role in the preservation of the water bodies. The incorporation of the policies for environmental protection into the objectives and aims of the various enforcers involved in the deterioration of the environment will have a positive impact on the performance of the policies and will assist in taking leaps ahead toward the mitigation of water pollution.

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Chapter 3

Water pollution in rural areas: Primary sources and associated health issues

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3.1 Introduction

Water is one of the most extensively distributed resources on the planet Earth. Additionally, it is an important resource needed in many sectors, whether it is industries, agriculture, domestic, etc. Most importantly, it is wanted as a crucial nutrient for maintaining life, functioning of natural ecosystems, health, and sanitation; the last two are the essential prerequisites for development, social equity, and human dignity to enhance the standard of living. Given its significance, it has been regarded as a basic human right globally, and therefore, it is required to handle this resource effectively and efficiently to satisfy global water needs. Though around 70% of our earth's surface is enveloped with water, the readily available and usable form of water is very less, accounting for only 0.5% of the total water. Moreover, this usable form is available in the form of lakes, ponds, aquifers, rivers, streams, rainfall, etc. The majority of water present on earth, approximately 97% is salty, hence, cannot be put to any use, and the remaining portion, around 2.5%, is freshwater, much of this percentage is further locked as polar ice or stored as groundwater and quite difficult to access and use. So, we do have a lot of water, but less than 0.3% is approachable for human consumption. Furthermore, the distribution of water throughout the world is uneven, and consequently, its availability is a growingly serious matter. Besides, with the increased pace of commercialization, urbanization, and industrialization, this figure continues to diminish. The incompetent and obsolete practices, dearth of knowledge and awareness, and plenty of other conditions further contribute to water pollution.

3.2 Water pollution: pollutants and primary sources in rural areas

3.2.1 Water pollution

Water pollution is defined as the phenomenon of contamination of water sources by various unwanted and undesirable substances termed as pollutants such as chemical compounds, pathogens, organic and inorganic substances, heat, trash, radioactive materials, etc., rendering the water unfit for consumption, as a result, it has a detrimental impact on human and environmental health. Because of pollution, polluted water can no longer be used for any intent. Furthermore, all forms of pollution, whether it is air or soil, etc., eventually make their way to water and contribute to water pollution. Additionally, the principal users of water, viz. agriculture, industries (comprising all industrial activities, mining, and energy generation) together with household, recreational as well as environmental, have an impact on water availability using physical water withdrawal and diminished recharging of underground water resources and water quality by way of the addition of harmful and undesirable substances.

3.2.2 Water pollutants

The water pollutants are categorized into several categories like the disease-causing organisms termed pathogens (bacteria, viruses, protozoa, parasites, etc.), inorganic pollutants [nitrogen (N), phosphorus (P), and toxic metals (cadmium, arsenic, lead, nickel, and iron), acids, anions, and cations

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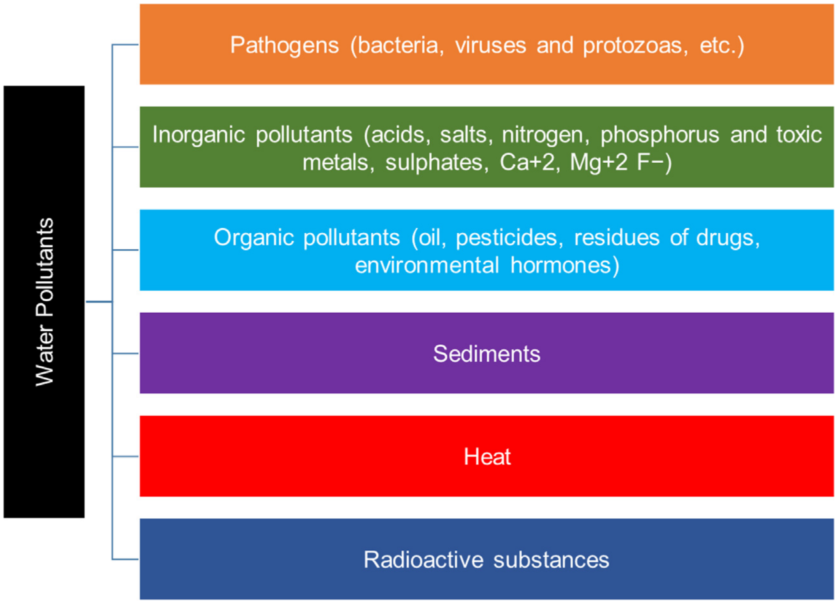

FIGURE 3.1 Showing the major categories of water pollutants.

(nitrates, phosphates, sulfates, Ca^{2+}, Mg^{2+}, and F^{-}), salts], organic pollutants (oil, pesticides, residues of drugs, environmental hormones), sediments, heat, water-soluble radioactive substances. Some of the important pollutants are represented in Fig. 3.1. These pollutants, in addition to polluting the soil, further pollute the nearby water bodies, particularly by surface runoff.

Trace elements, comprising manganese, copper, iron, molybdenum, zinc, and boron, are important for plant growth and development and are required in very small amounts. Not counting boron, all other elements are also known as heavy metals and are very harmful to plants at higher concentrations. Heavy metals like lead, chromium, mercury, cadmium, nickel, and arsenic are quite deleterious and hence, recognized as pollutants. Though water comprises heavy metals/trace elements naturally as it solubilizes them during its descending movement as part of the hydrological cycle from soil parent rock material (Ilyas & Sarwar, 2003), these contaminants may also find their way into water owing to various anthropogenic activities, for instance, extensive usages of chemicals, fertilizers, and organic amendments like sewage sludge together with wastewater enriched with metal may lead to wide-scale contamination together with inappropriate dumping of industrial as well as municipal wastes. Several chemical processes result in the transformation of heavy metals in soils. Processes such as adsorption-desorption, precipitation-dissolution, and complexation are of the greatest significance with regard to determining the bioavailability and movement of heavy metals in soils. Several metals, along with transition metals and organic micropollutants (OMPs) (Rodríguez-Lado et al., 2013), polycyclic aromatic hydrocarbons (PAHs) (Abey et al., 2017), substituted phenols (Lacorte et al., 2002), pesticides (Mekonen et al., 2016), and pharmaceutical chemicals and personal care products chemicals (PPCP chemicals) (Dodgen et al., 2017) have been regularly found in rural groundwater across the world. Although most of these pollutants are present at low concentrations, many of them have raised considerable toxicological concerns (Schwarzenbach et al., 2006). A study conducted by Li et al. (2020) noted numerous kinds of OMPs, greater than 1300 OMPs, comprising 886 semi-volatile organic compounds (SVOCs), 156 pharmaceuticals, 296 polar pesticides, 8 food additives, and 25 metals in the drinking groundwater samples. About 233 OMPs, together with 25 metals, were found at the minimum in one of the 166 samples of groundwater.

Agriculture is the greatest user, approximately 85% of the world's generation of pesticides to get rid of several pests; it is also employed in public health undertakings especially to check vector-borne illnesses like dengue and malaria and undesirable plants such as weeds and grasses. With advancements in technologies in all sectors, together, with changed lifestyles and numerous other reasons, a much greater number of pollutants are supposed to find their way into our water resources.

3.2.3 Primary sources of water pollution

Due to the accelerated pace of industrialization, urbanization, overpopulation, inappropriate disposal of municipal solid waste, sewage, and industrial effluents together with extensive usage of agrochemicals in farming, etc., water is getting severely polluted (Azizullah et al., 2011). Together, the inadequate management and monitoring of water quality are one of the principal causes contributing to loads of pollutants in the water bodies. The water quality standards rarely adhere. The addition of pollutants to surface and underground water is categorized into point or non-point sources (NPS). Because of the comfort in tracking the release and levels of pollutants, the point sources are comparatively easy to manage and check through suitable treatment at the source itself (Rissman & Carpenter, 2015). On the other hand, non-point inputs, frequently arise from widespread tracts of land and get carried over land, underground, and also by way of the atmosphere to the recipient stretches of water (Ahmad et al., 2016), thereby rendering it hard to evaluate and check.

As a consequence of swift economic and social development in the rural setups, speeding agricultural industrialization along with a fusion of urban and rural areas, the release of pollutants in the rural sector escalates as residential pollution and NPS pollution are exacerbated and industrial and urban pollution is moving to rural sectors at an alarming pace. Many sources in the rural sector, such as agriculture, small-scale industrial activities, domestic sewage, poor waste management, village dry toilets, livestock farms, etc. have been documented to contribute to the menace of water pollution.

Pollution in rural settings can be categorized into three major groups: agricultural, residential, and industrial pollution, however, there are other sources of pollution as well. Agricultural pollution originates due to fertilizers, pesticides, livestock wastes, and mulches to name a few, utilized in contemporary agricultural production whereas, residential pollution occurs as a result of infrastructure fabrication together with retrograde environmental management. Industrial pollution, which is pot-source pollution, is a result of the inappropriate allocation of rural businesses along with insufficient pollution control. Amongst these polluting sources, nearly the half volume of the main pollutants originate from agrarian sources. Some of the primary sources of water pollution in rural areas are mentioned below.

3.2.3.1 Agricultural sources

With the advent of the green revolution, India became a strong agricultural country leading to a substantial rise in agrarian products. However, this rise was accompanied by rising pollution from the agricultural NPS attributable to the enormous applications of chemical pesticides and fertilizers(Azizullah et al., 2011). The majority of the agricultural pollutants emanate from raw domestic sewage and agrarian sources such as manure, animal farms, and aquaculture together with the remaining causes. Agricultural NPS pollution has been a serious danger to water quality and the aquatic ecosystems of rural areas. This agricultural NPS pollution is often random, diffuse, tough to manage, and with excessive nitrogen and phosphorus.

Undeniably, agriculture is the chief reason behind the contamination of water with pesticides, as pesticide applications are carried out on a mass scale, usually either from aircraft or topically, by the manual shower. Invariably, pesticides are employed as a formulated product, that is a marketably obtainable blend of chemicals applied to slay, repel, or check specific pests. A formulation comprises the active as well as the inert ingredient(s). The latter is included in formulations in order to easily dissolve the pesticide in water, increase dispersion, or enhance stability. Provided, the inert ingredients are observed to be extremely poisonous, the label does not mention the details of the individual components together with their portions. Amongst the most exceedingly utilized added ingredients in pesticides is alkylphenol ethoxylate (APEO), similar to nonylphenol or octyl phenol ethoxylates (NPEO and OPEO). Numerous different kinds of formulated pesticides are available having varying proportions of active ingredients and adjuvants, determined by the crop variety and target pest. Several investigations have indicated that because of the usage of pesticide formulations as well as sewage sludge in the form of fertilizer, pesticides, and additional chemicals have been introduced in soils of farmland and groundwater at ppb concentrations (Lacorte et al., 2002). The physicochemical properties of pesticides together with environmental circumstances (like soil type, rain regimes, pH, total organic content, etc.) determine the leaching potential and ultimate level of organic pollutants in groundwater. Moreover, the difficulty is not just related to pesticides detected, what is more, is various other pollutants that may find their way as a consequence of the agrarian practices. Lacorte et al. (2002) found nonylphenol (NP) and octyl phenol (OP) owing to the deterioration of surfactants employed in formulations, together with bisphenol A (BPA), utilized in plastic cans. The researchers reported amounts up to 2.5 μg/L of NP, OP, and BPA, highlighting that these pesticide adjuvants can be possible and unsafe contaminants, which considerably diminish groundwater quality that we frequently utilize for drinking or irrigation intents.

Additionally, the underground water which is commonly untreated is mostly the primary source of potable water in rural settings and this underground water can be an important source of nitrate exposure as well. Due to inappropriate waste disposal, animal farm wastes, application of nitrogenous fertilizers, etc., the groundwater may get contaminated with substantial amounts of nitrate (Adimalla & Qian, 2019). Preceding investigations have found that nitrate contamination in underground water may occur as a result of both point (factories, animal husbandry) and NPS pollution (chemical fertilizers, atmospheric deposition, fungicides, etc.) (Almasri, 2007). Groundwater pollution is quite intricate and usually hard to notice, bearing long-term consequences (Shrestha et al., 2016). Additionally, the groundwater once contaminated is arduous to recover in comparison to surface water (Rahmati et al., 2014). Research conducted by Rahmati et al. (2014) noted a positive association between groundwater nitrate levels and the quantity of nitrogenous fertilizer used. Other studies employing the Geographic Information System have also observed the causal relationship between underwater contamination with nitrate the and application of chemical fertilizers in vegetable-growing agricultural land (Babiker et al., 2004).

3.2.3.2 Runoff and infiltration

Another greatest source contributing to water pollution in rural setups is runoff, especially from farmlands and the permeation of polluted water through soil, which ultimately ends up contaminating underground water resources. Furthermore, it is difficult to identify, locate and control runoff in rural settings which are mainly connected to agricultural runoff. As a consequence, any treatment of the contaminants gaining access to water bodies is nearly inconceivable, however, agricultural runoff can be managed by other means like reduced application of fertilizer together with appropriate disposition of animal wastes and fertilizers. Many times, the contaminants in watersheds can also penetrate to the bottom and contaminate groundwater. Several kinds of organic compounds have been observed in groundwater as a consequence of contamination events arising due to the percolation of chemicals from landfills, wastewater disposal, industrial runoff, or agricultural activities (Haeseler et al., 1999).

3.2.3.3 Livestock husbandry/management

Livestock husbandry is another contributor to water pollution. As they are usually dispersed and disorganized, in certain regions, their scale considerably exceeds the environmental capacity, and the majority of animal wastes are released without any prior treatment. The washing off or leaching off the livestock litter and fertilizers add substantial amounts of nutrients in neighbouring water bodies thereby leading to the problem of eutrophication. This further creates a diverse range of hazards and renders the water toxic as well as unsatisfactory water quality (Li et al., 2016).

Numerous pharmaceuticals have also been reported to contaminate the water samples, involving several antibiotics, psychotherapeutic drugs, hormones, anti-inflammatory medicines, cardiovascular system-related drugs, and anti-allergic medicines, to name a few (Li et al., 2020). Amongst all the pharmaceuticals, the major share was that of antibiotics contributing 65.8% to the total amount of pharmaceuticals. Excessive use and misuse of antibiotics contribute to groundwater contamination in several nations across the world (Lee et al., 2019; Meng et al., 2021; Mirzaei et al., 2018). About 23 antibiotics were identified in potable water samples taken from rural areas by way of employing high-performance liquid chromatography-tandem mass spectrometry technique, and among, them fluoroquinolones and macrolides were the most prevalent (Meng et al., 2021). In spite of adopting measures for checking the use of antibiotics by several countries worldwide, sales volumes of veterinary medically important (MI) antibiotics have raised constantly, thereby contributing to the contamination of water with antibiotic residues (Kim et al., 2018). Therefore, global focus has to be aimed immediately at adopting better management strategies so as to diminish the usage of MI antimicrobial products in the livestock industry.

3.2.3.4 Industrial activities/businesses

As businesses with raised energy expenditure and elevated pollution are shifting towards rural sectors, their inadequate distribution and broad operation are further deteriorating rural environments. Industrial activities like mining are usually carried out more in rural settings even though they are also observed in urban settings. Mining contributes to water pollution through acid mine drainage (AMD) with devastating consequences on biological activity in aquatic ecosystems. AMD is a natural process that occurs as a consequence of mining. Mining uncovers the sulfur-containing minerals (mainly iron sulfides), and as a result, it gets exposed to oxygen, moisture, together with acidophilic iron-oxidizing bacteria, which leads to the formation of sulfuric acid, dissolved iron, and precipitation of ferric hydroxide. Furthermore, sulfuric acid dissolves heavy metals present in mined materials thereby forming an acidic pH solution with the increased strength of copper, cadmium, arsenic, lead, etc. This solution may also seep into the soil, thereby contaminating both ground and surface water with devastating impacts on the environment. The volume of AMD liberated is a function of the magnitude of the volume of mined rock, the area of the uncovered surface, together with the concentration and kind of sulfides present. The formation and release of AMD keep happening even after the termination of mining resulting in grave perils to ecological systems. Higher amounts of heavy metals may also contaminate water resources due to various other businesses in rural areas. For instance, chromium contamination can occur due to tanneries and the leather industry (Ullah et al., 2009).

3.2.3.5 Change in living standards and inappropriate waste management

Due to changes in lifestyles and agricultural productivity structures, rural areas have gone through enormous alteration, for instance, elevated demand for animal products like meat, eggs, etc. (Sun et al., 2012). As a consequence, there has been a huge rise in discharge frequency and source intensity of NPS pollution, containing nutrient-rich runoff from farmlands, household wastewater, untreated agricultural waste, and wastewater from aquaculture, livestock, as well as poultry (Long & Liu, 2016; Yang et al., 2013). Together with these alterations in way of living, individuals in rural settings began to work in the direction of more and more economic profits in order to sustain their living. For this reason, higher and higher quantities of chemical fertilizers together with pesticides and other chemicals are employed.

Increased volumes of sewage and garbage have originated as a result of raised living standards, changed lifestyles, and products circulated swiftly to rural areas. The majority of the wastes are very complicated and released without any prior treatment. To add to the complexity, the waste treatment facilities are either absent or lag considerably in rural settings and hence are not provided with primary environmental protection facilities. Water samples from several rural parts have been shown to be contaminated with a great percentage of fecal coliforms and other microbial contamination, mainly due to improper sewage disposal, and handling of excreta. The sewage is often directly or indirectly dumped in water bodies leading to their pollution with harmful microbes. Open defecation is yet another culprit adding to the woes.

Fecal pollution in potable water can be introduced through both points, i.e., sewage release as well as diffuse sources like farmland runoff (Cho et al., 2016). Ground and surface water contamination with bacteria or other pathogens may generally happen through surface runoff from rural areas and pastures, as a result of improperly managed sewage disposal systems and septic tanks, the practice of open defecation, overburdened sewage treatment plants (STP), to name a few. Furthermore, in rural settings, open-dug wells and low water table also enhances the chances of water contamination with bacteria. Therefore, microbial analysis is generally conducted to find total and/or fecal coliforms in water, which are frequently found in the environment and are usually not detrimental to humankind. The existence of fecal coliforms together with E. coli is additionally an index for water pollution indicating the presence of human or animal wastes (Farooq et al., 2008). As per WHO (1993) standard for potable water, total and fecal coliforms should be absent in 100 mL of water sample, i.e., 0 count/100 mL. Due to the lack of monitoring of water quality and any treatment plants in rural areas, the condition can be terrible as bacterial contamination is generally predicted to be more in rural areas as compared to urban (Azizullah et al., 2011).

Moreover, millions of tons of agro-wastes comprising livestock droppings and crop residues are released or burned, which contributes to significant NPS pollution in rural setups and severe air pollution threats to human health and well-being (Zhang et al., 2015). In practical terms, strategies such as diminution at the source level, process interception, resource use, and end-of-pipe treatment are crucial in checking NPS pollution (Zhang et al., 2015). In addition, agro-wastes have huge potential for renewable utilization in biogas, manures, etc. (Chen et al., 2010), hence such interventions need to be adopted.

Furthermore, as a result of a change in the lifestyles of the rural population as well, packed products have also found their way into the rural sectors and because of a lack of awareness and poor management, the plastics find their way into the soil or water ecosystems. Because of the increased generation and consumption, substantial amounts of plastic waste are also added to the environment. To add, comparatively, fewer plastics are recycled, and reused thereby significant amounts are added into landfills or are discharged directly into the natural environment. The bigger, primary plastic items may encounter gradual disintegration, thereby leading to the generation of a considerable number of growingly tinier "secondary" microplastic particles. As a result, the overall surface area rises, which increases its capacity to soak up and concentrate, persistent organic pollutants (POPs) like dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyls (PCBs), etc. This enhances the exposure to organisms as the possibility to enter tissues by way of ingestion of microplastic particles, particularly from the aquatic environments. There are serious concerns related to these microparticles and their toxins which may find their entry into humans through the food webs, together, they may also be directly ingested through drinking water. The foodstuff may also get soiled by microplastics from airborne sources and they have been observed in human lung tissues. These microplastics have also been found in mountain soils in Switzerland, that is most probably windborne in origin (Rhodes, 2018).

In a recent investigation conducted by Li et al. (2020) on rural groundwater in China, phthalates [phthalic acid esters (PAEs)] were detected to be the chief organic micropollutants (OMPs). Amidst all identified PAEs, diethyl phthalate, bis(2-ethylhexyl) phthalate (DEHP), and dibutyl phthalate (DBP) demonstrated the greatest share of the sum of PAEs present in water samples. The extensive usage of PAEs in plastic products could be the reason for its large detection frequency together with its high levels (Balafas et al., 1999). Since PAEs are not chemically tied to articles, therefore, it might get readily liberated from plastic materials into environments (Benjamin et al., 2015). DEHP and DBP are the most frequently employed plasticizers, as a result repeatedly reported in underground and surface waters, including drinking-water samples from different nations (Lee et al., 2019; Luo et al., 2018; Magdouli et al., 2013).

3.2.3.6 Improper land use

In hilly areas, due to improper land use together with subsequent loss of water and soil erosion, NPS pollution may occur (Liu et al., 2016). For a long time, NPS pollution emerged as one of the key factors in causing eutrophication

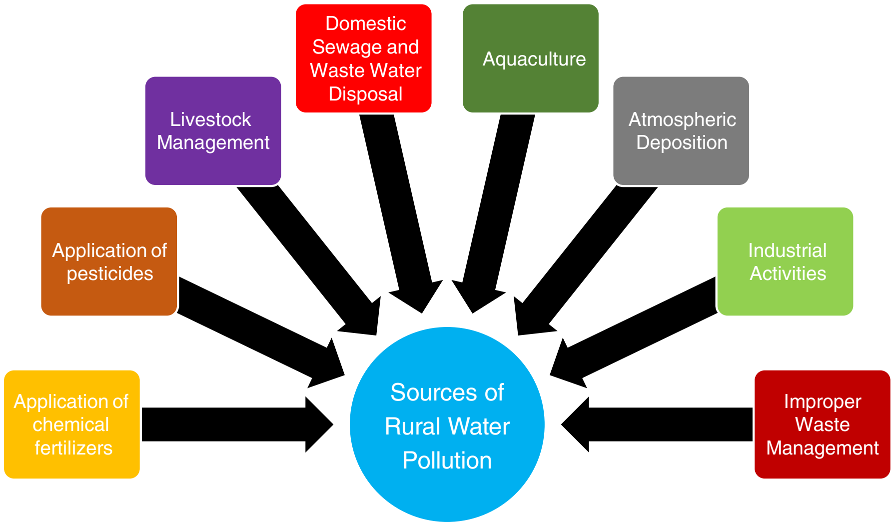

FIGURE 3.2 Some sources of rural water pollution.

of the surface water resources and therefore, enhances the risks to surface aquatic ecosystems (Zhang et al., 2017). Due to deforestation, the condition may worsen as a result of enhanced sedimentation and nutrient loss adding to the problem.

3.2.3.7 Natural and other anthropogenic sources

Contaminants like raised amounts of fluoride in groundwater have been observed as a result of the natural weathering of minerals such as apatite, fluorite, and topaz (Suthar et al., 2008). Anthropogenic activities for instance overutilization of groundwater for irrigation, and application of phosphate-based agrochemicals or fertilizers, together with pollution with effluent and sewage have also been documented to be associated with elevated fluoride levels in soil and groundwater (Brindha et al., 2011; Madhav et al., 2021; Ramanaiah et al., 2006). The aquifers or underground water get introduced with an excess of fluoride from the soil through natural seepage. In addition, a considerable association has been established between fluoride levels in groundwater and that in soils of farmland (Samal et al., 2015). Moderate to high fluoride pollution has been documented in about sixty blocks distributed in eight districts of West Bengal (Chatterjee et al., 2008), which is influencing around 12% of the entire rural population of this state (PHED Report, 2007).

Moreover, plants raised in polluted soil or watered with water contaminated with fluoride may result in their entry into the plant body as a consequence; they will easily enter the body of humans. In addition, other pollutants like acids if present in soil or acidic soils may increase the intake of fluoride by plants as a result of its increased solubility (Ruan et al., 2004). In addition, compounds such as n-alkanes have also been noticed in rural groundwaters with large detection frequencies which could be associated with their vast variety of sources (Li et al., 2020). The man-made sources comprise the burning of coal and petroleum goods. Together, natural causes include bacteria, greater plant wax, and alga (Cheng et al., 2016; Simoneit, 1986). Although, there is the scarceness of testimony with regard to the adverse impacts of n-alkanes in drinking water. Fig. 3.2 depicts the various sources of water pollution in the rural sector.

3.3 Water pollution and associated health issues

Water is an important nutrient for life. Apart from its availability, its quality is equally important in determining overall health and well-being. Around five million individuals worldwide, succumb to death because of consuming polluted water, poor sanitation as well as poor domestic hygiene. It is estimated that around 37.7 million people suffer from waterborne diseases in India aanually (UNICEF, 2019). In our country, the availability, and sufficiency together with the provision of clean and safe water is another chief community health matter, especially in rural areas (Dahnn et al., 2017; Ministry of Drinking Water and Sanitation, 2017). The perception of safe water in any society is based on the available water source quality, its preservation as well as handling in household settings. Some of the associated health issues related to rural water pollution are mentioned below:

3.3.1 Water-borne diseases

Water-borne diseases are caused in absence of clean water and unsatisfactory sanitation facilities. Furthermore, these primary conveniences are crucial for health as well as sustainable socio-economic development. As per estimates, about 5.2 billion individuals are able to obtain safe potable water facilities and 2.9 billion are in a position to get safely and securely regulated sanitary facilities (WHO & UNICEF, 2017). All over the world, miraculous improvement has been achieved concerning enhanced water and hygiene security over the past couple of decades (Cha et al., 2017). In addition, an upsurge from 76% in the year 1990 to 91% in the year 2015 has been observed with regard to access to improved water sources. The proportion of access to sanitation services has risen from 54% to 68% over these years (Ritchie & Roser, 2017). Comparatively better water and hygiene security is available in urban areas than in rural setups. This differential enhancement could be noted throughout landmasses in the majority of nations containing India (Ritchie & Roser, 2017).

In rural areas, the connection of piped water supply has approximately doubled in the past decade. India leads the world in terms of providing clean potable water to the majority of its citizens. However, still, about 66% of individuals are unable to obtain pure water and as a result depend on polluted water supposing as the main water source (Ministry of Drinking Water & Sanitation, 2018). Meanwhile, only a 30% increment has been observed with regard to access to better sanitation services like ventilated improved pit latrines, composting toilets, pit latrines with slabs, and flush/pour flush (WHO & UNICEF, 2017). More than half of the rural inhabitants still practice open shitting (WHO & UNICEF, 2017) which indicates the sluggish development in the field of sanitation. The unavailability of clean water for drinking and sanitation puts a ponderous toll on waterborne-associated illnesses having the biggest contribution of diarrheal illnesses (Ravindra & Mor, 2013).

Intake of fecally-polluted water results in about 1.8 million casualties every year as well as being the chief reason behind the occurrence of waterborne illnesses (Brusseau et al., 2019). The burden is relatively greater in developing nations, specifically in, rural areas because of their dependence on untreated water from catchment areas along with the dearth of sewage infrastructure and distribution networks (UNICEF & WHO, 2019). Faecal pollution is frequently assessed employing faecal indicator organisms, like *Escherichia coli*, that are simpler and affordable to determine compared to distinct pathogenic organisms and hence, quite advantageous for public health risk assessment from water resources (Edberg et al., 2000). Included as chief causes of mortality in India is still diarrhoea (Ravindra & Mor, 2018). Approximately, half of the total premature casualties in kids below five years of age have been related to the unavailability of clean water for consumption, sanitation, and hygiene practices (Manna et al., 2013; Verma et al., 2017). India is at the top among the 15 countries contributing to 75% of all diarrheal causalities in the world (Ali et al., 2018). Moreover, the condition is worse, especially in rural setups where the prevalence of diarrhea is observed to be 9.6% as compared to 8.2% in urban areas (IIPS, 2017). Inadequate infrastructure, contaminated water, or inadequate usage of water coupled with sanitation services may be the probable cause of this difference. The consumption of microbially contaminated water has been related to several waterborne diseases (acute diarrheal diseases, hepatitis,), gastroenteritis, typhoid, nausea, dysentery, etc. (Azizullah et al., 2011; Mahajan, 2017). Children and elderly populations with weak immune systems are comparatively more vulnerable. Therefore, microbial contamination of water is a grave concern with respect to public health and hence, demands special focus in order to reduce the burden of morbidity and mortality.

3.3.2 Organic substances

The connection between chemical contamination and the healthiness of mankind has been well-investigated (Kim et al., 2017; Koutros et al., 2015; Mehrpour et al., 2014). Issues have been elevated regarding environmental perils linked with chemicals like pesticide contact by several pathways, as the mechanism of action is not species-specific. The pesticides spread throughout the body by means of the bloodstream and can get eliminated via urine, skin, and expired air (Damalas & Eleftherohorinos, 2011). The noxiousness of pesticides is a function of the kind of exposure viz dermal, oral, or respiratory. Moreover, the threats may be short-term including irritation in the eye and skin, dizziness, headaches, and nausea, or long-term for instance cancer, diabetes, and asthma (Kim et al., 2017).

The connection between cancer and pesticides has been established through numerous investigations. Findings from a prospective cohort study revealed a relationship between two imidazolinone herbicides (imazaquin and imazethapyr) and bladder cancer (Koutros et al., 2015). Another investigation conducted on male laborers working in the Egyptian agricultural field displayed accelerated threats of bladder cancer with pesticide experience in a dose-dependent manner (Amr et al., 2015). Koutros et al. (2009) found considerable perils of colon and bladder cancer related to the chemical imazethapyr, which is a heterocyclic aromatic amine herbicide. Women who were occupationally exposed to the herbicide were also documented to have a considerably raised danger for meningioma compared to controls (Samanic et al., 2008). Significant associations between brain tumors and pesticides have also been noticed (Provost et al., 2007). Considerably raised threat of leukemia and lymphoma in children whose mother were exposed to pesticides during gestation has been documented (Vinson et al., 2011).

A number of organophosphorus pesticides have been found to impact the reproductive system of males by way of mechanisms such as diminution of sperm activities (e.g., viability, counts, density, and motility), impediment of spermatogenesis, decrease in weight of testis, injury to sperm DNA, and enhancing anomalous sperm morphology (Mehrpour et al., 2014). Michalakis et al. (2014) highlighted that encounters with organophosphate and organochlorine pesticides might be a potent threat in causing hypospadias, which is a birth defect. Numerous types of research have noted a relationship between pesticide exposure and signs of asthma and bronchial hyper-reactivity. It is observed that pesticide experience may lead to the aggravation of asthma by means of irritation, inflammation, immunosuppression, or endocrine impairment (Amaral, 2014).

A positive relation between diabetes and levels of numerous pollutants like polychlorinated dibenzodioxins and dibenzofurans (PCDD/Fs), PCBs, and numerous organochlorine pesticides [oxychlordane, trans-nonachlor, dichlorodiphenyltrichloroethane (DDT), DDE, hexachlorobenzene, and hexachlorocyclohexane] in serum have been reported (Jaacks & Staimez, 2015). Studies have also associated Parkinson's disease with pesticide exposure (James & Hall, 2015; Ratner et al., 2014). It has been noticed that chronic exposure to metals and pesticides can be linked to the onset of Parkinson's disease at a tender age (Ratner et al., 2014). Together, the investigators noted that the length of exposure was a crucial factor in checking the magnitude of the effect.

The perils are often arduous to determine because of the participation of several factors like period and extent of exposure, the kind of pesticide in terms of its toxicity and persistence, together with the environmental characteristics. Accidental exposure to pesticides can be exceedingly risky to mankind as well as remaining life forms as they are intended to be poisonous (Sarwar, 2015). Occupational exposure to pesticides may also prove to be deleterious to individuals working with them, in addition to those who get exposed by way of using them at home, consuming foods or liquids contaminated with pesticide residues, or by way of inhalation of polluted air while spraying (Pimentel et al., 2013). Exposure to extremely low concentrations has also been linked to harmful consequences for the health at initial development (Damalas & Eleftherohorinos, 2011). To complicate the matter, children are relatively more vulnerable in comparison to adults because of their physical makeup, behaviour, as well as physiology (Mascarelli, 2013). Exposure to pesticides has got related to many deleterious impacts inclusive of cancer, hormonal impairment, asthma, allergies, hypersensitivity, birth abnormalities, diminished birth weight, fetal death, etc. (Amaral, 2014; Baldi et al., 2010; Koutros et al., 2009; Meenakshi et al., 2012; Wickerham et al., 2012).

Pesticides such as DDT, aldrin, dieldrin, chlordane, heptachlor, endrin, and hexachlorobenzene are POPs that oppose deterioration and hence persist in the environment for several years (Yadav et al., 2015). Additionally, since these chemicals have the potential to bioaccumulate and bio-magnify in different trophic levels, these can get bio-concentrated over up to seventy thousand times compared to their original concentration (Hernández et al., 2013). Recurrent usage may contribute to declining biodiversity and accelerated pest resistance and resurgence (Damalas & Eleftherohorinos, 2011). About 95% of pesticides employed, bear the capacity to influence even the non-target life forms and can extensively diffuse in the environment (Simeonov et al., 2013). Environmental processes such as degradation coupled with sorption determine pesticide persistence in soil. The effects of certain pesticides may last for generations, thereby negatively influencing soil conservation and diminishing soil biodiversity and soil characteristics (Jacobsen & Hjelmsø, 2014). Due to the widespread and extensive employment of these agrochemicals, no individual is entirely unexposed while the majority of illnesses are multi-factorial which further complicates public health assessments. Thus, the preparation of environment-friendly pesticide substitutes and Integrated Pest Management techniques are needed to combat pesticide-related problems.

Antibiotic residues can have harmful effects with respect to human and environmental health. However, the presence of antibiotic remainders in rural potable water and their likely health impact needs to be explored. An investigation carried out by Meng et al. (2021) observed that health hazards connected with antibiotics in potable water were well below tolerable levels and expected to have minor health implications. However, out of all the antibiotics determined, salinomycin demonstrated the highest hazard to human health. MI antibiotics are drugs having definite active antimicrobial constituents utilized for curing human diseases. The contamination of water with MI antibiotic residues is a serious matter for both aquatic ecosystems and community health, especially due to their ability to lead to the evolution of antimicrobial-resistant microbes.

3.3.3 Inorganic constituents

Metals, though important for health and fitness, however, excess concentration leads to water pollution and culminates in serious health issues post-consumption. Manganese is a vital trace nutrient for organisms (Emsley, 2003) regulating the functioning of various enzymes, but increased exposure may result in serious neurological disorders, the brain being the chief target (Crossgrove & Zheng, 2004). In severe situations, it may cause long-lasting neurological damage with signs and symptoms identical to that of Parkinson's disease (Inoue & Makita, 1996).

The raised levels of iron in water can also be a potential hazard. Nevertheless, compared to its insufficiency, iron overexposure is a minor and uncommon issue however, it can cause severe health issues such as cancer

(Parkkila et al., 2001), diabetes (Parkkila et al., 2001), heart and liver ailment (Milman et al., 2001; Rasmussen et al., 2001) together with neurodegenerative maladies (Sayre et al., 2000).

Cadmium is another toxic metal of huge interest with respect to toxicity. Cadmium ingestion has been associated with acute gastrointestinal issues, like vomiting coupled with diarrhea (Nordberg, 2004). Chronic exposure may lead to kidney injury (Barbier et al., 2005), reproductive complaints (Johnson et al., 2003), bone impairment (Kazantzis, 1979) along with tumour (Waalkes et al., 1988). Cadmium exhibits significant involvement in carbohydrate metabolism in humans (Cefalu & Hu, 2004), however, in its hexavalent state, it has been connected with skin diseases, cancers, and illnesses associated with the digestive, excretory, respiratory, and reproductive systems.

Nickel, is another broadly spread metal in the environment and could be noticed in water, soil, and air. Nickel compounds have the potential to elicit varied harmful effects, for instance, nickel allergy termed as contact dermatitis, cardiovascular maladies, lung fibrosis, kidney-related troubles, and respiratory tract cancer to name some (McGregor et al., 2000; Seilkop & Oller, 2003).

Lead is naturally present in trace quantities in water and soil (Raviraja et al., 2008). Water may pick up lead through varied sources such as vehicle exhausts, agrochemicals, paints, and industrial wastes (Nadeem-ul-Haq et al., 2009). Exposure to excessive amounts of Pb for a long duration may adversely affect the critical body parts and systems like the nervous, hematopoietic, digestive, reproductive, skeleton, cardiovascular, immunological, and kidneys (Riess & Halm, 2007; Venkatesh, 2004). Lead at even trace amounts, can be extremely dangerous during pregnancy leading to delayed fetal development, reduced childbirth weight, and miscarriage (Bellinger, 2005; McMichael et al., 1986).

Mercury is toxic to the health of mankind and the environment, by reason of its potential to get biomagnified through the food web. In water bodies, it may get converted to its organic form i.e. methyl mercury which is its deadliest state (Fatoki & Awofolu, 2003). Being an able cellular toxicant, it negatively impacts several critical processes within neurons. It has been implicated to impair neurotransmitter generation together with reduced manufacture of vital hormones like thyroid and testosterone (Fatoki & Awofolu, 2003).

Arsenic is acknowledged as a potential menace to community health in numerous nations such as Bangladesh, Vietnam, Nepal, Myanmar, China, including India (Islam-Ul-Haque et al., 2007). The condition is worst in certain states with exceeding levels going beyond 10 ppb (μg/L) as per WHO standards. Encounter with greater amounts of arsenic may contribute to diminished red and white blood cell generation, impairment of heart rhythm, gastrointestinal irritation, blood vessel injury, and "pins and needles" feeling in extremities (Abernathy et al., 2003). Chronic exposures have been associated with melanosis, hyperkeratosis, leukomelanosis, black foot disease, cardiovascular disease, neuropathy, and cancer (Caussy, 2005).

Ingestion of groundwater contaminated with fluoride has jeopardized about 200 million individuals residing in 29 diverse nations around the globe by way of various health perils of varying degrees (Bhattacharya & Chakrabarti, 2011; WHO, 2006). If we talk about India, fluorosis is endemic in about 20 from a total of 29 states, comprising 65% of rural residences (Kundu & Mandal, 2009; UNICEF, 1999). Greater than 65 million Indians including six million children are in danger as a consequence of fluoride defilement in groundwater (UNICEF, 1999). Within the allowable limit, ranging between 0.5–1 mg/L, fluoride intake is suggested to be advantageous in the formation and upkeep of healthy teeth and bones (UNICEF, 1999). Conversely, ingestion above this range contributes to softening of bones, and mottling teeth, together with neurological impairment (UNICEF, 1999). Hence, WHO has fixed 1.5 mg/L as the allowable limit in potable water (WHO, 2006). Fluoride consumption of more than 2 mg/L results in serious dental and skeletal fluorosis (Chatterjee et al., 2008; UNICEF, 1999). It has been found that fluoride bio-accumulate in plants from sources such as aerosols, soil, and irrigation water (Bhattacharya et al., 2017; Saini et al., 2013). Therefore, the intake of veggies and crops contaminated with fluoride may be another effective mode for entering the human body together with drinking water.

Research led by Bhattacharya et al. (2017) explored the situation of fluoride defilement in pulses, rice, and veggies grown in the Purulia and Bankura districts of West Bengal. The researchers highlighted the movement of fluoride from polluted soil and groundwater to plants grown there escalating the seriousness of fluoride poisonousness in nearby dwellers, as relatively the accumulation of fluoride in rice, vegetable, and pulse samples of the investigation site was found to be in a greater degree in comparison to aggregation in reference sites. To add, cumulative estimated daily intake through ingestion of food and potable water in individuals dwelling in study sites were detected to be more compared to their counterparts residing in control sites.

Nitrate is one of the commonest groundwater contaminants, particularly in rural areas due to agrarian activities. The risk of water pollution both in terms of surface and groundwater can escalate in view of unreasonable consumption of chemicals and fertilizers thereby leading to harmful consequences (Adimalla, 2019; Kundu & Mandal, 2009). The nitrate entering the human body through the food chain or consumption of contaminated water may generate N-nitroso compounds (NOC), which are strong animal carcinogens (Schullehner et al., 2018). Some scientific investigations have displayed a connection between higher exposure to nitrate with thyroid malfunction, and gastrointestinal cancer (Powlson et al., 1995). Studies have also associated consumption of nitrate-contaminated potable water with cancers of the esophagus, stomach, brain, bladder, colon, pancreas, rectum, and kidney (Schullehner et al., 2018; Ward et al., 2018; Zumel-Marne et al., 2021). Raised risks of colon, kidney, and stomach cancer have been found amongst individuals having a greater intake of nitrate through water ingestion and meat consumption as compared to those with lesser consumption of both. This kind of dietary pattern has been suggested to lead to raised NOC formation. Scientific studies have also reported that women with greater average nitrate concentrations in community water supplies had enhanced perils of cancers related to the thyroid, kidney, ovary, and bladder (Tariqi et al., 2021).

In a recent investigation performed by Yu et al. (2020) with the intent to evaluate the hazard of exposure to potable water nitrate for both adults and juveniles, the hazard quotient value of juveniles was found to be considerably greater than that of adults due to their greatest exposure risk which further highlights that they are comparatively more susceptible to health hazards of nitrates. Furthermore, on account of their specific physiological characteristics, and behavioural habits, together, considering their bodies being in a developmental phase, there is enhanced gastrointestinal absorption of particular materials, predisposing them to environmental pollutants (Chen et al., 2016).

Consumption of water having raised nitrate concentrations around the first trimester of pregnancy has been linked with the occurrence of birth defects in neonates (Ahamad et al., 2018; Powlson et al., 1995; Ward et al., 2018). The health problem of infants named methemoglobinemia also known as the blue baby syndrome is directly connected with increased concentrations of nitrate in potable water (Kundu & Mandal, 2009; Madhav et al., 2021). According to WHO, 11 mg/L is the limit for nitrate nitrogen. The relatively increased levels of nitrate in rural sectors could be due to chemical fertilizers together with geological factors (Kundu & Mandal, 2009; Yu et al., 2020).

Contaminants such as NP and OP, being primary disintegration products of APEO, and BPA, can desorb out of cans as well as plastic bottles in which pesticides are stored. The physicochemical characteristics of these chemicals, portrayed as recalcitrant and having a large log Kow, enable them apt candidates for groundwater pollution, notably in rural and other regions where these are regularly used for agronomic intents. These chemicals have been accused as potent endocrine disrupters (CEC, 1997). Since DEHP is the most common plasticizer, they have been repeatedly observed in water samples of underground, surface, and together with drinking water in several nations. Furthermore, the amount of DEHP metabolites in urine samples of humans has been found to be strongly associated with abdominal obesity as well as insulin resistance (Stahlhut et al., 2007). Water samples have been observed to have DEHP levels that far surpass water quality standards, therefore, the health implications of PAEs are required to be assessed with regard to public health concerns (Li et al., 2020).

3.4 Conclusion

Water pollution in rural settings is a grave concern brought about by multiple sources. Agriculture being the principal basis along with other anthropogenic activities has deepened rural NPS pollution. The levels of rural NPS pollution further escalate more significantly due to the backward agricultural economy and poor environmental awareness of peasants. There is a close connection amid water pollution and health effects, as contamination of water renders water unsafe for consumption and so is a serious community health issue. The attainability of pure water and satisfactory sanitation services are key elements for checking varied waterborne illnesses. These fundamental conveniences are necessitous for health as well as sustainable socio-economic growth. Therefore, a society governed by public health and cleanliness education together with enhanced water resource preservation is pressingly wanted to safeguard people in rural areas. Moreover, on account of the dearth of comprehensive knowledge regarding restraining and handling water pollution in addition to the paucity of flawless water quality standard systems and realistic legislative regulations, agricultural NPS pollution will turn into one such greatest troubles to the sustainable growth of rural settings and to the community at large. Hence, the system for checking agricultural NPS pollution should focus on the right legislation and policy framework, together with surveilling system, funding mechanisms, and scientific guidelines and standards. The handling of agricultural NPS pollution necessitates integrative approaches which will encompass a variety of organizations, government divisions, and the community. The problem of rural water pollution can be addressed efficiently by utilizing agricultural wastes and converting them into a resource by way of biogas generation, crop straw gasification, establishment of biogas septic tanks, and making use of household sewage and wastewater from livestock rearing. Moreover, technologies like decentralized land treatment of droppings of farm animals, and crop straw conversion can also lead to renewable resource usage of agricultural wastes together with the betterment of water quality and ecological environment in the rural sector. Specific practicable approaches such as formula fertilization by soil examination, water-conserving irrigation technique, and integrated pest management can also aid in combating the challenges of rural water pollution. Together with that construction of fixed garbage disposal sites and the setting up of a coordinated garbage disposal station can further help in diminishing pollution discharges of household refuse. Besides, it is critical to stringently contain progress and exploitation of hillsides in the middle and upper reaches of potable water source regions, together with fortifying restoration of vegetative cover and employment of measures to conserve soil and forests in order to boost conservation and protection of water in these areas.

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Chapter 4

Impact of climate change on rural water resources and its management strategies

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4.1 Introduction

Water is necessary for different life forms and their existence. Weather variability poses a major threat to the water resources, agricultural production, and well-being of India's 1 billion population in the 21st century. Many parts of the country have an unequal geographical distribution of water resources, ranging from the northwest arid region, where precipitation is limited, to the northeast, which receives the highest rainfall in the country. Because freshwater resources become scarce, conserving and managing them is critical. Freshwater resource management mainly depends on understanding how climatic, biophysical, and socioeconomic systems are interrelated at diverse geographical scales. Recently reported climate change events to have a considerable effect on the availability of water quantity (over or under) or quality.

Several disastrous climatic extremes have struck India in recent decades. The climatic extremes occur with reference to four seasons in India. Flood catastrophes affect approximately 13.8% of the geographical area of the country (Planning Commission, 2011), and around 33 million of the population (Kumar et al., 2005) were exaggerated by floods (1953–2000). On July 26, 2005, India's economic center (Mumbai) received about 944 mm of rainfall, creating devastation and countless casualties (Kumar et al., 2008).

From 2002 to 2013, the study of Asoka et al. (2017) groundwater reservoirs in northern parts of the country decreased at a pace of 2 cm/yr, whereas southern parts improved at a pace of 1–2 cm/yr due to changes in rainfall patterns and pumping analyzed by GRACE data. For instance, the 2016 drought affected around 10 states and 330 million people, resulting in a $100 billion economic loss (ASSOCHAM Report, 2016). The southwest monsoon is responsible for roughly 80% of India's rainfall (Lacombe & McCartney, 2014). However, in India, the amount of rainfall observed has a decreasing trend, while a marginal increase was depicted in the northwestern and peninsular parts of India (Mondal et al., 2015). The agrarian economy of the country, which is highly dependent on the monsoon season for production, is extremely vulnerable to the predicted change in the weather. Existing water resource systems including monitoring, handing out, communication, broadcasting, and storage networks, have significant data acquisition gaps and are unable to cope with the expected difficulties of a fast-changing environment.

The National Action Plan on Climate Change (NAPCC) was formed in the year 2008 as a national guide plan to address the consequences, improvement, and adaptation for climatic variability. In the long run, India has emphasized a 20% improvement in WUE due to a 23–33% increase in forest cover (Pandve, 2009). The Indian government is attempting to persuade farmers to utilize micro-irrigation techniques such as drip irrigation to reduce groundwater usage by roughly 20%, according to the "per drop per more produce" by the NITI Aayog campaign. The "Jal Shakti Abhiyan" is a wonderful step towards initiating and paying attention to conserving water resources at the rural and global levels.

Therefore, the interaction between variability in the climate and rural water resources is of immense value to society's well being. Because the atmosphere, hydrosphere, cryosphere, land surface, and biosphere are all integrated into the climatic system, climate change causes variations in the hydrological processes. As a result, variability in climate has an impact on rural water resources both directly and indirectly. The chapter's intention is to illustrate the consequences of long-term climatic variability on water resources and their mitigation and adaptation strategies.

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4.2 Climate change and causes of climate change

4.2.1 What is climate change?

"Climate change" is the term used to describe long-term variability in different weather parameters such as temperature and rainfall. These fluctuations are considered to be natural, but since the 1800s, human activity has been the major factor responsible for climatic variability. This is primarily due to the burning of fossil fuels, which produces greenhouse gases (GHGs) that trap heat. Change is characterized by the intergovernmental panel on climate change (IPCC) as changes in the state of the climate that can be detected by variations in its characteristics and that last for a long time, typically decades or prolonged, as a result of internal natural processes, external forcing, or constant anthropogenic change in the atmosphere composition or change in land use patterns. The United Nations Framework Convention on Climate Change (UNFCCC) also assumes that a changing climate across comparative periods of time is caused, directly or indirectly, by human activity that modifies the composition of the atmosphere on a global scale.

4.2.2 Causes of climate change

Accordingly, variability in each of these processes can be both natural and human induced, premised on fluctuations in GHGs concentrations, particles in the air tiers, land use, land cover, and radiation from the sun, which affect the absorption, dispersion and release of radiation within the atmosphere and at the earth's surface. Climate change is a complicated relationship between the planet Earth, the ocean, the atmosphere, and the land systems. The following fragment discusses several of the major causes of climatic variability and its impacts.

- **Power generation:** The use of fossil fuels to generate heat and electricity, such as coal, oil, and natural gas, contributes significantly to world emissions. The maximum generation of power is still from the use of fossil fuels, with just around 25% coming from wind, solar, and other alternative energy sources.
- **Manufacturing goods:** Emissions from the manufacturing and industrial sectors are mostly caused by the burning of fossil fuels, which are used to produce energy for the manufacturing of concrete, metal, gadgets, polymers, textiles, and other goods. Additionally, mining and other industrial plants produce gases.
- **Forest destruction:** Forest destruction, or by cutting down trees, releases carbon into the atmosphere. Because trees absorb carbon sequester, deforestation and cutting down of forest trees decrease the ability to store carbon. Clearing of forests to make way for farmlands, grasslands, shifting cultivation or other purposes increases emissions.
- **Maximizing transportation:** Fossil fuels are often used to power vehicles, trucks, ships, and aircraft. As a result, the transportation industry has a significant impact on emissions of greenhouse gases, particularly carbon dioxide. Although emissions from ships and airplanes continue to rise, road vehicles still make up the majority of the pollutants.
- **Energy combustion by buildings:** Building structures worldwide that are simultaneously both residential and commercial use 50% of all power generation. Since they are still dependent upon fuel, oil, and natural gas for heating and cooling, they continue to produce a substantial amount of GHGs emissions.
- **Increase in livestock farming and use of fertilizers:** When livestock such as cows and sheep digest their food, they produce a significant amount of methane. The excess use of nitrogen fertilizers for a higher yield of the crop produces nitrous oxide emissions.
- **Natural processes:** Climate change events also include the relocation of the equinoxes, the peculiarity of the planet's orbit around the sun, and the tilting of the earth's axis, which influences how solar radiation is dispersed in space and time. Other natural processes include geological movements, which either directly or indirectly cause a change in weather systems and greenhouse responses, as well as volcanic eruptions, which release large amounts of gases by lowering the amount of solar radiation that reaches the earth's surface, lowering temperatures, and changing the earth's atmosphere convection currents.

4.2.3 Climate change evidence

The following part discusses how rainfall and temperature patterns changed in India as evidence of climate change.

4.2.4 Trends in rainfall patterns

The studies examine the impact of rainfall variability on water resources, agricultural production, economic production, and food security in rainfed regions. The monsoon season account for around 80% of total rainfall in the nation (Lacombe & McCartney, 2014). However, in India in different states, trend analysis research was conducted and observed the declining trend in the rainfall annually, while a marginal increase was observed in some parts of India's northwest and peninsula (Mondal et al., 2015). India's agriculture sector, which largely depends on the monsoon season for production, is extremely susceptible to anticipated climatic fluctuation. Between 1951 and 2010, in Central India the monthly rainfall decreased significantly in the month of July and August (Singh et al., 2014). In the Solan district of

Himachal Pradesh, the annual rainfall exhibited a decline at a rate of −0.79 mm/yr. The seasonal and monthly changes in rainfall demonstrated the sensitivity of change. The monthly rainfall showed an increasing trend in the months of (January, April, July, and September) while decreasing in the rest of the months. Among the seasons, the winter season observed an increasing trend in rainfall, while the other seasons observed a decreasing trend (Mehta et al., 2022). Jaswal et al. (2015) investigated the rainfall variations in Himachal Pradesh at 37 locations (1951–2015). The rate of annual rainfall decline was 4.58 mm/yr. Dharampur (7.04 mm/yr), Kasuali (6.18 mm/yr), and Nalagarh (0.60 mm/yr) all had a drop in annual rainfall.

The rainy days number decreased, but the number of severe events increased in several major river basins (Jain et al., 2017). In the lower Shivalik region of Punjab, Kaur et al. (2021) also examined a notable decline in annual rainfall from 12 mm to 17 mm, 9 mm to15 mm in Kharif and monsoon season at Patiala ki Rao, Saleran, and Ballowal Saunkhri. The decrease in rainfall patterns and the increase in extreme events affect the water resources in different regions of India. Drought is a widespread phenomenon that impacts a large number of populations. Every year, India's population increases at a faster rate. It is a cause for alarm for food security and socioeconomic fragility, considering that about 33% of the geographical region (Mishra & Desai, 2005), is mostly caused by irregular monsoon rainfall.

4.2.5 Trends in temperature patterns

Climate change, as well as its consequences and vulnerabilities, is among the world's most pressing environmental concerns in the 21st century (Pachauri et al., 2014; Stocker et al., 2013). The direct impact of climate change is visible in the average global temperature. In the upcoming years, the global average temperature is expected to rise by 0.6–0.8°C. The hydrological cycle is directly impacted by temperature differences due to an increase in evapotranspiration processes. The climatic variability and warming of the planet have become the greatest constraints due to decreasing food insecurity. The major causes of variability in weather are GHGs, urbanization, and industrialization. In comparison to the pre-industrial period, the increase in atmospheric CO_2 concentration caused a 1°C rise in the world's average temperature (Allen et al., 2019).

Over the past 100 yr, the average temperature in India has risen by 0.62°C (Government of India, 2021). India has been warming up, and 2016 was the hottest year ever recorded since national records began being kept in 1901. The last 16 yr have seen all 5 of the warmest years (2000–2016). The nation's average temperature increased by 0.22°C/10 yr from 1971 to 2003. (Kothawale & Kumar, 2005). In the next years, increased atmospheric water vapor concentrations and more frequent and heavy rains will be the results of increased water evaporation brought on by rising global temperatures. Sea levels are rising as a result of the rapid melting of ice glaciers across the planet. Finally, water from the melting glaciers reaches the ocean. Less snowfall occurs in the Northern Hemisphere, where it frequently accumulates and serves as a water resource. Local reservoirs contain less water after the winter when there is less snowfall. Throughout the growing season, farmers who are unable to irrigate their crops due to a lack of water have a wide range of problems. According to Srivastav et al. (2021), as most countries in the world are susceptible to temperature rise, the United States will have losses in wheat production of 5.5–4.4% per °C, India will experience losses of 9.1–5.4%, and Russia will experience losses of 7.8–6.3% per °C rise in temperature.

4.3 The climate change impact on water resources

4.3.1 Climate change impact on groundwater

Groundwater accounts for a small portion of the total earth's water, but it contains approximately 30–35% of the planet's fresh water. The possible influence of climate change on groundwater systems must be carefully considered. The most visible consequence of climatic variability is on surface water levels and quality, which have a direct influence on farm productivity as well as the population whose main source of consumable water is dependent on groundwater (Madhav et al., 2021). As the groundwater is mainly dependent upon rainfall, due to variations in the rainfall patterns, the surface water level is affected. In rural regions, roughly 85% of drinking water comes from groundwater, which is significant as compared to other countries. In general, India has the potential to restore groundwater of 45.22 Mha/m/yr. However, the water level has declined dramatically in numerous regions of the country in recent years as a result of the threat to the sustainability of groundwater. In India, the scenario in Gujarat state is dire. Ahmadabad city in the state of Gujarat has reported a drop in the water table of 4–5 m each year. In the capital of the country, the water level has dropped by more than 10 m. In addition to the high frequency of the rainy season, Kerala's groundwater level has been sinking. (Kale & Pantawane, 2020).

Sea-level rise is a global problem, with an average global rise of over 25 cm in the last 100 yr, and therefore sea level is going to encompass a significant effect on the coastal region. The sea and water balance levels are associated with each other. To assess the effects of the anticipated changing climate on groundwater aquifers, we must emphasize on changes in groundwater recharge (Dixit et al., 2022; Srivastav et al., 2021). As a result, sea level rise causes saline water to penetrate groundwater in coastal aquifers, threatening groundwater resources (Madhav et al., 2020;

Nazneen et al., 2022). The most important assumption is that a 1 m decrease in groundwater level increases overall carbon emissions by more than 1% due to an increase in the consumption of fuel. In India, groundwater accounts for around 52% of total irrigation demand in different sectors. Furthermore, several studies predict that rising temperatures and decreased rainfall reduce net recharge, which directly impacts groundwater levels. The increase in the rate of population growth will also face conditions of water stress and scarcity by the year 2025.

4.3.2 Climate change impact on surface water resources

On a global basis, water is abundant. Nevertheless, only 0.3% of it is usable by individuals, with an even smaller proportion available. Surface water, predominantly river runoff, provides around 300 cubic miles of water. The potential of surface water is determined by a variety of factors, including weather parameters, rainfall intensity and duration, catchment area and size, soil, slope, and land use. India has a vast and diverse network of river systems, the most notable of which are the Himalayan river systems that drain India's leading lowlands. India has about 20 river basins. A total of 14 main rivers produce 1406 thousand million cubic meters (TMC) of average annual water output, medium rivers of about 44 provide (112 TMC), and a number of minor streams contribute around 127 (TMC). The usable surface water resources are around 600 (TMC), while surface water storage is approximately 160 TMC (Chakravarty, 1990). Due to the increased consumption of residential, industrial, and agricultural use, the majority of river basins are water stressed.

Monsoon rainfall in India has already been declining since the 1950s. The occurrence of heavy and frequent rainfall has also increased. An unexpected variation in the monsoon season might result in a major disaster, causing drought conditions and flooding across broad regions of India as shown in Fig 4.1. Over the previous five decades, India experienced severe droughts in 1965, 1972, 1979, 1987, and 2009, destroying more than 40% of the country (Kaur, 2009). The economic survey revealed that when rainfall levels decrease 100 mm below normal throughout the Kharif and Rabi crop seasons, farmer income declines by 7–15% during the Rabi and Kharif crop seasons due to the rise in temperature and change in the rainfall pattern from 1970 to 2015. In northern parts of India, a declining trend in daily Sutlej River stream flow analyzed over 41 yr (1970–2010) has been noticed at three stations (Kasol, Sunni, and Rampur). The basin is important because of its tremendous potential for hydroelectric power generation and agricultural activities (Singh et al., 2014). Between 1961 and 1995, there was a significantly decreasing trend in average annual river flow in the Beas and a statistically significant increase in

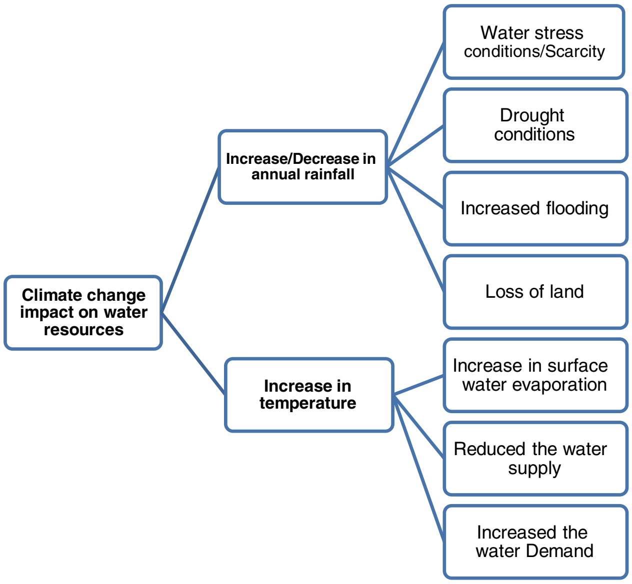

FIGURE 4.1 Change in weather patterns affects the water resources.

winter river flow in the Chenab, which was attributed to variability in snow and glacier melting (Bhutiyani et al., 2008). Annual agricultural productivity may be reduced by 15–18% on average and up to 20–25% in rainfed regions due to climate variability. It addresses how farmer insecurity will intensify associated with climate change and promotes adequate crop insurance as well as the employment of improved technologies to strengthen farming. Currently, agriculture is irrigated to a level of around 45%. The Indo-Gangetic plain, as well as regions of Gujarat and Madhya Pradesh, are widely irrigated, but due to inadequate irrigation facilities, areas of Karnataka, Maharashtra, Rajasthan, Chhattisgarh, and Jharkhand are especially susceptible to climate change. In 2017, the winter season was the hottest on record due to less rainfall in the year. The India Meteorological Department (IMD) predicts that a hotter summer in 2018 will worsen the country's water situation.

The India Meteorological Department reports that the dry western meteorological subdivisions of West Rajasthan are the most drought-affected regions in India, with 31 drought occurrences repeated between 1875 and 2004 (130 yr). Comparative to Gujarat, which had 27, Jammu and Kashmir experienced 28 incidents of drought. The smallest droughts have occurred in the northeast (Shewale & Kumar, 2005). Variations in rainfall will have an impact on water resource management and planning in a number of ways, including the creation of hydrological infrastructure, the prevention of floods and droughts, and urban planning and development.

4.3.3 Climate change impact on spring water

In India, 80% of the population in the Himalayas depends upon natural water resources such as kuha, bodhi, etc. for agricultural and household activities. The main source of drinking water in rural areas of the Himalayas has been springs over the last few years. Due to the change in climate and variation in weather patterns, the natural water resources dry up or become seasonal. It has been determined that approximately 15% of rainwater percolates down to recharge springs, while the remainder flows down and causes flooding in plain areas. In Sikkim, about 80% of rural people rely on spring water for their water security. Land use change, environmental degradation, and the development of highways by affecting mountains for infrastructure development impact the aquifer systems. If the infrastructural activities persist for a long time, it will impact the livelihood of mountain residences.

It has been determined that the spring water's sensitivity to the environment follows an annual periodic pattern that is highly dependent on the melting of snow, rainfall, and evapotranspiration. Karst aquifers were found to be the most susceptible of all kinds. The recharge areas in the headwater zone are being impacted by changes to the forest and urban environments. In the Central Mountain zone (Kosi River basin, Kumaun), the number of permanent springs is shrinking at a rate of 3/yr, while the number of non-perennial springs is increasing enormously by 1/yr (Panwar, 2020). The spring water probably has high concentrations of ammonia, chloride, sulfate, and fecal coliforms, indicating that shallow aquifers are more susceptible to non-point pollution sources. Future projections indicate that excessive runoff and the occurrence of catastrophic events, such as floods and landslides, may have an effect on spring flow and water quality. Regional scientific research on springs that focus on hydrogeochemical dynamics, security risk, recharging zone dynamics, and the creation of spring-shed management programs are urgently in need of support. This is because the impact of climate change and anthropogenic activities is anticipated to worsen significantly over time.

4.4 Policy initiatives to conserve water resources

India is a fast-developing nation with the leading percentage of the world's impoverished people, i.e., 30%. Climate change poses a significant concern to the nation's water resources in terms of variations in rainfall intensity and severity, groundwater recharge, floods, and drought catastrophes, as well as pollution of different water resources. The National Water Policy (NWP) of India's government was first announced in 1987. The environmental and ecological implications of water distribution in the context of fast climate change were highlighted in the NWP of 2002. For the objectives of managing and planning water resources, the NWP (NWP of India, 2012) emphasized that water must be perceived as a common-pool resource. In India, the proportion of flora has plummeted while the urban and bare soil portions have expanded. Changes in land use and cover may improve the management of water resources (Unnikrishnan et al., 2016).

Highlights of Indian National Water Policy, 2022

Drinking water is given first priority when it comes to water allocation, followed by agriculture, hydropower, navigation, industry, and other purposes, according to the National Water Policy of 2002. Progressive new ways to water management are required under the policy.

Key elements consist of:

- Drinking water should always be a component of irrigated agriculture and multi-purpose operations if there is no other source of it. All individuals and creatures should have access to clean drinking water as a top priority.
- The extraction of groundwater needs to be controlled and limited.
- The quality of both surface water and groundwater should be frequently checked. It is necessary to implement a stepwise strategy to improve water quality.
- Each of the various uses of water should be managed more effectively.
- It is important to promote awareness of water's limited availability.

There is an urgent need to improve data access, improve data collection networks and storage, and support interdisciplinary research institutes around the nation in order to address future issues with water resources. Implementing scientific decisions about water and climate change policy in order to address the consequences, mitigation, and adaptation of climate change, the National Action Plan on Climate Change (NAPCC) was introduced in 2008. India has concentrated its efforts on a long-term increase in forest cover of 33% and a 20% increase in water use efficiency (Pandve, 2009). The water resources at a glance in India are shown in Table 4.1. It is necessary to take action to conserve water resources and reduce the factors contributing to climate change and its negative impacts.

4.5 Management and conservation of water resources

The increase in the growth rate of the population and the increasing demand for water resources are decreasing the supply of fresh water. Therefore, there is an urgent need to protect and efficiently manage this vital life-giving resource for long-term development. The availability of water from the sea/ocean is regarded as low owing to the expensive cost of desalination. India must move quickly to implement appropriate rules and legislation, as well as

TABLE 4.1 India's water resources in a description.

Average annual rainfall in India (2020)	1289.6 mm
Per capita availability of water in India (2011)	1545 m^3/yr
Country's area as % age of global proportion	2.4%
Percentage of water	4%
Average annual water resources (as per water availability reassessment in India using space inputs-2019)	1999.2 BCM
Estimated utilizable surface water resources	690 BCM
Total annual ground water recharge (reassessment of ground water report—2020)	436 BCM
Total annual utilizable water resources	1126 BCM
Rank in per capita availability	132
Water quality rank of India	122
Total cultivable land (2017–18)	153.99 Mha
Gross sown area (2017–18)	199.99 Mha
Net sown area (2017–18)	139.18 Mha

From: WRS Dte, BP-1 Dte, CWC, RGI, IMD, Central Electricity Authority, Ministry of Agriculture & FW (http://eands.dacnet.nic.in).

implement effective conservation measures. In addition to developing water-saving technology and processes, efforts will be made to avoid contamination. There is a need to encourage watershed development, rainwater harvesting, water recycling and reuse, and conjunctive use of water for sustainable water supply in the long run.

Various techniques and water-conserving technologies for the sustainable use of water are listed below:

A. Watershed management**:** Watershed management is primarily an effective management technique for the restoration of surface and groundwater resources. It entails drainage suppression as well as groundwater storage and replenishment by different technologies such as percolation tanks, and recharge wells. However, watershed management involves the preservation, restoration, and sensible use of all-natural resources. The goal of watershed management is to maintain a balance between individuals and the environment. Community participation is vital to the success of watershed development. The various effective methods of watershed management are shown in Fig. 4.2.

The various steps considered in the planning of the watershed include:

- Base map creation in preparation for assessment.
- Watershed reconnaissance study for overall development.

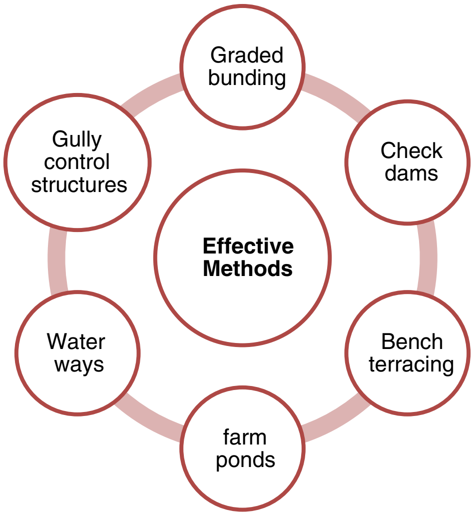

FIGURE 4.2 The effective methods for water conservation with watershed management.

- In assessing the attributes of rainfall.
- Soil mapping and land categorization for agriculture, forestry, grazing, horticulture, and other purposes based on capability classification.
- A list of current farm sizes and land uses is being created.
- Crop production patterns and potential, current and potential markets, and potential collective action arrangements are all being assessed.
- Conducting topographical and hydrological surveys for engineering projects.
- A geo-hydrological survey to identify potential groundwater development regions.
- Development of a time-bound integrated strategy for soil and water conservation; aquifer recharge; lucrative afforestation; agricultural growth; grasslands; and horticulture.
- Objectives for project implementation are determined.
- Considering the societal costs and gains.

The central and state governments have developed several watershed development and management programs around the nation. Some of these are also being put into practice by non-governmental groups. Haryali is a central government-sponsored watershed improvement project that aims to help people in rural areas save water for drinking, irrigation, fishing, and afforestation. They are carrying out the project with the help of the general public. The Neeru–Meeru initiative in Andhra Pradesh and Arvary Pani Sansad in Alwar, Rajasthan, have both developed various water-harvesting structures through public involvement, including percolation tanks, dig-out ponds (Johad), and check dams. Water harvesting structures in households are now permitted in the state of Tamil Nadu. There can't be any construction without buildings for water harvesting. The general public has to be made more aware of the advantages of watershed development and management throughout the nation.

B. Rainwater harvesting

Rainwater harvesting is a technology that collects, transmits, purifies, and stores runoff water from rooftops, parks, roadways, open spaces, etc. Additionally, it is used to resupply groundwater into aquifers. It is a cost-effective and environmentally friendly way of water conservation to send rainfall to reservoirs, pits, and bore wells. Rainwater collecting increases the amount of water that is available, stabilizes groundwater levels, improves groundwater quality by lowering nitrate and fluoride levels, lessens soil erosion, prevents flooding, and, if used to refill aquifers, prevents saltwater intrusion in coastal areas. Traditionally, surface storage structures like lakes, ponds, irrigation tanks, etc., are used in rural regions to collect rainwater. In Rajasthan, kunds—structures for harvesting rainwater are built next to or inside the home or village to keep the collected water. By collecting rainwater, a community may utilize less groundwater for household purposes. In various states around the nation, rainwater collection is currently being implemented on a large scale. Rainwater collection is very useful in urban areas when there is a water shortage due to population growth and other factors.

4.6 Different methods for collecting rainwater

- Catchment: To be utilized to collect and store rainwater.
- Conveyance system: Once the water has been harvested, this transports the water from the catchment to the recharge zone.
- First Flush: This method is used to drain out the first rain.
- Filter: A mechanism that rinses rainwater after it has been collected.
- The filtered water that is ready for use is kept in tanks and recharge structures.

Factors responsible for the harvesting and amount of rainwater: The amount of the runoff; the catchments' characteristics; ecological consequences; the technology's access; the capacity of the tanks for storing; types, slopes, and materials of roofs; and the regularity, volume, and quality of the rainfall.

Methods of rainwater harvesting

1. Rooftop rainwater harvesting: Rainwater from buildings and homes is collected on the rooftop, which serves as a catchment. First, a flush is one of the parts of the rooftop rainwater collection system.
2. Surface runoff harvesting: The system is what gathers rainwater, which eventually drains the region as runoff water. By using the appropriate procedures, rainwater runoff is collected and utilized to recharge aquifers.

Modifications to the construction regulations enacted by the Ministry of Urban Development and Poverty Alleviation make it mandatory for all building developments on plots of 100 sq m and beyond to employ harvesting of rainwater. The Jal Shakti Abhiyan Catch the Rain campaign for the year 2021 was launched by the Hon'ble Prime Minister of India on March 22, 2021. Catch the Rain-2022 was launched by the Hon'ble President of India on March 29, 2022, and shall continue till November 30, 2022.

C. Reuse and recycle of water

Reuse and recycling are two more ways that may increase the supply of fresh water. The water left over from bathing and washing dishes can also be utilized for gardening in urban settings. You may water your garden with the same water you use to wash your car. This would save water of higher quality for drinking. Water recycling is currently being done on a small basis. However, there is a lot of potentials for recycling to replenish water.

4.6.1 Emerging solutions to reuse water

Several places are out of possibilities and are recognizing that top-notch urban water reuse is significantly less expensive than the other solutions (Newcombe, 2009). An alternative source of water is provided by treated wastewater, particularly in areas where there is a shortage of water. Wastewater that has been properly treated for use in agriculture, industry, and potable supply can replenish water resources and overcome the availability gap. For example, treated wastewater supplies 20% of the total amount of water used in Gran Canaria, where it is used to irrigate 5000 ha of tomato and 2500 ha of banana plantations (MED-EUWI, 2007). Reverse osmosis and microfiltration are the two main technologies often used for the potable reuse of wastewater (Drewes et al., 2003).

D. Drip irrigation

By allowing water to gently flow to plant roots from above the soil surface or from below the surface, drip irrigation is a type of micro-irrigation system that may help to preserve water and nutrients. To minimize evaporation, water should be sprayed directly into the root zone. In drip irrigation systems, water is provided by a number of transmitters, pipes, and valves. Depending on how well it is planned, built, maintained, and managed, a drip irrigation system may be more efficient than other irrigation systems, such as surface irrigation or sprinkler irrigation.

Each dripper emits drips carrying water and fertilizer, delivering the nutrients evenly to the root zones of every plant over the whole field. The drip irrigation system employs a network of mainlines, sub-mains, and lateral lines with emission points positioned along their lengths to supply water to the crop. Each dripper/emitter valve emits a consistent, measured flow of water and nutrients into the root zone of the plant.

E. Aquifer storage and recovery (ASR)

The technique involves injecting surface water sources, including freshwater resources and water reclamation, into an aquifer for future recovery and consumption. Wells are widely used for the insertion and recovery of wells. ASR may be able to help keep rainwater confined in regions where it cannot permeate the soil quickly (i.e., urban regions). In these areas, rainwater is redirected to rivers. Municipal, commercial, and agricultural applications all involve ASR. ASR is used for public, trade, and farming purposes.

F. Desalination

Desalination is a technique for demineralizing seawater. It is the process of taking salts and minerals out of a substance, like soil, that are unfavorable for cultivation. To provide water suitable for irrigation or household activities, saltwater is desalinated. Brine is a byproduct of this process. Filtration is a standard procedure in submarines and ships used for commercial purposes.

The Institute for Water, Environment, and Health (UNU-INWE) of the United Nations University did research in 2019 that found that there are around 16,000 desalination units in 177 different countries that generate about 95 million m^3 of fresh water every day. Australia is an extremely dry nation that suffered greatly from the severe drought from 1997 to 2009. Australia was the first nation to adopt the approach to growing plants.

G. Cover crops

Crop cover is essential for maintaining the equilibrium of the ecosystem since it prevents soil from eroding, increases soil water availability, controls weed growth, manages soil nutrients, etc. Every crop cover responds differently and has a unique sensitivity to weed control and water drainage (Meyer et al., 2019; Schappert et al., 2019). The cover crop improved plant available water by 21–22% while increasing soil water retention at field capacity-related moisture potency by 10–11% (Andrea et al., 2016).

4.7 Conclusion

The impact of weather variability is expected to increase in different regions of the country. The variation in rainfall patterns and the increase in temperature affect rural water resources. The declining groundwater table and aquifer systems have an impact on rural livelihoods. India's economy mainly depends upon the monsoon for agriculture, and various research analyses the decreasing trend in the monsoon as it affects the production of crops. The projected challenges of a rapidly changing climate cannot be addressed by the present data collection techniques, including analysis, observation, transmission, dissemination, and storage. To conserve and sustainably manage water resources to fulfil the demand of the rural population, it is crucial to adapt to new technologies and policies.

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Chapter 5

Traditional methods of water purification in rural areas

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5.1 Introduction

Water is one of the most critical parameters for the growth and sustenance of life. The world's economic growth and development are inextricably associated with access to clean water. Every individual has the basic right to safe and sufficient potable water for personal and domestic uses. However, with the ever-increasing population and pollution of the existing natural resources, there exist the most critical problem, i.e., inadequate access to clean water (Shannon et al., 2008)

Fortunately, brisk advances in water science and technology over the past century have led to the invention and application of a plethora of water-purifying methods. These include membrane filtration, advanced oxidation processes, and biological treatment methods (Ahuja, 2018; Lin & Valsaraj, 2005). These methods offered a hope to enhance the quality of water around the world and increase the life span of humans.

Nevertheless, alarming global statistics highlight the scarcity of access to safe potable water. Nearly 2 billion people lack access to safely managed potable water services, wherein 0.8 billion people do not have access to even basic services, such as accessibility to clean and safe water sources within 30 min. Also, 80% of the population resides in rural areas. The annual death rates and diseases associated with the lack of access to safe drinking water are alarming (Montgomery & Elimelech, 2007). Especially developing countries and rural areas in developed countries are the most affected because of poor sanitation and water-handling practices. Additionally, the effect of climate change is also likely to increase the threat to water quality in these regions. Various safe potable water regulations are proposed both at the national and state or province level worldwide with an aim to meet the water quality standards in rural areas. But numerous technical, social, and political complications hinder the implementation of water purification technology in these remote areas (Kot et al., 2011). Consequently, rural residents continue to rely on open-source water bodies for personal and domestic purposes. It has been reported that around 120 million people rely on surface water bodies such as rivers, lakes, or shallow wells as their primary source of water for personal and domestic purposes (Pichel et al., 2019). However, the quality of water from open sources is often compromised due to the considerable load of dissolved and particulate matter from natural and anthropogenic sources. Wherein some contaminants can be easily recognized by evaluating them based on smell, color, taste, and turbidity, while other contaminants are odorless and invisible. Thus, consumption of water from these contaminated water sources increases the susceptibility of the population to water-borne illnesses like cholera (*Vibrio cholera*), enteric diseases, typhoid fever (*Salmonella typhi),* and protozoan infections (*Ascaris lumbricoides)* (Pichel et al., 2019; Sharma & Bhattacharya, 2017). Therefore, surface water requires purification treatments to make it safe for human consumption. Wherein the extent of treatment required would depend on the impurities present. The conceptual idea of water purification for human health has been documented in history, approximately around 500 BCE (Elder, 1949). Traditionally, various purification methods have been established and reported to be adopted by the rural community that essentially eliminates visible contaminants, such as plant debris and soil fractions. To meet daily water requirements, rural communities continue to rely on these traditional methods to date. Some of the traditional purification methods that have been used for ages are sedimentation, filtering, chlorination, and boiling, as shown in Fig. 5.1 (Chu et al., 2019; Megersa et al., 2014; Yongabi, 2010). Apart from these traditional methods, additional low-cost techniques, such as improved filtration methods and chemical disinfection, were also developed over time to remove chemical and invisible contaminants

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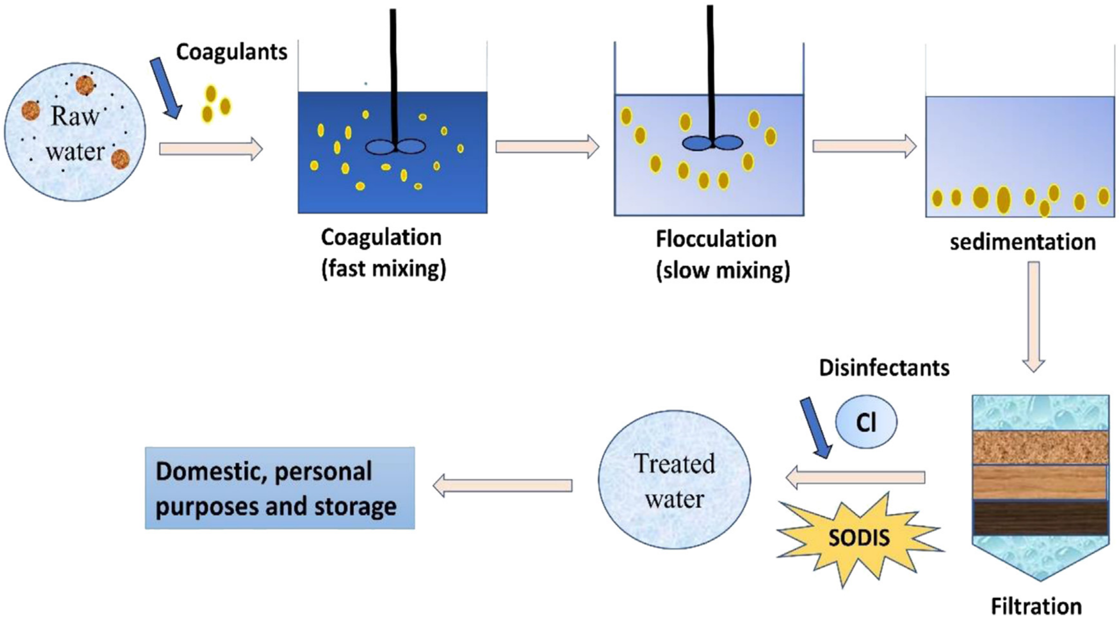

FIGURE 5.1 Water treatment flowchart in rural areas.

(Chu et al., 2019). These techniques have emerged as an approach that empowers and allows people to meet their daily needs and enhance their living standards. WHO now supports household and small-scale community-level treatment methods as effective means for achieving the reduction of waterborne diseases (WHO, 2007). Various treatment processes employed in the rural community have been discussed in detail in the current chapter. As advanced water purification methods are difficult to implement in rural areas due to operation costs, it is important to disseminate the traditionally established methods in such locations. This enables decision-makers and water authorities to design more reliable policies to achieve safe, clean water for rural communities. This chapter thereby provides a holistic review of the history of water purification and traditional water purification methods being used in rural areas. Furthermore, the chapter also reviews the various research carried out evaluating the efficiency of the methods and problems associated with it.

5.2 History of water purification

In the history of human civilizations, it has been noticed and acknowledged that the key factor ascribed to the emergence or fall of human civilizations depended on how effectively water was managed in the culture. Ancient societies recognized the underlined role of water in human endurance (Smith, 2017). Inhabitants relied on wells, rivers, lakes, and streams as their sources of water for domestic and personal purposes (Ishaku et al., 2011). However, these sources were also occasionally employed as sewage and wastewater disposal sinks. Subsequently, resulting in the decline of water quality, rendering it unfit for human consumption and leading to the outbreak of diseases (Vuorinen et al., 2007). Nevertheless, public health and environmental concerns prompted the development of water treatments.

As reflected in the literature, history concentrates on parts of Africa, the Middle East, Southern Europe, America, and Asia to India (Danil De Namor, 2007). Historically, due to a lack of knowledge on invisible, tasteless, and odorless contaminants, the quality of water was mostly evaluated based on visual inspection. Therefore, water that lacked visible impurities was considered safe water for consumption. This thus explains why the traditional water purification methods documented in history focused primarily on improving the appearance of the water (Mala-Jetmarova et al., 2015). Awareness of water quality and an attempt to improve the drinking water quality started prior to 500 BCE, and the earliest reports of information on water treatment were sourced from Indian Sanskrit books—Susruta Samhita, Ayurveda, (c.2000 BCE) and Egyptian engravings. Indian manuscripts guide people to store water in copper and earthen vessels, filtering turbid water through charcoal, sand, and gravel, exposing it to sunlight, and boiling it. Furthermore, ayurvedic books provide additional information on the use of natural herbs like amla and khus, natural seeds, particularly "*Strychnos potatorum*" (cleaning nut tree), different types of stone—"*Gomedaka,*" quartz and pear for water purification. Egyptians are recorded to be the early users of coagulants such as aluminum and iron sulfate to remove suspended particles (Elder, 1949).

However, the first water supplies with treated water to large-scale areas were evidenced during the initial stages of the Bronze Age under the Minoan civilization (c.3300–1100 BCE). The striking feature of the Minoan civilization was the use of earthen infiltration devices that were loaded with charcoal and sand to remove impurities. The period prior to 500 BCE–1000 AD. can be marked as the period of water transportation with underground tunnels, branching clay pipes from springs, cisterns, and precipitating water to storage in reservoirs, which also implies the technical standards of the period (Mala-Jetmarova et al., 2015; Sklivaniotis & Angelakis, 2006). This evidence also concurs well with the article written by Greek physician Hippocrates, the "father of medicine" (c.460–350 BCE), on the importance of water quality. He suggested the use of a cloth bag for straining water from closed systems, which was later popularly referred to as the "Hippocrates sleeve" (Elder, 1949). Romans (around the 2nd century AD) are known for their massive aqueduct system for uncontaminated potable water. Subsequently, during the 8th century AD distillation process was proposed by an Arab alchemist Jabir ibn Hayyan (Baker & Taras, 1949). It was only at the beginning of the 17th-century breakthroughs in water treatments started to progress. The advances then could be attributed to the invention of the microscope, which enabled scientists to visualize microscopic organisms in the water. Other simultaneous developments in the 18th and 19th included improvements in filtration technology that could eliminate these microorganisms (Elder, 1949; Mays, 2013; Sklivaniotis & Angelakis, 2006; Vuorinen et al., 2007). However, with the industrial revolution and the associated extensive exploitation of natural resources, the chemical contamination of these resources raised concerns in the environmental community. A range of chemicals, including hydrocarbon halogenated aliphatic and aromatic compounds, and heavy metals, were found to be present in natural water. Thus, to address these pollutants, termed emerging pollutants, the 20th-century documents the use of chemicals for disinfection, desalination technology, nanofiltration membranes, and advanced oxidation processes.

5.3 Methods of water purification in rural areas

Rural communities worldwide adopted simple and affordable water purification methods to meet their daily water requirements. Traditional water purifying methods primarily concentrated on two aspects (1) Disinfection and (2) Particulate matter removal (visible suspended to floating solid particles and small colloids). Disinfection is the process of eliminating pathogenic organisms like bacteria, viruses, and parasites. The process is carried out using physiochemical methods such as chlorination, chemical and phytocoagulation, solar disinfection, and boiling. At the same time, the removal of particulate matter is accomplished by sedimentation and filtration. Although these techniques offer adequate water quality that is physically acceptable, it should be emphasized that the quality of water obtained falls short of the current regulatory standards. The following sections provide an overview of the purifying techniques adopted in rural areas.

TABLE 5.1 Settling time required by various particle size matter in 1 m of water.

Particle type	Diameter of the particle	Particle settling time in 1 m of water	
Gravel	10 mm	1 sec	Settleable solids
Sand	1 mm	10 sec	
Fine sand	100 μm	2 min	Turbidity
Silt, dust, protozoa, algae	10 μm	2 h	
Clay	1 μm	8 d	Colloidal solids
Virus, colloids	0.1 μm	2 y	

From: Peterson (2001).

5.3.1 Physical and mechanical methods

5.3.1.1 Sedimentation

Sedimentation is a simple physical pre-treatment process prior to the application of other purification methods. Sedimentation plays an important role in the removal of undesired biological contaminants and suspended particle matter (sand, silt, and clay) from water under the influence of gravity. Traditionally, the process involved filling the containers with water, leaving them undisturbed for a longer period of time to allow the sediments to settle under the influence of gravity, and then decanting the water to remove the sediments (Mays, 2013). At the household level, this procedure is suitable and easy to operate. However, for community water supply, sedimentation tanks were developed to improve purification capabilities while minimizing the space required for installation. These tanks are run in continuous mode to meet the daily requirements of the community (Ochowiak et al., 2017). Table 5.1. Provides details on the settling time required by the particles based on their diameter.

5.3.1.2 Filtration

Filtration is a typical mechanical or physical method used in a traditional water treatment process following sedimentation. It has been reported that the first-ever experiments on water filtration were conducted by Sir Francis Bacon in 1627, wherein he believed and thus tried to produce drinking water from salt water. However, his experiments failed at that point in time which thereby led to additional research on filtration by other scientists (Mays, 2013). Thus, it was the study conducted by Sir Francis Bacon that initiated a

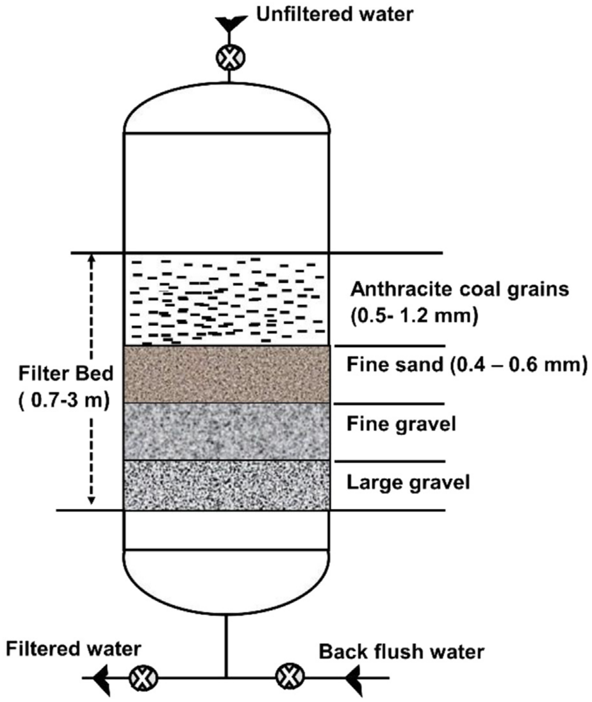

FIGURE 5.2 Schematic illustration of multi layered traditional filtration method.

new interest in filtration technology. Traditionally, filtration was done by passing raw water through the porous media to remove any particulate matter or suspended colloids from fluids. A few common methods used by rural communities worldwide are winnowing (Mali), filtration using cloth, plant materials (India), clay vessels (Egypt), and ceramic filters (Bangladesh) (Vigneswaran & Sundaravadivel, 2011). Over the decades, people in rural areas developed a traditional vertical filtering system that is layered with locally available different pore-size materials. The system typically includes layers of sand, gravel, charcoal, zeolite, and activated sand (Shafiquzzaman et al., 2011). Briefly, the method involves pumping water from open water sources into the vertical filtering system and allowing water to percolate under the influence of gravity through the materials. Subsequently, filtered water can be collected at the dripping end of the filtering system, as shown in Fig. 5.2. Manual scrubbing is recommended for filters, such as ceramic filters, in order to remove adsorbed impurities that block the pores of the filter (Nandiyanto et al., 2019). Various point-of-use filtration techniques, such as biosand filtration, are used worldwide as a cheap, low-maintenance, and user-friendly solution in rural area for water treatment.

5.3.1.3 Biosand filtration

5.3.1.3.1 Biosand filtration

The biosand filtration (BSF) technique is a common and promising technique used in a rural area. Wherein the filter is built employing locally available raw materials, thus making the entire assembly and the technique cost effective. The basic concept of BSF relies on the conventional slow bed sand filter. However, in BSF, the point of use lies above the layer of sand. This thus saturates the entire sand bed in the filter with water throughout the operation. Thereby facilitating the microbial proliferation around the sand particle and the filter media. Excessive biofilm growth across the filter layer forms the Schmutzdecke, which removes larger microorganisms, colloids, and contaminants from the water sources (Stauber et al., 2006). Studies revealed that BSF sizing is one of the crucial parameters in order to achieve the desired water volume. Also, the flow rate determines the effectiveness of the filter in removing the microorganisms (Pooi & Ng, 2018).

5.3.1.4 Solar disinfection (SODIS) and boiling

Boiling and exposing water to sunlight hold the oldest records of water purification dating back to 2000 BCE in the Indian manuscript (Elder, 1949). However, only after the invention of the microscope in the 17th century, the scientific basis for this method was established. Solar disinfection (SODIS) and boiling are considered simple and low-cost methods of water purification at the household level. These methods are proven to provide effective disinfection against pathogenic organisms (Rainey & Harding, 2005; UN-Water, 2013). To ensure complete disinfection, water must be boiled at >65° C at sea level and stored in closed water containers. However, this method is not always convenient, particularly if the fuel supplies are limited, expensive, and labor-intensive. (Imtiyaz et al., 2021). Nevertheless, SODIS treatment processes are known to be feasible as the method is relatively inexpensive (McGuigan et al., 2012). The SODIS method exploits the capacity of both ultraviolet (UV) radiation and temperature to inactivate water-borne pathogens. Inactivation processes depend primarily on atmospheric solar conditions, wherein the visible wavelength of 320–450 nm and UV-A radiations are effective against bacteria and viruses (McGuigan et al., 1999). In the SODIS treatment method, plastic water containers [polyethylene terephthalate (PET)] or a series of transparent tubes filled with water are exposed to direct sunlight for 6–8 h. Prolonged exposure is needed on cloudy days to ensure complete thermal inactivation (Smieja, 2011). To accelerate the thermal pasteurizing effect, rooftops can be painted with black paint. Subsequently, water containers are placed at a certain angle to maximize the surface area of UV absorption (Haider, 2006; Kuo, 2017).

5.3.2 Chemical methods

Large-scale disinfection of water in rural is mainly carried by chlorination, ultraviolet light, and ozone. Shinde et al. (2021), in a recent quantitative review, include a database

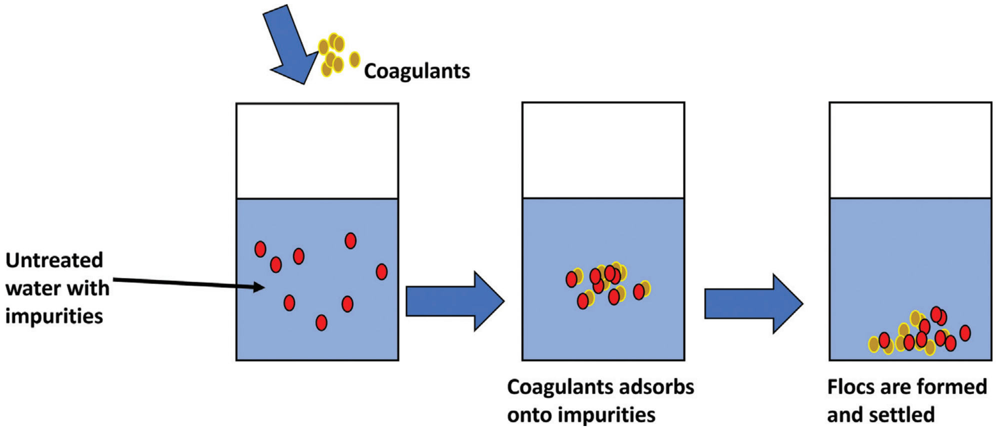

FIGURE 5.3 Schematic illustration of coagulation process in a reaction container.

for various treatments being used in rural areas. The review suggested that chlorination is the most popular and widely used disinfection technique and coagulation to fasten physical processes.

5.3.2.1 Chlorination

With the outbreak of cholera (*Vibrio cholera*) in the 18th century, a water engineer named John Snow used chlorine to disinfect water for the first time in 1850. The use of chlorine in the water supplies showed a drastic reduction in the fatality rate across the community. At present, large-scale disinfection of water in rural areas is achieved by chlorination. At the domestic level, chlorine is added at a dosage of 0.2–2.0 mg/L of free chlorine, which would leave 0.02–0.3 mg/L of residual chlorine in drinking water (Mazhar et al., 2020; Nielsen et al., 2022). On a larger community scale, chlorine is added to water tanks and wells as hypochlorous acid (HClO) or calcium hypochlorite granules, or sodium hypochlorite solution (Brandt et al., 2017). The treatment works on the principle that when chlorine is introduced to water, the element dissolves and creates free radicals. These radicals destroy pathogenic organisms by severing molecular chemical connections or by damaging their cells. Commercial solution of chlorine is available at low costs in many parts of the world. However, the use of chlorine solutions as a chemical disinfectant is ineffective if not used at a correct dosage (threshold of 0.6–1.0 mg/L) (Das, 2002). Basic user training is recommended to improve the efficiency of the chlorine disinfection process.

5.3.2.1.2 Coagulation

Coagulation is a chemical water treatment process wherein the electrostatic charges on the pollutants in the water are exploited for their subsequent removal. The process involves adding positively charged chemical coagulants (alum, ferric sulfate, ferric chloride, or polymers) or plant-based coagulants to the raw water. The addition of charged particles neutralizes the charge and thus further reduces forces that stabilize the dissolved and suspended particles by double-layer compression. Consequently, double-layer compression leads to aggregation/coagulation of suspended particles which settle down due to gravity, as shown in Fig. 5.3 (Bhatia et al., 2007; Van Benschoten et al., 1990).

5.3.2.2 Chemical coagulation

Aluminum and Iron based coagulants (such as alum, ferric sulfate, and ferric chloride) are used worldwide for treating raw water from a different source. Alum is the most extensively used chemical coagulant in large-scale water treatment plants, industrial plants, and household purposes (Van Benschoten et al., 1990). However, its efficiency depends on the optimum dosages and physical and chemical properties of raw water. Jaeel (2017) conducted a study on the optimum dosage of alum and effective pH conditions for turbidity removal. According to the study, as raw water is taken from different sources, a jar test should be carried out specifically when the turbidity of water fluctuates. Jar test can be performed by using various doses of coagulants ranging from 10 mg/L to 40 mg/L followed by rapid agitation of the container to enhance collision of particles and subsequently allow them to settle for 45 min. The process would thus enable us to determine of the exact dosage of the coagulant required in order to achieve optimum removal efficiency.

5.3.2.3 Bio-coagulants or phyto-disinfectants

The use of chemical disinfectants and filtration systems for treatment is often beyond the financial capacity of a few rural communities. Additionally, due to limited access to remote areas, the supply of chemicals and materials needed for water treatment is unpredictable. Therefore, rural communities, especially in Africa and Asia, adopted plant-based coagulants to accelerate the clarification process (Madsen et al., 1987; Mbogo, 2008). Megersa et al. (2014) extensively reviewed natural soil and plant-based coagulants and flocculants used by rural communities worldwide. The study revealed that *Moringa oleifera, Azadirachta indica,* roots of *Anaphalis cuneifolia*, and *Eclipta alba* are potential coagulants for efficient water treatment. The process of using phyto-coagulant involves extraction of seeds from the fruit, followed by drying them for complete removal of the moisture. The dried seed material is subsequently ground into a fine powder. Depending on the volume of water and type of seed material used, a mixture of water and ground seed powder can be prepared (Olsen, 1987). In a study conducted by Madsen et al. (1987), 0.3–0.5 g of ground seed powder of *M. oleifera* was employed to filter 100 cm^3 volume of river water. The suspension was continuously stirred for 10–15 min; thereafter, the suspension was allowed to sediment under gravity and then decanted. In the highlands of Ethiopia, women in rural communities use bentonite clay, locally called "Rauwaq" together with other plant materials as a flocculating agent for water purification. This practice is shown to accelerate the sedimentation process by destabilizing fine particles and enhancing particle aggregation (Olsen, 1987).

5.4 Problems associated with traditional purification techniques

As outlined earlier, rural communities around the world adopted low-cost technologies for water purification at the household and community scales to meet their daily water requirements. It is evidenced that these methods are capable of improving water quality and reducing the risk of waterborne diseases. However, the successful implementation of these traditional methods demands technical efficiency. Also, many of the traditional techniques cannot achieve the required, acceptable limits for potable water. The choice of a water purification method depends primarily on the end use and the extent of pollution to the water. Also, the choice of water purification method varies with the source of the raw water as the extent of pollution would depend upon a range of different anthropogenic activities (Karim et al., 2020). Coagulation and flocculation are the most commonly used methods in water purification. Chemical coagulants, including aluminum sulfate, poly-aluminum-chloride, or synthetics polyacrylamide derivates, are economically intensive and are proven to have side effects on human health and the environment (Van Benschoten et al., 1990). Continuous consumption of water treated with chemical coagulants may result in carcinogenic, neurological, and cognitive issues in humans (Van Benschoten et al., 1990). Thus, the dosing of these chemicals into the water for the treatment should be undertaken under the close supervision of an expert. This could sometimes be challenging in the rural setup due to the lack of expert labor. Additionally, the unregulated disposal of waste may result in environmental pollution due to its low degradability. Considering the cost and availability of local materials, rural communities adopted the use of natural phyto-coagulants for purifying water. These plant materials are environmentally safe, bio-degradable, and enhance the water quality by disinfection (Madsen et al., 1987). However, for both chemical and phyto-coagulants, the efficiency in the removal of particles is influenced by an array of factors, such as the pH of the raw water, the extent of pollution, and the type of coagulant and flocculant being used for the purification (Igwegbe et al., 2021). The pH and temperature affect the solubility of coagulants inside the water, thereby negatively affecting the goal (Rosińska & Dąbrowska, 2021). Pritchard et al. (2010) conducted an experiment to study the parameters affecting the effectiveness of *M. Oleifera* as a coagulant. The study revealed a pH below 5.5 reduced the removal efficiency by 55%, which further dropped at pH 4. A range of temperatures (4–60°C) and the shelf life of seeds were investigated in the study by Pritchard et al. (2010). Water temperature at <15°C and seeds aged >18 months were shown to significantly hamper the effectiveness and efficiency of the coagulation process. In the water treatment process, if the initial coagulation stage is not complete, the consecutive phases, which are flocculation and sedimentation, would be negatively impacted. Therefore, care must be taken to provide optimum conditions for the coagulation process to harness its efficiency. However, the sedimentation process is effective only for undesirable particulate suspended matter (sand, silt, and clay) and other biological contaminants that are only under the influence of gravity. In the traditional filtration system, contaminants such as viruses and bacteria that are smaller than the pore sizes of materials used in the filter would pass through and contaminate the filtered water. Furthermore, repeated loading of filters with water that contains dissolved particles results in frequent clogging of the pores, which requires substantial maintenance to maintain the filter capacity. However, none of these physicochemical treatment processes are capable of inactivating pathogens and microorganisms in the water.

Chlorination, boiling, and SODIS are the most common and least expensive methods of disinfection processes against pathogenic organisms. Although boiling is an easy household process known to kill disease-causing organisms, rural communities rely on firewood for boiling, which is not economical and also results in deforestation and environmental pollution (Imtiyaz et al., 2021). SODIS method efficiency depends on UV light intensity, physical conditions of the bottles, and cloud cover (McGuigan et al., 2012). Long-term use of the same plastic container may result in leaching chemicals of bottle materials like adipates and phthalates into the water during exposure, as mentioned by the Swiss Federal Laboratories for Materials Testing and Research. Chlorination is an actively used technique in rural areas; Backer (2002) found that certain pathogens like *Cryptosporidium,* cysts, and parasites of protozoa were resistant to chlorination even at high concentrations (Backer, 2002). Furthermore, organic matter present in raw water acts as a precursor for the generation of chlorine byproducts (CBPs). This includes trihalomethane, trichloroethylene, halo acetic acids (HAA), with smaller amounts of halo aldehydes, halo acetonitriles (HANs), and halo-ketones that are toxic to human health and environment (Das, 2002). Additionally, the rate at which CBPs are generated is dependent on pH (neutral or slightly alkaline) and concentration of aqueous chlorine (Backer, 2002; Gallard & von Gunten, 2002; Ge et al., 2006). Botlagunta et al. and Mathi (2015) further reviewed immunological and biochemical perspectives of CBPs, their genotoxicity, and their carcinogenicity on human health.

5.5 Conclusion

Over the years, with the advent of technology, various water treatment techniques have been developed and implemented successfully at a large scale across the globe. However, many of the techniques developed are cost-intensive and also demand skilled labor. Thus, the application of these techniques in the rural setup has been challenging due to the lack of infrastructure. Many of the rural areas thus typically rely on traditional water purification practices, such as coagulation, sedimentation, boiling, and SODIS to meet their basic need for potable water. The traditional methods have been found to be capable of the removal of the majority of suspended particles and, to a limited extent pathogenic biological contaminants. However, the alarming rate of occurrence of emerging pollutants in natural water sources demands the implementation of improved and advanced water treatment processes in the remotest locations across the globe, as water is the primary and most basic need of a community.

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Chapter 6

Traditional techniques of water purification in rural areas

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6.1 Introduction

One of the things necessary for human survival is water because of its multi-functional purposes like domestic and industrial usage. Statistically, research has it that there are about 1400 million cubic kilometers of water in the world and about 97% of the total volume is sea water while the remaining is groundwater. Some of these waters can be found in lakes, rivers, and swamps. A major percentage of freshwater is highly polluted. Water purification can be said to be the generalized name for all processes that are used in making the water suitable for essential needs like drinking, medical purposes, industrial use, and all other functions of water. Water purification is structured to lower contaminants in the water to a healthy and desirable state (Adeleye et al., 2016). Waterborne diseases are contracted through contaminated water and are caused by viruses, bacteria, and other microscopic organisms. Waterborne diseases like typhoid, cholera, dysentery, and hepatitis A affect millions of people daily, especially the ones living without safe water in rural areas (Jayalakshmi et al., 2017). Diarrheal tops the chart on child mortality compared to measles and malaria. Economic losses and high mortality rates are also gotten by epidemic water diseases. Due to dispersed settlements in rural areas, sources of drinking water are mostly devolved in form of dug wells, tube wells, or hand pumps. Globally, the population of people without access to clean drinking water in the year 2012 was estimated to be 700 million although it has been recorded that common diarrheal illnesses could be lowered by about 30% with the household treatment of water. The method of treating water differs according to various communities and is also dependent on the quality of the source water quality. The water that gets into treatment plants is usually groundwater (found below the surface of the earth in between the soil and the rock) or surface water (e.g., rivers, lakes, streams, and oceans). More treatment is required for treating surface water as they contain higher sediment, toxins, and chemicals than groundwater. Insufficient water services coupled with sanitation in the rural parts are among the main problems facing developing countries (Marobhe & Renman, 2013). The supply of water is an important inevitable natural resource for environmental health due to its direct link to human health and community development. The treatment of water is a vital factor in the determination of the ecological veracity of water bodies and systems in rural areas (An & Park, 2017). This is because the influence of water on the major aspects of life is quite dominant. Rural areas duly signify the main focus as regards the foundation of existence adequate for definite land settlements for a period of time. Several wastewater treatment methods do not efficiently remove contaminants to meet standard water quality (Adeleye et al., 2016). Water supplies are affected when surface water is contaminated because the pollutants can travel to drinking water sources. These problems bring to clarify the importance of alternative water treatments to support existing ones. In developing countries, many people are still living in small towns and villages. These people have a scarcity of community supplies of water. Hence, they obtain their supplies from resources that are unprotected and overly polluted thereby causing the treatment of water in these rural areas an object of concern. The traditional method used in the decontamination of water is done by the use of chemical agents such as chlorine and similar chemical composites as regards their simplicity and effectiveness (Liu et al., 2014). Across the globe, rural communities adopt

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simple forms of water treatment that target filtration and removal of visible impurities from water sourced locally. In as much as these methods remove pollutants and a percentage of dirty particles in water, they are still limitations that make them insufficient to be termed a modern-day type of water. For survival, the old formats at which water is decontaminated for the purpose of serving either a small household or community are adopted in rural areas to suit their situations irrespective of their low level of mechanization. Some traditional methods of treatment include filtration, sedimentation, disinfection, and coagulation. Asides from regular treatment methods like the aforementioned, research carried out by (Marobhe & Renman, 2013) recorded that in the majority of households, coagulation, and flocculation method was used to remove dissolved and suspended matter instantly. Some of the seeds used for the purification of water includes field bean, bambara nuts, groundnuts, and cowpeas. The seeds are granulated and kept in plastic bags for daily use for a duration of about 2 months. Other seeds used for coagulation are moringa, mustard, and nirmali seeds (Jayalakshmi et al., 2017). In order to introduce new and modern methods of water purification and treatment to these rural settlements, special features of these traditional methods are worth analyzing before other solutions based on innovations are proposed to them. This article discusses in detail traditional methods generally used in rustic parts of developing countries. It will also provide data to be used in the communities by researchers working to improve drinking water for rural areas.

6.2 Water is essential for human life

Water is fundamental for human existence and the improvement of social order. Insufficient admittance to it adversely affects well being, which influences adversely on efficiency and human government assistance. In any case, these days 2.1 billion individuals need admittance to safe drinking water at home; fundamentally in the provincial areas of emerging nations. Significant exertion has been made to further develop water access, however, there is still space for development. The financial qualities of nations could influence the improvement of water access (Gomez et al., 2019). In rural networks all over the planet, the absence of clean water and disinfection are significant supporters of avoidable demise and sickness. The absence of clean water expands weakness to conditions including loose bowels, ailing health, jungle fever, lymphatic filariasis, digestive nematode diseases, trachoma, and schistosomiasis (Hove et al., 2019). According to World Health Organization (WHO) and United Nations International Children's Emergency Fund's (UNICEF) Joint Monitoring Program (JMP), roughly 844 million individuals overall needed admittance to safe water in 2015. A greater part of them were people who lived in the provincial locales of non-industrial nations. A survey attempted to determine the relative significance of a few rural area quality indicators for recreational uses in which 'water purity' is considered one of the quality indicators**.** In rural areas, 77.9% of households have drinking water facilities either within or near their premises whereas in urban areas 91.9% of households have such facilities. A case study from some rural habitation in Rajasthan, India showed that the drinking water of this district contains different kinds of enteropathogenic microscopic organisms like *Escherichia coli, Enterobacter aerogenes, Klebsiella,* and so on. The microbial burden in drinking water as estimated through standard plate count (SPC) fluctuated extraordinarily from 8.3×10^4 to 28.3×10^4 among various areas of the site considered. The information obviously proposed that individuals in this district are in serious danger of water-related illnesses and well-being issues. The ceaseless utilization of such dirtied water could present serious well-being gambles, particularly in babies reported about Hiware Bazar village, in Maharashtra which is also a success (Bhattacharyya et al., 2018). Story of a very poor village transforming into one of the richest villages in India by adopting water conservation in 40,000 contour trenches around hills and redesigning cropping patterns to have more cash crops by the efforts of the Sarpanch Popatrao Pawar. A review from the Department of Protection of Citizens' Rights of Colombia shows that 5.4 of 13.6 million who live in country regions do not approach water supply frameworks, 8.2 million do not have sterile units or sewage, and simply 1.5 million approaches consumable water. In Colombia, the absence of these administrations produces medical issues, for example, being a delegated reason for baby mortality, and grimness. Somewhere in the range of 2004 and 2006, 20,000 youngsters passed on as a result of illnesses brought about by unfortunate water quality. Flórez et al. (2018) a part of the populace has some unacceptable discernment about the overflow of the hydro asset, specifically, those in country regions that have vicinity to the paramos, in light of the fact that they give around 70% of the water of the large urban communities. Techniques for drinking water well being the board that addresses gambles connected with environment fluctuation and change are expected to convey securely oversaw water administrations in the country region of the creating scene. Environmental change compromises drinking water security in country regions in complex ways. In applying transformation, weakness, and versatility examinations one next to the other for a situation concentrated on Vanuatu, we have exhibited the commitments that various methodologies can make to problematizing environment fluctuation and change for provincial drinking water security in emerging nations. The variation approach raises the significance of perceiving water quality dangers established by present and future environmental risks. The weakness approach focuses on how social cycles cause environmental effects making more water security issues for some than others. The versatility approach features the benefit of empowering individuals to have adaptability by the way they access safe water under unusual environmental conditions, and the need to support water assets. These reciprocal methodologies can and ought to be utilized together while considering drinking water well-being on the board under environmental change (Kohlitz et al., 2020). Water redistribution from country to metropolitan regions will remain a key strategy reaction to the patterns of expanding urbanization, changing water supply unwavering quality under environmental change, and developing populaces. Water redistribution projects are frequently costly, tedious, and can have huge ramifications for contributors and beneficiaries, as well as the climate (Garrick et al., 2020).

6.3 Different traditional water treatment methods

6.3.1 Filtration through clay vessels

A clay water filter has numerous benefits, including being cheap, lightweight, chemical-free, and easy to use. It may also be made locally using locally available clay and other materials. The capacity of a clay-pot water channel to eliminate particles and microbes from water depends on its surface charge and pore size (Bielefeldt et al., 2010). In Egypt, this technique for treating water is widely employed. Highly turbid water can occasionally be filtered using clay jars with the right pore size. Water that is cloudy is collected and given time to settle in a large clay jar. The jar's porous clay wall will then allow the water within to flow out. By setting it at the lower part of the permeable clay jar, this trickling water gathers in a container (often a clay pot). To work on the physical and bacteriological nature of drinking water, Wongsakoonkan et al. (2014) look into the best sorts and ratios of materials for producing clay pots. Varying clay-pot water filter ratios produced noticeably different turbidity levels and eliminated *E. coli* and coliform bacteria.

The effects of the content of Ukpor clay on the characteristics of artificial molding sand using river Niger sand were investigated by Edoziuno et al. (2015). The mechanical strength of some clay samples was determined by Akpomie et al. (2012) who also molded the permeability dependency of the adsorptive properties of kaolin and described its arrangement and configuration. Kaolin is a mineral that is found throughout Nigeria as tiny platelet particles of aluminum silica. Previous studies have been carried out to analyze the efficiency of ceramic filters for the treatment of water (Abiriga & Kinyera, 2014; Ali et al., 2017; Islam et al., 2014; Jalali et al., 2016; Nair & Kani, 2017). According to (Ekpunobi et al., 2019) a mixture of clay, diatomite, and sawdust was used to make ceramic pot filters (CPF). Analysis of the untreated and treated water samples revealed removal efficiency of 64%, 79%, 62%, and 100% for TDS, turbidity, TSS, coliform, and *E. coli*, respectively. Every result was within the WHO limit. The outcomes supported the materials' appropriateness for use in the manufacture of filters (Fig. 6.1).

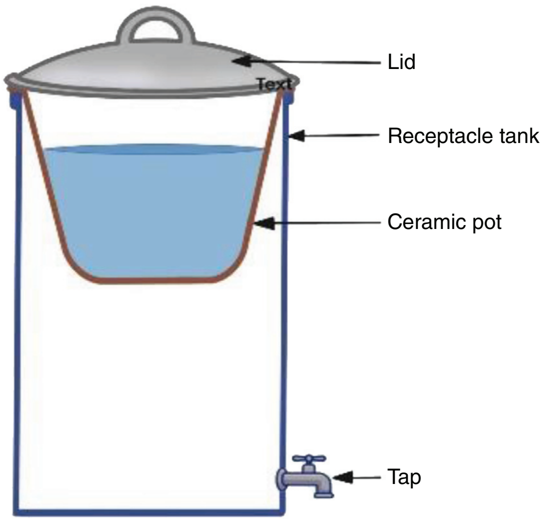

FIGURE 6.1 Filtration through clay vessels.

6.3.2 Filtration via winnowing sieve

The winnowing sieve method of filtration is employed when the source of water is contaminated by wind-borne contaminants such as dry plants, stalks, and large elements (Vigneswaran & Sundaravadivel, 2009; Vigneswaran et al., 1983). Large particles and other physical contaminants in the water are eliminated during the filtration process. A winnowing sieve filters out all the contaminants from raw water, resulting in the collection of fresh, drinkable water. The Bamaka region of Mali has many villages that utilize this kind of filter. As the sieve cannot strain out tiny suspended particles in raw water, this technique cannot be employed when the water is extremely muddled or opaque (Vigneswaran & Visvanathan, 1995).

6.3.3 Solar disinfection

This is one approach to employing solar water disinfection to eliminate microbiological organisms linked to waterborne illnesses. This technique is mainly used in rural areas of poor nations without access to centralized water treatment facilities. Untreated water is placed in a clear vessel and bared to sunshine for several hours before consumption using solar disinfection Fig. 6.2 (McGuigan et al., 2012). Antimicrobial activity is caused by the interaction of ultraviolet (UV) light and high temperature. If exposed to light for a sufficient amount of time, solar disinfection will eliminate the majority of disease-causing microorganisms. At higher temperatures, this is more effective. Glass can

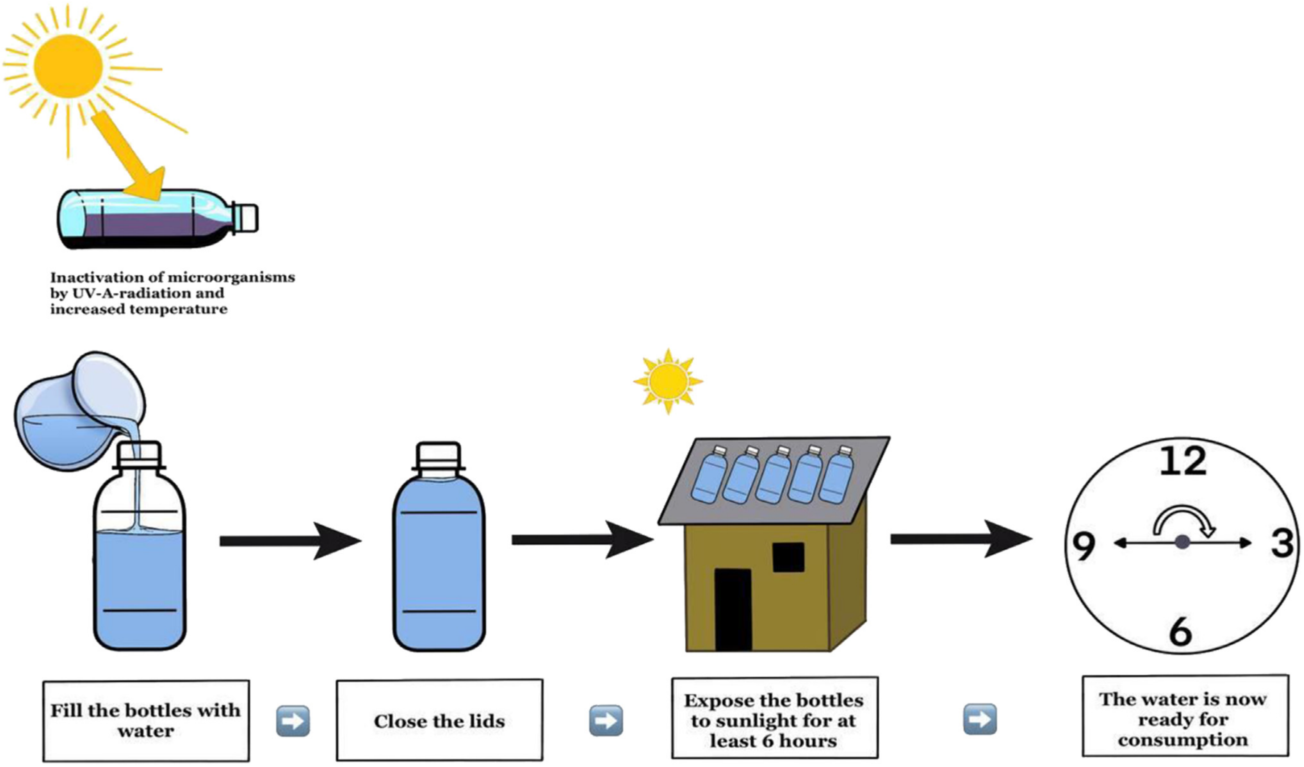

FIGURE 6.2 Solar disinfection.

be used in this process, but users are more likely to reuse plastic beverage flasks, which are commonly composed of PE (polyethylene) or PET (polyethylene terephthalate), or even elastic stacks, due to their lower cost, weight, and fragility (Dunlop et al., 2011; Walker et al., 2004). Additionally, the WHO recommends Solar disinfection (SODIS) as a suitable approach for drinking water filtration in such a situation (Byrne et al., 2011). The main drawbacks of this approach, despite its many benefits, are the lengthy durations of sunshine exposure needed for effective water disinfection (Luzi et al., 2016). It is frequently used as a method of decontaminating water in the environment with a shortage of adequate cleaning by the above mentioned generally used procedures because of its simplicity of implementation and low associated expenses (Cowie et al., 2020). There are advantages and disadvantages to solar disinfection. The fact that this procedure requires sunny weather and takes longer than other methods is a drawback.

6.3.4 Sedimentation

As one of the most essential techniques for water refinement, sedimentation is broadly utilized and seen everywhere. The viability of sedimentation, which basically lessens turbidity, relies upon the sort of suspended molecule size and the allowed settling time frame. It is a regular strategy for water treatment. Turbidity and unsafe microbes can be eliminated by utilizing the sedimentation interaction. It is a technique for disposing of solids in the water that float and settle. Sedimentation tanks are utilized in the strategy to eliminate greater materials (Obialor et al., 2019). Sedimentation might be trailed by additional treatment methodology. Understanding how sedimentation is utilized to clean wastewater is critical to hydrate. Sedimentation is the most common way of eliminating silt and minuscule particles from water. Gravity will pull the heavier silt down to deliver a muck layer, which is the way this cycle regularly happens when the water is unmoving. Water with suspended solids can be eliminated by utilizing gravity (Wisniewski, 2013). In the water treatment process, this action can be misleadingly actuated. To bring down the convergence of particles in the water, sedimentation is utilized. Sedimentation has the advantage of diminishing the need for coagulation and flocculation. Particular tanks are important for the treatment of sedimentation water. To guarantee that the particles settle, a sedimentation tank offers the expected help. In spite of the fact that sedimentation will happen normally over the long run, water treatment requires a tank to accelerate the technique (An & Park, 2017).

6.4 Chemical disinfection

There are various synthetic substances that can clean water. The productivity and security of these mixtures habitually vary. Compound sanitization will not destroy all sickness-causing microorganisms. There are benefits and hindrances to substance sterilization. Chlorine tablets are most often utilized by the overall league to sanitize savoring water homes during a crisis. Chlorine is a useful water sanitizer that functions admirably against microorganisms that are habitually connected to waterborne sicknesses. You can involve chlorine in fluid or gas structures (Latif et al., 2022). Contrasted with UV or ozone sterilization, chlorination is a more affordable hotspot for treating water. Sanitizers utilized for substance sterilization are:

- potassium permanganate ($KMnO_4$),
- chlorine (C_{12}),
- hypo chlorite,
- iodine (I),
- chlorine dioxide (ClO_2), and
- ozone (O_3).

Adding synthetic compounds or giving the sloppy water time to settle can assist the soil to settle to the lower part of the holder and make the water with clearing. Halazone, chlor-dechlor, and hydrochlonazone are a few tablets that are showcased and available to be purchased. (Latif et al., 2022).

6.4.1 Filtration through herbal plants

Chemicals are used in water purification operations in developed nations even though their safety for human health over the long term and their effects on the environment are still debatable. Therefore, finding sustainable substitutes that are better for the environment and human health is desirable. Since ancient times, it has been a customary practice to use plant materials as natural coagulants to reduce wastewater turbidity (Jayalakshmi et al., 2017). Rather than compound coagulants, plant-based regular coagulants are protected (Asrafuzzaman et al., 2011), eco-accommodating, and for the most part poisonous-free (Bratby, 2016). Natural herbs with antibacterial properties, such as amla, neem, wheatgrass, tulsi, etc., are excellent in water purification. Additionally, there are no negative side effects from using these herbs as human medicine (Rajesh & Wankhade, 2016). Natural coagulants don't corrode either, therefore worries about pipe erosion are gone. Natural coagulants have also been discovered to produce a significantly reduced volume of sludge to five times lower (Ndabigengesere et al., 1995).

- ***Moringa oleifera* (drumstick) seeds**: The proteins found in the seeds of Moringa plants function as powerful coagulants. According to studies, using the seeds from the *Moringa* plant to purify water has numerous advantages over using other coagulants, including being cost-friendly, not changing the pH of the water, and producing less mud than using alum (Folkard & Sutherland, 2002; Muyibi & Evison, 1995; Ndabigengesere et al., 1995) effective in removing suspended material hard water softener (Muyibi & Evison, 1995) and effective less expensive biosorbent of cadmium from aqueous medium (Sharma et al., 2006). In addition to removing turbidity, *Moringa oleifera* has antibacterial qualities. According to reports, *M. oleifera* powder can lower both low and high turbidity levels in surface water (Abiriga & Kinyera, 2014; Sharma et al., 2006).

  Vigna unguiculata: An annual legume plant is called *Vigna unguiculata*. Tanzanians are familiar with it as a food crop and as animal feed. *V. unguiculata* can be utilized as an erosion-control crop and as a nitrogen-fixing crop. Temperatures that are warm and dry are ideal for its growth. A minimum of two distinct coagulating proteins with molecular weights of about 6 kDa are anticipated to represent the active components of *V. unguiculata* (Annika, 2011).
- ***Parkinsonia aculeate***: It is a little shrubby tree that can grow as high as 10 meters. It is a member of the family *Fabaceae*. The tree produces two different sorts of seeds, about 25% of them are delicate and will sprout without pre-treatment, and the rest have hard seed shells and demand processing to germinate (Annika, 2011). The efficiency of *P. aculeata* seeds' crude extract in laboratory tests has shown that the seeds are powerful polyelectrolyte coagulants for clearing both naturally occurring and artificially produced turbid water. The (Marobhe & Renman, 2013) turbidity is decreased by the cationic coagulant protein from *P. aculeata* seeds. The effectiveness of *P. aculeata* seeds and alum in removing turbidity was quite comparable (Marobhe et al., 2007).
- ***Peanut seeds***: Turbidity expulsion of 93.2% was gotten by involving nut seeds as coagulant (Birima et al., 2013). However, the concentrate with refined water brought about just 31.5% expulsion of turbidity.
- ***Opuntia ficus-indica***: *Opuntia ficus-indica* is a *cactaceae* from parched and semi-arid districts. The utilization of *Opuntia streptacantha* as a minimal-expense biosorbent for lead in water treatment. The utilization of *Opuntia* sp. as a coagulant in water treatment has been accounted for by certain creators (Sáenz et al., 2004). The entire cladode, dried and processed was utilized as a coagulant-flocculant specialist with excellent outcomes (Bandala et al., 2012).

6.4.2 Filtration through cloth

The filter medium is a thin white cotton cloth or discarded clothing. Raw water containing pollutants like plant matter, insects, dust, or coarse mud particles can be purified with this filter. Only a very tiny amount of filtration of the

FIGURE 6.3 Filtration through cloth.

deferred elements in the water can be accomplished. As a result, excessively murky water cannot be filtered using this method (Fig. 6.3). It works well for well-water purification. In Indian villages, Mali, the southern region of Niger, and probably many other developing nations, cloth filtration is a practice that is fairly widespread. In some Indian villages, wood ash from the Sal tree (*Shorea robusta*) is mixed with water and then filtered through a cloth if the raw water is muddy and strongly scented (Vigneswaran & Sundaravadivel, 2009).

6.4.3 Chlorination

The most popular water disinfectant is chlorine. It comes in pill, powder, liquid, and gas form. Municipal water disinfection frequently makes use of chlorine gas, but handling it improperly can be dangerous. The following chlorine products are suggested in liquid, powder, and tablet form:

- **Liquid**: Chlorine laundry bleach (about 5% chlorine). Swimming pool disinfectant or concentrated chlorine bleach (12–17% chlorine).
- **Powder**: Chlorinated lime (25% chlorine), dairy sanitizer (30% chlorine), and high-test calcium hypochlorite (65–75% chlorine).
- **Tablets**: High-test calcium hypochlorite (65–75% chlorine).
- **Gas**: The usage of chlorine gas is a cost-effective and practical method for using a lot of chlorine. Steel cylinders weighing 100–2000 pounds are used to store it. The cylinders are filled with liquid chlorine by the packager until about 85% of their total volume is filled; the remaining 15% is filled with chlorine gas. To prevent tank rupture at high temperatures, these ratios are necessary. It is crucial that gas cylinders never come into contact with direct sunlight. The chlorine user must also be aware of the daily maximum gas withdrawal rate for the cylinder. For instance, the highest withdrawal rate from a 150-pound cylinder is roughly 40 pounds per day discharging to ambient gravity at room temperature (Bull et al., 1995; Vigneswaran & Visvanathan, 1995).
- **Chlorine carrier solutions**
  A high-chlorine carrier solution is mixed in a tank and pumped into the system by the chlorinator for smaller systems or individual wells. Only a little amount of this carrier needs to be added when utilizing 200 ppm. Depending on the structure, additional standard results can be required to make better use of the current chemical feed machinery (CDC, 2008).
- **Routine water chlorination (simple)**
  Most chlorinated public water systems regularly chlorinate their water. The water is chlorinated to the required level, plus an additional amount to deliver 0.2–0.5 ppm of free chlorine when tested after 20 minutes. Some viruses might not be completely destroyed by simple chlorination. The efficacy of chlorine as a disinfectant increases with both the chlorine residual and the contact time. Following the manufacturer's directions, chlorinators should be blended and adjusted. Standing causes chlorine solutions to progressively degrade. To keep the required chlorine residual, fresh solutions must be made as needed. To ensure efficient equipment performance and solution strengths, chlorine residual should be evaluated at best once per week. The method, form, amount, and results of residual tests should all be documented with dates. There are sensors that can detect when the chlorinator needs to be serviced and automatically turn off the pump and sound a warning bell or light (Caffrey et al., 2020).
- **Well-water shock chlorination**
  In a water system, shock chlorination is used to reduce iron- and sulfate-reducing bacteria as well as to get rid of fecal coliform bacteria. The entire well depth, the formation around the well's end, the pressure system, the water treatment equipment, and the distribution system must all be disinfected for shock chlorination to be effective. The water in the well as well as some of the water in the formation surrounding the well are displaced in order to achieve this by siphoning a significant amount of super-chlorinated water down the well (Saha et al., 2012). To ensure the equipment is properly protected, review the requirements of the water treatment kit. With shock chlorination, the entire system is exposed to water with a chlorine concentration high enough to kill iron and sulfate-reducing bacteria, from the water-bearing formation to the well-bore and the distribution system. The shock chlorination procedure is difficult and complicated. There are precise methods and chlorine concentrations for shock treatment (Boulder GNS, 2002).

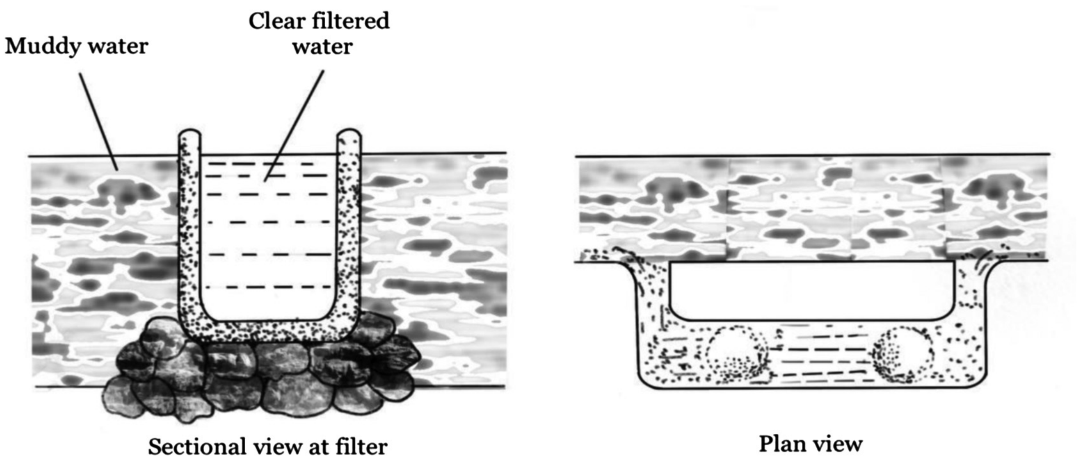

FIGURE 6.4 Jempeng stone filter.

6.4.4 Jempeng stone filter

It was created in Saringan batu Jempeng, Bali, Indonesia, to filter water. Here, an irrigation canal carrying muddy water has a little artificial pond or a bypass channel dug into the side of it. The artificial ponds have stone filter units by Jempeng. The filter unit is made of a permeable substance known as "cadas". This unit has a wall that is 10–12 cm thick, a diameter of 50 cm, and an average height of 60 cm. This item is positioned in front of a gravel bed that supports stones. The filter unit's porous wall allows muddy water to pass through and gather inside. The usage of such a device as a community water treatment facility is possible. Even very murky water can be treated by it. The key benefit of this product is that the only expense incurred is the cost of the investment (Guin & Gupta, 2017). Practically, there are no costs associated with operation or maintenance, such as cleaning (Fig. 6.4).

6.4.5 Horizontal flow coarse media filter

This method is ideal for turbid streams with turbidity larger than 50 NTU and uses rough gravel or crushed stones as filter media. As water moves horizontally across the filter bed, suspended particles are filtered and sedimented simultaneously. In addition, infections are somewhat removed by biological processes that are comparable to gradual sand filtration. Research at the Asian Institute of Technology in Bangkok, Thailand, found that the unit can remove turbidity by 60–70% and coliforms by roughly 80% (Boller, 1993).

6.4.6 Upflow gravel filter

This technology appears to have the ability to assist in overcoming the difficulties caused by deteriorating raw material sources. In a UGF, water flows through a bed of gravel from bottom to top. Impurities are held in the filter throughout this passage, with sedimentation serving as the primary particle transport and removal process. UGF has great potential for removing turbidity and TSS because it allows for lengthy filter runs and significant solids storage with little increase in head loss. Numerous MSF systems with UGF have been in place for more than 20 years at costs that seldom go over 4% of household income. Due to the use of locally sourced filter material that can be cleaned and sieved by community labor, UGF is seen to be a good pre-treatment method for rural water supply systems. Due to the deterioration of watersheds brought on by deforestation, erosion, and the release of untreated wastewater, the usage of up-flow gravel filtration is important for the water supply systems in rural and small towns in Colombia (Sánchez et al., 2009).

6.4.7 Two-stage filter

A technology for treating water that has some promise is two-stage filtration. According to estimates, this technique can effectively handle the majority of water treatment processes used today. Two-phase filtering system with the first phase being an up-flow granular sand sifter for system 1 and an up-flow gravel sifter for system 2. A down-flow fine sand filter served as the second stage after both. Based on the nature of crude water two-phase filtration process is an appealing option in contrast to either the regular or in-line direct filtration (Dantas & Bernardo, 2006).

6.5 Challenges

Due to a large number of anthropogenic factors, the availability of drinking water worldwide, especially in rural areas is a serious concern. In many rural places, surface waters are used for drinking purpose, but due to their poor-quality characteristics, substantial treatment techniques are required to have safe drinking for humans. Groundwater has better quality than surface waters but their desired characteristics are deteriorated due to the percolation of agricultural runoffs, improper domestic wastewater effluent disposals, and landfill leachates. Hence, treatment methods rely upon the water resource quality, its origin, transport, exposure to various environmental and anthropogenic factors, distribution of natural habitats, etc. (Treacy, 2019). According to United Nations Report 2018, the world's rural population was estimated to be 3.9 billion out of which Asia and Africa account for 90% the same. India tends to have a rural population of 906 million by 2022. Getting safe drinking water is going to become a challenging concern for rural people due to urbanization, industrialization, modern agricultural techniques, the use of chemical products, the prevalence of emerging contaminants, and heavy metals that would contaminate water matrices and directly enters the food chain. Natural water scarcity of a particular area depends upon factors like geography, geology and hydrology, and climatic conditions. Natural calamities like floods, hurricanes, and landslides seriously affect the water table by trapping contaminants sourced from pollution-affected areas. Recontamination at the collection, transport, and storage also accounts for damage to the drinking water quality. Rural wastewater treatment needs energy-efficient methods owing to the energy resources available in the location, man power availabilities, and economic status of the people living there. Water purification methods mentioned in this book are passive methods that do not require energy for operation or demonstration. But the methods utilized for drinking water purification seen in the previous chapters also have some challenges in implementing them in rural areas due to certain constraints. Solar disinfection, chemical disinfection, filtration, and sedimentation are the simple means of drinking water treatment adopted in rural areas. Due to low cost, reduction of viruses, bacteria, protozoa, and other germs, little or minimal change in taste, extremely low possibility of recontamination, etc., SODIS of water was adopted by many rural communities as a simple, inexpensive, and successful choice for water treatment. If transparent plastic bottles have been reused, SODIS is relatively affordable. Since suspended particles like heavy metals and other non-biological agents are a key barrier to sunlight's ability to properly detoxify the waters in containers, pre-treating turbid water to remove suspended particles via flocculation, filtering, or other methods is needed in SODIS. Additionally, a lot of clean, undamaged bottles are needed to prevent cross-contamination. Sun disinfection can only treat a small volume at once; otherwise, it will take a longer time to decontaminate using solar power. Another difficulty in solar decontamination of water is the availability of sunlight in rainy seasons or cloudy days and the latitude of the region. Decontamination of microbes relies upon the intensity of sunlight and UV radiation (McGuigan et al., 2012). On cloudy days, the UV radiation from the sunlight is not sufficient enough to produce reactive oxygen species (ROS) to decontaminate microbes and hence the containers have to be placed on the rooftop or elevated spaces under direct sunlight even for about 2 days. A slightly curved sheet of aluminum foil wrapped upon the bottles increases the penetration of light. Some protozoa can create holes or cysts that are resistant to solar UV rays. The majority of pathogenic protozoa are either more difficult for SODIS to eliminate or require higher radiation doses (Luzi et al., 2016). Another major concern in adopting SODIS with plastic bottles is the possibility of leaching of plasticizers and potentially carcinogenic compounds at higher levels into the water (Schmid et al., 2008). Hence the bottles have to be replaced at least every 6 months. Pre-sedimentation or coagulation reduces the disinfection demand of raw water obtained from water streams. Combination methodologies like chlorination and flocculation with hypochlorites and ferrous sulfates (Pu-R technology) are efficient in treating microorganisms and pathogens, but is a laborious process with flocculation to happen first and then pathogenic disruption by hypochlorites which is also a time-consuming process (Kurniawan et al., 2020). Moreover, there is an emerging concern regarding the toxicity of metal-based and polymer-based coagulants. Aluminum-based coagulants showed toxicity in the range of 100 mg/L to 200 mg/L to humans and had growth retardation in plants (Al-Mutairi, 2006; Kurniawan et al., 2020). Polymer-based coagulants tend to impact the health of animals even in the range of 400 μg/L to 60 mg/L and are carcinogenic above these levels (Lapointe & Barbeau, 2019). Hence natural plant-based coagulants are preferred over chemical and polymer-based coagulants owing to their reliability, less sludge generation, and non-toxic nature. Though chlorinating water is a better option for point source water decontamination, psychosocial, and contextual factors of people restricted the use of this method (Geremew et al., 2018; Hariganesh et al., 2020). Capital costs are higher for collecting water in centralized water tanks commonly for chlorine disinfection (Li et al., 2022). Also, odor and taste changes, skin irritations, lower capability to kill protozoa, and production of toxic by-products when exceeding the permissible concentration levels (typically around 5 mg/L) are considered to be the disadvantages of the chlorination process. Also, it was determined that the threshold taste values of chlorine and their residues vary with the pH of the aqueous system. Disinfection of water using other chemical compounds such as bromine and iodine is associated with the generation of toxic chemicals of phenols, anisoles, and indoles as residues, which further impose negative characteristics on the water quality. The removal of trash, floating particles, and wind-borne pollutants from water can be accomplished with winnowing sieves and cloths, but it is ineffective for the removal of smaller suspended particles. With these kinds of filters, pathogenic pollutants cannot be removed either (Sharma et al., 2021; Vigneswaran & Sundaravadivel, 2011). Filtration techniques like horizontal flow filters, up-flow gravel filters, and two-stage filters are simple in construction with sand and gravel layers, but the rate of filtration is very low. These filtration methods may be viewed as a total treatment system, with treated water without any major pollutants leaving the filter possibly being delivered to the distribution system following a straightforward post-chlorination. Also, these methods are applicable to small-scale societies (Vigneswaran & Sundaravadivel, 2009). Proper maintenance and cleaning are needed to avoid recontamination. Filtration using herbal plants is another simple and promising technology for water purification and decontamination. Neem leaves, tulsi leaves, moringa pods, and citrus lemons are being used for this purpose. Despite their effectiveness in cleaning up contaminants and removing suspended particulates from water, plant materials have been discovered to alter the water's characteristics, making them unpleasant for drinking (Bhattacharjee et al., 2013). For example, neem leaves impart a little bitter taste to the water; tulsi leaves, citrus imparts an odor to the water. Rural water treatment scales up in pilot scale levels can be implemented for a group or regional communities. In order to disinfect water utilizing electrolytic processes, such as producing oxidative free radicals that kill microorganisms by destroying their chemical structure, SODIS typically employs the effects of electricity produced by photovoltaics. Alternatively, an ultraviolet lamp is powered by battery-stored solar energy and is operated at nights or in cloudy conditions to perform secondary solar UV water treatment. Hence the rural water treatment methods are applicable according to the geography, climate, water resources and quality, availability of resources to adopt the treatment methods, training and skills of the people in implementing the techniques.

6.6 Conclusion

A fundamental tool for health and a source of life is water. It is needed for industrialization and domestic uses, and is very important for human existence. Water has become scarce and treatment of available ones. Availability of water in India and its importance, different traditional methods for purifying water in the rural areas like filtration through (clay vessels, cloth, and herbal plants), boiling, SODIS method, sedimentation, chemical disinfection, chlorination, Jempeng stone filter, horizontal flow coarse media, *M. oleifera* seeds, and *V. unguiculata* were all analyzed in the review. The solar method is found to be simple, easy to practice, affordable, and very commendable for use. The use of potash alum although cheap and quite effective requires more intensive research in order to determine its level of toxicity. Current technologies adopted for water treatment were founded on a traditional method based which are being side-lined of late. In this detailed research review, filtration through herbal plant were presented, their efficiency as well as their downsides for further studies.

Conflict of interest

No conflict of interest.

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Section 2

Technical aspects of rural water management

Chapter 7

Conventional methods and materials used for water treatment in rural areas

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7.1 Introduction

The chemical elements hydrogen and oxygen make up water. It is the cornerstone of earthly life and can be found in the lithosphere, atmosphere, and hydrosphere and is both omnipresent and omnipotent. In the atmosphere, it is present in the form of vapor as clouds, liquid as precipitation, and solid as hail. Water is only present on the planet "Earth" while other planets of the solar system lack this important compound. It is the mercy of almighty God or benign nature which has bestowed us with the abundance of water. Hydrology is of paramount significance because it is water that controls climatic conditions, landforms like erosional and depositional on the continents, the fluvial process, glacial process, and cast process are all the result of water.

The river on the land surface has a very low amount of water, but it is of very great importance because these are considered the lifeline for the easiness of human and environmental society. River water is being dammed for irrigation and multipurpose projects. The freshwater lakes have outlets and centrifugal drainage patterns, e.g., the Great Lakes in North America—Superior, Michigan, Erie, Ontario, and Huron are interconnected water bodies near the border of the United States and Canada. The lakes like Great Bear and Great Slave are the best source of good water that is potable for drinking purposes. Saline lakes and inland seas have a great volume of water which is not even good for drinking yet provides a healthy environment for plants and trees survival. Groundwater is a great gift of nature provided to humanity as it can be used for drinking, irrigation, agricultural practices, and industrial purposes. Oceanic water is of utmost importance in the biological world and constitutes the largest amount of water overall, i.e., 97.6% of total water present on earth. Due to increasing global warming the ocean level will increase to such an extent that there will be water over all the land surface. According to the data around 71% of the earth is covered with oceans in which 77% of rainfall falls and 23% on the land surface and in case of evaporation 86% from the oceans and 14% from the land surface.

In rural areas people face many challenges including scarcity, pollution, water management, storage, etc. As all water is not in usable form it needs to be managed, treated, or purified in different ways. From ancient times to nowadays, many houses consist of rainwater harvesting systems and baoris (step-wells) for water storage (rainwater) for future security. Some areas consist of rooftop and underground catchment areas to manage the water (Vignesaran & Sundaravadivel, 2009). Safe and free drinking water should be the birthright of all life on our planet but pollution does not allow it to happen along with some other factors. The causes of this pollution can range from industrial activities to agricultural activities to our daily routine.

7.2 Types and sources of water contamination in rural area

This can be divided into two major categories:

1. Natural causes
2. Anthropogenic causes

Natural causes of water contamination in rural areas include climatic change, natural disasters like droughts, earthquakes, floods, etc., weathering of rocks, geology of rocks, and atmospheric deposition.

Anthropogenic causes of water contamination in rural areas include farmer activities like the use of pesticides, weedicides, herbicides, etc., runoff from agricultural fields, feedlots, barnyards, construction activities, mining, wastewater discharge like sewage, domestic, animal waste, etc.,

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bathing and washing in water bodies, poultry farms, hatcheries, timber harvesting, etc. (Khatri & Tyagi, 2015).

The modern world is a gift of industrialization but it should not be at the cost of the life of either flora or fauna. A sustainable approach must be followed in order to achieve a balance between the needs of the present and the needs of the future. Water contaminants can act as poisons and may cause several diseases such as cholera or diarrhea. Another cause for concern is that these contaminants can cause harm to different organs of the body as they can travel to them through our digestive tract (Van Derslice & Briscoe, 1993).

The water has been getting polluted since long ago via various sources or in different ways in rural areas. Direct discharge of wastewater in the water bodies is one of the reasons. The discharged wastewater may consist of chemicals like pesticides, weedicides, herbicides, fertilizers from the agricultural fields, domestic sewage or other domestically used water, and effluents from industries in villages (Isalkar, 2010). The quality of water anywhere can get affected via both point source and non-point sources, drought, industrial or sewage discharge, due to lack of knowledge, education, and awareness regarding contamination of water. According to data, more than 200 crore people are living in water-stressed countries, at least 200 crore people are consuming fecal contaminated water and around 3.575 million people die every year from waterborne or related diseases which accounts for 80% of diseases globally (Haseena et al., 2017; WHO, 2015).

7.3 Effects of low-quality water in rural area

The lack of water and the stress that results from it poses the biggest threat to human health, including environment, the world's food supply, economic, and social progress in the twenty-first century (Brooks, 2002). Domestic water use makes up only 9% of Sub-Saharan Africa's total water consumption needs, but in rural parts of semiarid zones, particularly in northern Nigeria, the lack of water to meet this need is a serious worry (Inkani, 2015). Water scarcity can be managed by installing special tanks for the storage of rainwater for irrigation in the future, using drip irrigation method for sustainable watering, and opening special schools for farmers to enhance their farming techniques and to acknowledge the adaptations required in respect of climatic changes, drought, to the sustainable raising of livestock. Due to the rapid growth of urbanization and industrialization in Bangladesh, both surface water and groundwater have become contaminated. Most significantly, arsenic contamination and industrial by-products are affecting the potability of this natural resource. Despite having an abundance of water sources, Bangladesh is a heavily polluted nation that struggles with a lack of clean water (Faroque, 2021). Since water can serve as a universal solvent, which makes it particularly simple to contaminate, harmful substances from various sources dissolve into it. In addition to that many problems occur due to contamination of water like lack of safe potable water, diseases, and challenges in purifying, or treating the water for removal of the different types of contaminants. Most illnesses and fatalities are caused by water-related diseases, which primarily afflict the underprivileged residents of the surrounding areas. The main channel for the spread of Dracunculus medinensis along with other helminth parasites and bacterial enteric illnesses was discovered to be the contaminated ponds (Ilegbodu et al., 1987). In a related development, a survey conducted by the World Health Organization in 1991 revealed that about 96,000 guinea-worm infections, with Nigeria being one of the 13 major African nations where the diseases spread have been attributed to people continuously consuming polluted water in rural communities which includes hepatitis B, C, liver sirocco, cancer, etc. (Galadima et al., 2011). Industrialization, agricultural practices, environmental conditions, inadequate water supply, and sewage treatment facilities are the main causes of water pollution. Primarily, the industry is the major contributor to water pollution and examples of this include the tannery, pulp, paper, textile, food, iron, steel, nuclear, and distillery industries which are being established in rural areas as a result of the enormous rise of industrialization. In the course of industrial manufacturing, a variety of poisonous chemicals, organic and inorganic compounds, toxic solvents, and VOCs may be produced. These wastes will create water pollution if they are introduced into aquatic habitats without being properly treated (Chowdhary et al., 2020). Important pollutants including As, Cd, and Cr that are released into wastewater come from the industrial sector, which also contributes significantly to dangerous pollutants (Chen et al., 2019). Furthermore, agriculture and water pollution are strongly intertwined. Water pollution is largely caused by pesticides, nitrogen fertilizers, and organic farm wastes from agriculture. Agricultural practices will contaminate the water with diseases, salts, pesticides, phosphorus, soil sediments, and nitrates (Parris, 2011). In conclusion, both natural and human-caused factors contribute to water contamination. Urbanization, population increase, industrial output, climate change, and other variables, as well as religious activities (Dwivedi et al., 2018), will all have a direct impact on water quality (Halder & Islam, 2015). Another factor contributing to declining water quality is the improper disposal of solid waste, sand, and gravel (Ustaoğlu et al., 2020). Human health is severely impacted by unsafe water. According to the UNESCO 2021 World Water Development Report, approximately 300,000 children under the age of five, or 5.3% of all deaths in this age group, occur each year from diarrhea brought on by contaminated drinking water, improper sanitation, and poor hand hygiene. In a comparative study of tap water, purified water, and bottled water, tap water was an essential source of gastrointestinal disease (Payment et al., 1997). Health diseases like cancer, neurological disorder, cardiovascular disorder, diarrheal, and respiratory disorders are also common in rural areas (Ullah et al., 2014). The mortality rate due to cancer is high sometimes in rural areas in comparison to urban areas as they are lacking in treated water facilities or vice versa due to anthropogenic activities leading to water contamination. Major challenges faced by people are phasing out the prior persistent organic pollutants and to control or prevent the usage of new persistent organic pollutants, controlling the use of pesticides or herbicides or any other chemicals in the field and their runoff from the cropland, in the creation of efficient systems for treating home waste and its control, in optimizing eutrophication, and customer acceptance, in metal removal, in acid neutralization, and in an introduction of efficient non-toxic reagents to the contaminated water, in pollutant containment and process monitoring, in using polishing treatment to reduce wastewater's micropollutant loading, in enhancing water safety, sanitation, and hygiene, and in developing affordable methods for disinfecting water (Schwarzenbach et al., 2010).

In this chapter various purification methods are discussed which were and even presently are performed by people in rural areas. These methods are traditional methods of water purification dating back to history. The methods discussed here are boiling, sedimentation, solar disinfection, chemical disinfection, coagulation, three pot method, filtration via different ways like cloth, winnowing sieve, clay vessels, Jempeng stone filter, gravity filters, coconut filters, oyster filters, and sand filters; clarification and filtration using plant parts, horizontal flow coarse media filter and by using elements.

7.4 Purification methods

7.4.1 Boiling

Boiling is the process where the vapor pressure of any substance becomes equal or more than the atmospheric pressure. This is a very old and useful technique for water purification (WHO, 2015). This was the first method used by ancient people all over the world. By boiling water, we can remove pathogens like spores, cysts, ova, bacteria, worms, parasitic eggs, viruses, etc. (Cohen & Colford, 2017). Boiling removes the dissolved gases from water like CO_2 and hence change in the taste of water takes place. This method needed firewood and even in some places, sunlight can be used to boil the water, hence making this process a homely process (Cotruvo & Sobsey, 2009). While boiling, the container should be kept constant because shifting can increase the chances of recontamination. This method is irrespective of the water's color and nature (clean, cloudy, muddy, pure, impure). The disadvantage associated with this method is the consumption of a lot of fuel. This results in deforestation, as people in rural areas are more dependent on locally available sources. Burning of fuel also generates fumes and gases, which are harmful to human health and the environment.

7.4.2 Sedimentation

Sedimentation is a method of removing suspended particles in contaminated water (Ochowiak et al., 2017). This process provides an effective method for the removal of sediments (Chhetri et al., 2016; Simate, 2015). Most of the suspended particles in the water possess specific gravity of more than 1, i.e., of water. These particles remain in suspension in turbulence. So water should be in calm condition to settle at the base as a result of gravity, in short, gravity plays an important role in sedimentation (Chhetri et al., 2016; Field & O'Connor, 1996; Liu et al., 2015; Patziger et al., 2012; Tarpagkou & Pantokratoras; 2014). After this, these suspended particles can be filtered and transferred to another container. This process is a pre-treatment method of water purification as filtration, boiling, and disinfection are done after this to get more purity in the water. This process can be enhanced by using coagulants. The most commonly used coagulants are chemicals like ferric sulfate, alum, etc. Plant parts of *Moringa* seeds, prickly pear cactus, fava beans, etc. are also used for boosting the sedimentation process.

Disadvantage of this process is being a slow process as the requirement of time is much higher and the pollution trend is shown in a specific band over time. This is limited in the high end by turbulence and by diffusion at the low end due to Brownian motion. Emulsions, extremely dense materials that settle quickly, and mixes of materials with different densities cannot be used with this approach because they do not settle. Viscosity is dependent on the surrounding temperatures. Typical measurement time is relatively long compared to other procedures (20–60 min might be taken).

7.4.3 Solar disinfection

Solar disinfection is the process of exposing water to sunlight for 5–6 h or depending upon the condition of water contamination to get it disinfected by the effect of temperature (Reed, 2004). This method does not require a temperature higher than 55°C (Joyce et al., 1996). Under this temperature, *Pseudomonas aeruginosa, Escherichia coli, Shigella flexneri, Salmonella typhi, Salmonella paratyphi, Salmonella enterica, Salmonella enteritidis, Enterococcus faecalis,* and *Vibrio cholerae* get inactivated from contaminated water (McGuigan et al., 1999). For this purpose, contaminated water is kept in a transparent container and then placed under direct sunlight. To increase the effectiveness of this method people generally placed the container on a corrugated iron roof. This is a quite easy, effective, and efficient method of purification and is widely used in rural areas as this is a cheap and less laborious method. The water treated by this method should be consumed within a few days. On days when sunlight is less available like in winter or rainy seasons, this method does not work which is a disadvantage to this method.

7.4.4 Chemical disinfection

This is a process of adding a chemical disinfectant to the water. This chemical acts on microorganisms and organic matter present in contaminated water. The most recurring chemical disinfection compounds are chloramines, chlorine dioxide, ozone, chlorine, and tea tree oil (Bal et al., 2006). Chlorine tablets are used most commonly for disinfection of water in schools, waterworks, etc. Chemical disinfection is a primary step of microbial removal from water, after which another disinfection or purification method needs to be done which is a limitation for this method. Disinfection efficiency is defined in the form of Ct value which is the product of contact time (min) and disinfect concentration. This Ct value is affected by both pH and temperature (Kuo & Nguyen, 2008).

In ancient Egypt, aluminum sulfate or iron sulfate alone or both in mixture were used to extract suspended solids from water for purification. Hippocrates who was known as the "father of medicine," has designed a water filter, made up of a cloth bag. He used to hang that bag upright on a metal stand for the purification of water especially for his patients. This cloth made the water clean, and odor free by trapping the sediments of water (Smith, 2017). In Greece, this fabric bag called the Hippocrates Sleeve, was used before boiling to strain the water.

7.4.5 Coagulation

This is a method of treatment for removing solids present in water by altering their charges, in this some chemical or plant-based substance known as coagulants are added to enhance the process of coagulation (Bochkarev et al., 2003) (Fig. 7.1). Since the beginning of the 20th century, women of Sudan have been using seeds of *Moringa oleifera* by swirling them for a few minutes with water in cloth bags. *M. oleifera* found in parts of India, Arabia, Africa, and Madagascar (Amagloh & Benang, 2009; Madsen et al., 1987; Tunggolou & Payus, 2017). Herbs were used as natural coagulants to treat surface waters. Ripen seeds of *Strychnos potatorum*, seed coats of *Elettaria cardamomum*, roots of the rhizome of *Vetiveris zizanioides*, and leaves from *Phyllanthus emblica* (Jiang, 2015).

For bacterial removal, *M. oleifera* found to be the superior among all other plant coagulants in nature and as efficient as alum as bentonite clay (Madsen & Schlundt, 1987) and as wood ash. The coagulating effect of aluminum sulfate causes suspended particles to clump which is a very helpful step to enhance the speed of the filtration process

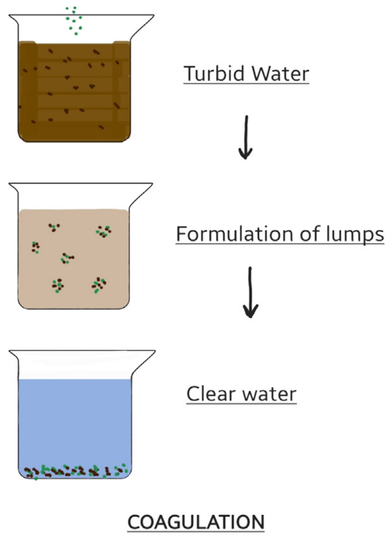

FIGURE 7.1 Coagulation process for water purification.

and purify more water, hence increasing the availability of potable water. This was the first known chemical water treatment (Khoury & Gallisdorfer, 2020). Talking about the purification of water of the riverain Sudan by using natural coagulants is considered as the most important traditional method of purification by adding them in turbid water as an extract or to the suspension to achieve floc formation (Jahn, 1977).

7.4.6 Three pot method

This is a very basic, reliable, low-cost, and easy-to-perform method in any circumstances. In this method, dirt and a few germs are removed from contaminated water. This includes 3 pots in which water is stored one after another and the overall contribution of the three-pot system (Fig. 7.2), generated by the idea of the "development pyramid" (Chegkazi, 2012).

Before pouring in pots water is filtered via cloth always and before filtration water is allowed to settle at least for one day each time. This will allow dirt to settle at the bottom and help in purification of water. Periodically, this pot will be washed out and sterilization of pot might be done to maintain the safety level. Water should always be consumed from the third pot only. This is commonly seen as no special effort or instrument needed for this process to be done, instead, people can perform this themselves with local or available resources. After this process other methods of purification are needed to be done as it does not totally remove diseases causing germs which is a limitation of this method.

7.4.7 Filtration

This is a method of filtering of solid particles from a liquid or gaseous fluid while allowing the fluid to pass through

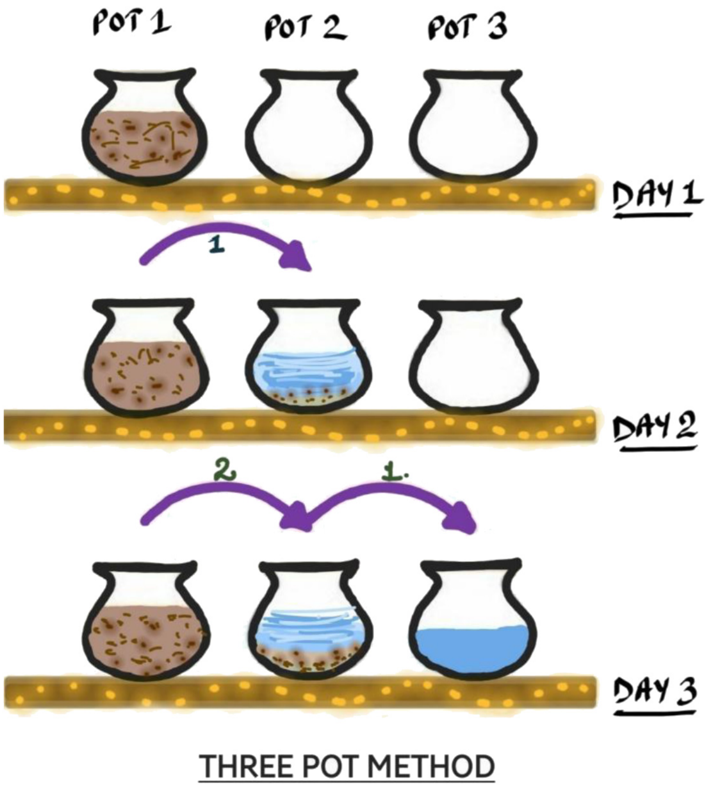

FIGURE 7.2 Three pot method for water purification.

(filters, sieve, stones, sand, gravel, etc.) while retaining the solid particles. This is the very first method of purification of water and this also improves the effectiveness of other purification methods. Water filtration has become necessary nowadays due to pollution. For this purification there are many technologies being used worldwide, but there are also many natural ways present in our system that have been in use for hundreds or thousands of years before man had made these alternatives technologies. Cotton cloth is preferred but it should not be much thick to minimize the time of filtration. This will not make the contaminated water completely safe for drinking which is a disadvantage but can be used for a daily basis purpose. In Ancient India, people have used sand and gravel before boiling the water to filter it. This method was taken from a Sanskrit manuscript "Susruta Samhita." Filtration is sometimes also done by sieve, to remove wind borne pollutants, leaves, and coarse particles, etc. But this method is not 100% feasible as after filtration we need to perform other methods to remove further impurities.

7.4.7.1 Filtration through winnowing sieve

This method has been widely used in Mali (Bamaka area) (Shelar et al., 2019). This method is feasible only when the source of water is polluted by impurities (tree leaves, twigs, and coarse particles) carried by wind. The filtration is being done here as water is allowed to pass through a winnowing sieve and the impurities get filtered out (Jones, 1987). This method cannot be used when water is muddy or turbid as it must be containing fine suspended particles, which are unable to be removed by this process (Vignesaran & Sundaravadivel, 2009).

7.4.7.2 Filtration through cloth

In this method of filtration, a white cotton cloth is used to filter the water having impurities like insects, debris, leaves, dust particles, or coarse mud substances. Filtration by this method is not possible to a small extent if suspended particles are present in the water (Vignesaran & Sundaravadivel, 2009). Many villages like Mali region of Niger and villages in India use wood ash of *Shorea robusta* before filtering with cloth. In Matlab, Bangladesh, women used to filter water by using sari which is effective in reducing the risk of cholera (Huq et al., 2010).

7.4.7.3 Filtration through clay vessels

This method of filtration is common in Egypt. This method is suitable for turbid water purification only not for the microbial removal. In this method water is filled into a jar already filled with clay. Then it is allowed to trickle via the porous clay wall of the jar and after that water is collected by placing a pot below the clay jar (Vignesaran & Sundaravadivel, 2009).

7.4.7.4 Jempeng stone filter method

This method of purification is performed in the Saringan batu Jempeng region of Bali in Indonesia (Shelar et al., 2019). To carry muddy water from one place a small artificial pond or bypass canal is cut on the side of the irrigation canal. Jempeng filter units are carved out of "cadas' which is a porous material and placed in artificial ponds on the top of a gravel bed which is supported by stones. The unit has a diameter of approx. 50 cm, a height of 60 cm and a wall having thickness of 10–12 cm. Muddy water or highly turbid water filters via this porous wall of the filter unit but it fails to remove microbes. This method is very useful in a village water treatment unit as the only cost involved in this is the installation or investment cost. There is no operational or maintenance cost for cleaning is necessary in this method (Vignesaran & Sundaravadivel, 2009).

7.4.7.5 Gravity filter

Gravity filtration is a method of filtering impurities from solutions by using gravity to pull liquid through a filter (Patil et al., 2013). Through this method contaminants found in indoor and outdoor sources like lakes, rainwater, streams and rivers, the solid-liquid-gaseous impurities of water can be removed. Even in some cases an advanced system can filter out diseases causing micro-organisms like bacteria and parasites causing diseases like typhoid, cholera, dysentery, etc. In Khem, people used this filter to purify or to clean the muddy water which was collected from the Nile river with addition of alum, after which coagulation was to be done (Khoury & Gallisdorfer, 2020).

7.4.7.6 Coconut filters

Coconut performs filtration of water via absorbing it through a layer of fiber (Jamilatun & Mufandi, 2020). The coconut milk is considered the second purest after water. Commercially people tend to use coconut carbon filters as water purifiers to remove contaminants, toxins, and particulate matter. Coconut shells trap most parasites, particles, and toxins. Cryptosporidium and Giardia parasites can be filtered by this method. Coconut husk has also been used for the removal of odors, contaminants, and tastes. The carbon present in coconut husk is found to have higher volume of microspores, which leads to better filtration than wood or coal (Katre et al., 2020). Coconut shells were also used in purification in rural areas of Tanzania. This is also used in fluoride filtration (Said & Machunda, 2014).

7.4.7.7 Oyster filters

Oysters are most commonly found in Australia and are native to the Pacific coast of Asia. Oysters are not just used as food in restaurants but also considered as a natural water purifier globally (Shih & Chang, 2015). These remove toxins naturally while feeding in water. The water after flowing through the oysters becomes potable or safe to drink. In some areas, people are still using natural oyster reefs for water purification. Adult oysters on an average can filter more than 60 gallons of water per day (Patel & Shah, 2020).

7.4.7.8 Sand filters

Sand has been in use for water filtration for 2000 years. Romans and Greeks mainly used sand filters to remove sand from water. Sand can be removed by filtering small particles of 25 μm. Slow sand filters are used to purify drinking water (Wotton, 2002; Yusuf et al., 2019). Mainly this filtration is used for the purification or treatment of ground water for the removal of iron in dissolved form. Sand filters are normally used to remove flocs of manganese and iron in oxidized form converted by aeration and get trapped between the sand filter (Hu et al., 2020). This was commonly used in Western Europe and London earlier, in a pond of Gosaba island in West Bengal (Ohlenschlaeger et al., 2016).

7.4.7.9 Filtration through hollow wax balls

In experiments conducted by Aristotle (384–322 BCE), hollow wax balls were submerged in saltwater for the duration of a complete day and night. A salty film was left on the wax after the wax ball filtered the water. The salty and earthy remnants would be sieved off, according to Aristotle, making the water potable. When seawater was heated to a boil, Aristotle said that the resulting "sweet vapors" were completely drinkable (Smith, 2017).

7.4.8 Clarification and filtration using plant parts

Plants are always considered the best and natural choice for filtration of water among all and especially when wetland areas are under consideration for purification of water. As plants filter water by addition of oxygen and removal of carbon dioxide from the respective water. Even some plants are there which are also used for the removal of heavy metals and toxins from water and simultaneously enhance the growth of beneficial bacteria, e.g., water lettuce and water hyacinth are found to be so effective that they are used in the first step of water purification.

This method is often seen in southern districts of Tamil Nadu and Kerala, India. In this method nuts of locally available plants are used for the filtration process. Here, highly turbid water, i.e., having fine suspended and colloidal particles, which are coalesced and settled by using nuts prior to filtration by cloth filters. Nuts are believed to excrete coagulant chemicals after absorption of water and catalyze the process. Similar to nuts some roots are also used like wiry roots of the rhizomes "Ramachham" (*Veterinaria zizanioides*) which are placed in a clay jar, having tiny holes in the bottom of it. Now, water is allowed to run through the layer of roots in the jar and later water will move out via tiny holes in the bottom and then be collected. Generally, this filtered water is found to be very clear and also has a pleasant smell (Vignesaran & Sundaravadivel, 2009).

Thetran kottai was also used to purify water in early times. This is a seed which when rubbed with the store forms a jelly like substance, which later mixed with water and water becomes pure. It is believed that a single seed is enough for the clearance of all chemical pollutants in 30 liters of water. Herbs like amla which is having high content of vitamin C, khus, water lily roots, and the seeds of the Nirmali (*Strychnos potatorum*) were used and they even now people should follow them as water is being polluted more and by this we can reduce reliance on harmful chemicals. One study mentioned about Nile water's purification by using horse beans and alum. Rauwaq, an Arabic word which means clarifier, is used by people of riverain in Sudan. It is a general word which can be used for any coagulant, especially for clay soil (Lacy & William, 1954; Mentkevich, & Orlova, 1966). In rural Peru and Mexico people used mucilage collected from leaves of Cactus like *Opuntia ficus indica, O. tuna* and more species related to these for the clarification of the muddy water. In the first century BCE, the Diophanes of Nicaea suggested adding macerated laurel for purification of rainwater and Paxmus suggested that immersion of bruised coral or pounded barley would also result in clearing the bad taste of water (Smith, 2017).

7.4.9 Horizontal flow coarse media filter

This method uses coarse gravel or crushed stones as filter media and is feasible for turbid water with turbidity greater than 50 NTU. This unit can account for 0% removal of coliforms and 60–70% turbidity removal. The filtration and sedimentation of suspended solids occur while water is passing horizontally through the filter bed. Contemporary to these biological mechanisms, slow sand filtration helps in removal of pathogens (Vignesaran & Sundaravadivel, 2009).

7.4.10 Using elements

As revealed in ancient texts of Hinduism, heat, sunlight, and copper was used by them to purify water. Different heavy metals have different types of properties, so based upon the properties different metals are being used for purification of water in rural area.

Copper has a practical use in purifying drinking water. People are using it frequently for its water purification properties (Varkey & Dlamini, 2012). Natural copper (Cu_2O) mainly steals electrons, when mixed with water contaminated by bacterial cell walls and membranes, it inhibits the processes between the cells or intracellular cells which are involved in production of energy and replication of DNA. Recent studies have shown that copper can be used to remove viruses and bacteriophages from potable water (Khoury & Gallisdorfer, 2020).

Iodine is also used to purify water (Backer & Hollowell, 2000). The first people to use iodine as a medicine were from ancient Greeks. Gram-positive and Gram-negative bacteria, yeasts, mycobacteria, viruses, fungi, and protozoa can all be killed by iodine, including methicillin-resistant Staphylococcus aureus (MRSA). Within 15–30 seconds of contact, the majority of germs are eliminated. This has been proven more effective than chlorine treatment in inactivation of cysts of *Giardia.*

Silver is also considered for water purification by eliminating microbes. Silver's documented use dated back to the Egyptians (1500 BCE) and Hippocrates, who lived in the third century BCE, used it to cure ulcers and open sores (Smith, 2017). Microbes are subjected to a multifaceted assault by silver (Davies & Etris, 1997). Bonding to protein sulfurs is the first route. Normal interactions between these sulfur groups maintain the protein's folded structure. The protein loses strength if it is in the silver ions and sulfur contact, which prevents the protein from folding properly. Second, silver disrupts the metabolism of microorganisms by attaching to sulfur, iron is stabilized, and silver modifies the structure of the microbe.

7.4.11 Screening

In this purification method different types of screens are used on the basis of size of particles present in contaminated water which are to be filtered. This is also a very basic, old, easy and feasible way for purifying water. These can be of different sizes at different places or steps of water purification. These works as sieve to remove larger to smaller particles e.g., debris, stones, gravel, sand, leaves, bark, etc. but fails to remove microbes and very fine soluble impurities. These can be installed in the front or at the starting of the pumps or water inlets and outlets.

7.4.12 Bone char

This is a process of using charred animal bones which mainly consists of calcium carbonate and phosphates which will replace the fluoride ions and purify the water (Delgadillo-Velasco et al., 2017). Bone char is a naturally occurring, porous, black carbon substance that resembles activated carbon in appearance and is used in rural Tanzania for defluoridation. Animal bones, typically cow bones, are burned to create the char. In order to prevent ashing, the bones are roasted in a sealed jar to 700°C to create bone char and this is considered as the most cost effective and the oldest material for fluoride removal. Its effectiveness is seen in removal of organo-chlorine pesticides and metals like aluminum, arsenic (Chen et al., 2008),

TABLE 7.1 Comparison of the purification methods.

Purification method	Considerable points	Operating expense	Setting up expense	Skill
Boiling	Alters the taste	Medium	Low	Not required
Sedimentation	Turbidity reduction	High	Medium	Required
Solar disinfection	Makes disease free by killing germs	Medium	Low	Not required
Chemical disinfection	Microbial removal further treatment needed	High	Medium	Required
Coagulation	Makes water potable	Medium	Low	Required
Three pot method	Needs further treatment as only particles are settled	Medium	Low	Not required
Filtration	Many types of filtration are present and further treatment needed sometimes depending upon contamination.	Low	Low	Both
Using plant parts	Filtration, coagulation, taste improvement, chemical disinfection, etc. all are done	Medium	low	Both
Flow coarse	Filtration by gravel or crushed stones, sedimentation, turbidity, and bacterial removal	Medium	Medium	Required
Using elements	Copper, silver, iodine potability enhanced	Medium	Medium	Required
Screening	Larger + smaller all visible contaminants	Medium	Medium	Both
Bone char	Adsorption, remove fluorides	Low	Low	Required
Charcoal	Adsorption	Medium	Low	Required
Activated charcoal	Adsorption, 200× of its weight toxins removal	Medium	Low	Required

chromium, zinc, cadmium, and copper (Ko et al., 2000), lead (Deydier et al., 2003), etc. and used both as a de-ashing agent and a color-sorbing agent in the refinement of sugar (Jacobsen & Dahi, 1997).

7.4.13 Charcoal

This method of purification works on the adsorption principle (charcoal will adsorb the impurities present in the contaminated water, but leaving microbial impurities) (Nishida et al., 2017). Charcoal was used for water purification and medical purposes by Sumerians (3000 BCE), Egyptians (2000 BCE), Indus Valley cultures (1500 BCE), Israelites (1550 BCE), and Greeks (400–300 BCE). The Chauvet-Point d'Arc cave in southern France has cave paintings that have archaeological traces of charcoal. Charcoal and red/yellow ochre were used to create these paintings, which are thought to have been created between 32,000 and 30,000 years ago (Chauvet et al., 1996).

7.4.14 Activated charcoal

This is simple to process and used in many ways in water purification. According to American study, charcoal manufactured from coconut shells have a macro-porous structure that promotes quick airflow. Chemical structure of charcoal comprises fragments of carbon sheets in randomly arranged patterns (Kroto et al., 1985; Shibuya et al., 1999). Carbon has a negative charge similar to clay, which attracts cations from metals, organic contaminants like benzene and chlordane, dissolved gases like hydrogen sulfide, and other pollutants. Charcoal activation and steam activation increase the surface area, improving these adsorption qualities. All volatile substances and some carbon are pushed off of charcoal when it is heated to a high temperature (1700–1800°F), expanding the pores in the process. One pound of activated charcoal can be made from about three pounds of raw charcoal. A water wash or an acid wash is used to remove the ash content once the activated charcoal has cooled. Then acid is removed with a second water wash (Smith, 2017).

Not suitable for compounds having low molecular weight and water with high solids, oil, and grease. Solid radioactive radon, trichloromethane (chloroform), and odors produced by glues used to build plastic water supply pipes can all be eliminated using a big granular activated charcoal filter. Microfine carbon, sometimes referred to as carbon block, is a tightly compressed form of charcoal that is useful for physically filtering lead and asbestos as well as eliminating protozoan cysts (*Cryptosporidium parvum* oocysts) (Otto & Haydel, 2013). The activated charcoal which is produced commercially has a tendency to adsorb toxins 200 times its own weight due to high surface area.

7.5 Comparison study

Comparison study of purification method is compiled in Table 7.1 on the basis of operating expenses, setting up expenses and whether skill is required or not for the process. Boiling, solar disinfection, and three pot methods do not require any specific skill for processing. The operating expense is maximum for the sedimentation and chemical disinfection and lowest for bone char and filtration. Setting up expenses is not much higher in any of the discussed purification methods. Except bone char, charcoal, activated charcoal all other purification methods require further treatments. In comparison to all the methods discussed in this chapter purification using plant parts is quite preferable easy to use, reachable for all, operating and setting up expense are not high, and most important being eco-friendly method it purifies water to a greater extent. This also comprises some of the methods digital own processing while using plant parts for water purification.

7.6 Conclusion

Water is a basic need of life, so availability of clean drinking water is uttermost requirement for survival. From the ancient time people around the world had opted different methods for purification of water. The people of Indus Valley Civilization has used zinc, copper, and lead for water purification. In conjunction with boiling copper, iron, and hot sand was used. Herbs like amla were also used to filter wells and plants parts by them. Greeks and Romans used a method of placing macerated laurels in rain water by diaphanes and immersion of a bag of pounded barley and bruised coral by Paxmus. In 1671, France used distillation method and in 17th century Italy used multiple sand filtration method for purification. Poor people living in rural areas around the world are unable to meet their basic needs for clean water due to water scarcity, pollution and sanitation due to lack of knowledge and availability of facilities. Economically weaker section of rural area cannot afford the burden of new advance technology of water purification; besides this they required skilled person to operate that technology in most of the cases so they prefer boiling, solar heating and usage of plant parts for purification. As part of sustainable development goals, the United Nations has set aggressive goal which apply directly to the future of the water purification market that is "By 2030, achieve universal and equitable access to safe and affordable drinking water for all." Government of every country has to act as per this goal. So traditional methods of purification of water seems to be a solution to achieve this goal. Awareness about the traditional and local technologies is required, which can be done by the incentives of NGO and government. As technologies vary from location to location, so providing knowledge about the local technologies is highly recommended. In some rural areas of world boiling and three pot method are preferred being easy and cheap method for water purification.

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Chapter 8

Effective and affordable water purification technologies for rural development

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8.1 Introduction

Access to clean water for domestic and drinking purpose is a right of each individual and the same has become a major challange of 21[st] centuary. There are three main factors that contribute to India's water dilemma. The primary factor is the lack of water for each individual in the light of burgeoning population, poor water quality of urban water treatment facilities; and decreasing groundwater due to excessive use in agricultural practices. Improperly treated or untreated water contains pathogenic bacteria, viruses, and protozoa making it unfit for human use (El-Sayed, 2020). Diseases like cholera, typhoid, fever, diarrhea, including others may be caused as a result of partially treated water consumption. Infections due to consumption of partially treated/untreated water are more prevalent in rural areas generally suffer scarcity of clean drnking water. Growing global population, pollution, industrialization, and climate change influence water quality and quantity. Rivers are more prone to pollution due to direct drainage of pollutants (organic, inorganic, biodegradable and non-biodegradable) from industries and agricultural runoff.

Drinking water must meet certain quality parameters including physical, chemical and biological. The physical parameters involve color, odor, taste, turbidity, temperature, solids and electrical conductivity. Temperature is an important water quality parameter that influences odor, viscosity, solubility, palatability and chemical reactions in water. The taste of water depends upon dissolved gases, organic and inorganic compounds. Solids in wastewater (dissolved or suspended) give an idea of organic/inorganic (Fe, Mn, As, Mn, chloride, sulphate, bromide) content. The total dissolved solids (TDS) in freshwater must be below 1000 mg/L. Conductivity provides the information of abundance of ions in water. Higher conductivity of polluted water indicates higher amounts of pollutants. The chemical parameters include *p*H, dissolved oxygen, alkalinity, acidity, hardness, biological oxygen demand, chemical oxygen demand and chlorine content. The most fundamental parameter of water quality is *p*H, which tells about acidic or basic character of water. The permissible *p*H for drinking water vary between 6.5–8.5 (Malik & Sugandh, 2022). High mineral content in water causes hardness (temporary or permanent). Dissolved oxygen (DO) indicates about the overall health and suitability of water for the survival of aquatic life. Higher DO signifies the better quality of water. Biochemical oxygen demand (BOD) is the amount of oxygen required by microorganisms to oxidize contaminants present in polluted water. Polluted water has more BOD versus freshwater. Biological parameters include bacteria, fungi, and viruses. These are responsible for causing waterborne diseases like cholera, typhoid, hepatitis, etc. Therefore, understanding the water quality parameters is necessary before its treatment and consumption. On the basis of water quality parameters, it can be used for intended applications.

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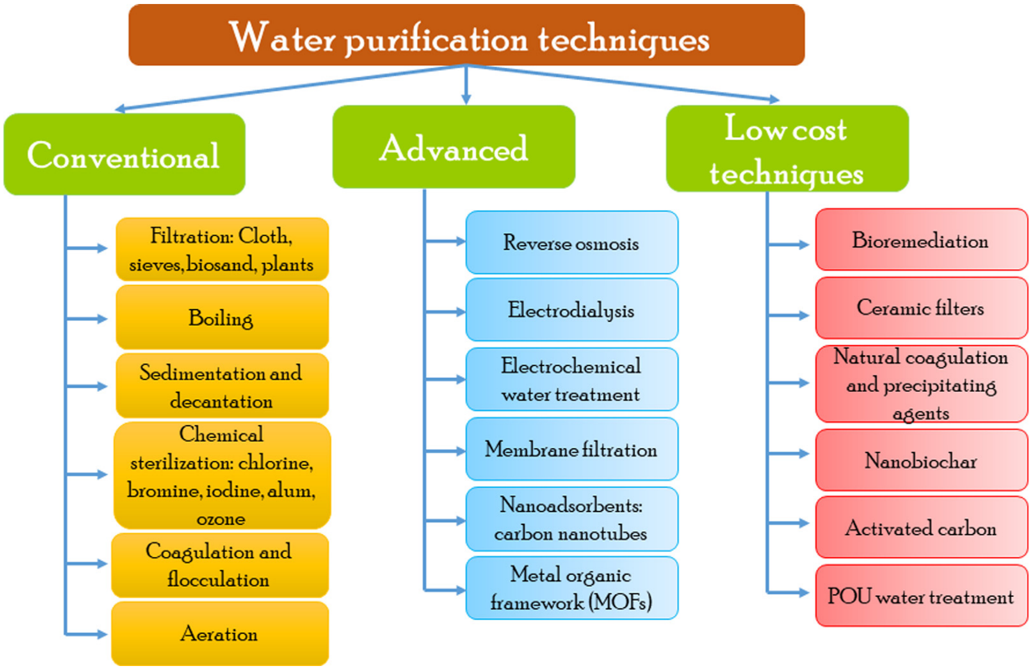

FIGURE 8.1 Conventional, advanced and low cost water purification techniques.

To make water suitable for domestic applications, numerous traditional and advanced technologies have been developed (Pichel et al., 2019). Fig. 8.1 represents conventional, advanced and low cost water purification techniques. Methods like boiling, filtration through cloth, plant parts, clay or mud, sedimentation, aeration, bio-sand, solar sterilization, and chemical disinfection have been used as conventional methods for water purification. Advantages, disadvantages and cost of conventional water purification technologies have been described in Table 8.1. The application of conventional methods is limited as they are time-consuming, less efficient and render the treatment process with harmful by-products. However, the limitations of conventional water treatment technologies can be overcomed by recent methodologies such as ion exchange, reverse osmosis, electrolysis, ultrafiltration, flocculation/coagulation, and adsorption. The use of appropriate technology for water treatment depends upon costs, pollutant type, efficiency and treatment time required (El-Sayed, 2020). All these technologies have their own advantages and disadvantages as described in Table 8.2. Out of the above-mentioned water treatment technologies, adsorption has gained immense importance. Biochar, activated carbon (AC), and nano adsorbents have been observed efficient for water treatment. These materials have unique properties like large surface area, porous structure, high adsorption capacity and chemical stability (El-Sayed, 2020). This chapter discusses about conventional, modern and cost-effective water treatment technologies alongwith cost involved. Carbon negative materials such as biochar and its modifications have particularly been accomodated to explore their potential in water treatment.

8.2 Conventional water purification techniques

8.2.1 Filtration

The filtration process separates solid from liquid and gases using suitable filters such as cloth, fibre, sieve or mud. Removal of contaminants takes place by various mechanisms including straining, flocculation, sedimentation, and surface capture. Filtration technique opens up extended application of water in irrigation, drinking water, domestic use, swimming pools, and aquariums. Different filtration media used for water purification have been discussed in the following sub-sections.

8.2.1.1 Cloth filters, winnowing sieve, clay pots, plant parts

Cloth filtration was traditionally used in villages to purify muddy water by removing suspended solids, insect and larvae in contaminated water, through fine and clean cotton cloth (Chaurasia & Tiwari, 2016). Textile materials including knitted, woven, and non-woven have been used for filtration. Non-woven materials possess better filtration efficiency. In villages, flat multifold cloth was frequently used for filtration of drinking water. The efficiency of filter

TABLE 8.1 Merit, demerit and cost of conventional water purification technologies.

Technique	Merit and Demerit	Cost (US$/Million L)	Reference
Screening, filtration and centrifugation	Removes dirt and suspended particulate Sieves are not so fine to remove turbidity, biofouling of membrane filters, clogging of pores in filters	25–450	Gupta et al. (2012)
Boiling	Kill microorganisms No residual effect, ineffective for turbid water	7500 (firewood) 1.68 $/month/L 5000 (LPG) 0.005 $/L/day 44000 (electricity) 0.044 $/L at 222 ZKW	Clasen et al. (2008) Clasen et al. (2008) Psutka et al. (2011)
Sedimentation	Effective in turbid water, simple process Require more time requirement for particle settling	5–10	Gupta et al. (2012)
Solar disinfection	Removes water borne pathogens, effective in turbid water. No effect on chemical pollutants	863* 0.63 $/person/year	Marugán et al. (2020)
Chemical disinfection (Chlorination)	Kill most of the bacteria as well as viruses. Cysts of *Giardia* are removed if contact time period is longer. No effect on *Cryptosporidium*; not much effective in turbid water, generation of Disinfection by products	2000–11000 (0.04–0.22 US$/20L)	Ngasala et al. (2020)
Coagulation and flocculation	Ease to operate, removes most of the waterborne pathogens and pollutants, it partially removes *Cryptosporidium*. Generation of large quantities of sludge, additional process like sedimentation and filtration required	25–500	Gupta et al. (2012)
Aeration	Simple method. Control taste and odour of water Limited pathogen removal	20–200	Gupta et al. (2012)
Ozonation	Effective against *Giardia* or *Cryptosporidium* Require high energy input and high cost, no residual effect	396 (0.36 €/m^3)	Banach et al. (2021)

*Drinking water consumption = 730 L/person/year; considering average water intake of 2 L/person/day (Vohidovna and Olimovich, 2022).

cloth depends on the number of folds and size of pores (Zerin & Datta, 2018). Filter cloth (or filter media) is designed and developed as per thermal or chemical requirements, how frequently the filter is used, and the cost of filter. Natural fibers as well as synthetic fibers can be used to make cloth filters. Filters made of cotton fiber are highly efficient to remove dirt and suspended particulates in water but their use is limited due to short life. Among synthetic fibers, polytetrafluoroethylene (PTFE) is the most effective filter due to its hydrophobicity, biostability and chemical resistance. The main problem associated with fabric filters is biofouling. The application of antibacterial nanoparticles onto fabric surfaces shows bacteriostatic effects, eventually reducing biofouling (Zerin & Datta, 2018).

Sieves are used to remove impurities in water body (like leaves, twigs, stalks, and other coarse particles). Fed water is passed through winnowing sieves where impurities are filtered out. Sieves are not so fine to trap suspended particles, hence these are ineffective towards filtration of muddy and turbid water (Alig, 2018).

Plant roots and leaves have also been used as natural filters to treat waste water. In this process plant parts adhere to coarse, suspended, or colloidal particles. Water passed through the layer of root and leaves is further treated with cloth filter. Vinegar can be added to the filtration process if raw water is saline (Alig, 2018). Many plant species and their extracts have been used as disinfectant and coagulant. Seeds of *Moringa oleifera* are reported as the most effective primary coagulant used in rural areas to purify water. Other plants like *Solanum incunum* (leaves), *Azadirachta indica* (fruit), *Phyllanthus emblica* (leaves), *Ocimum sanctum* (leaves), *Manihot esculenta crantz* (roots), *Abelmoschus esculentus* (gum) have also been used as natural coagulant and disinfectant (Megersa et al., 2014).

8.2.1.2 Biosand filters

Biosand filters are point-of-use (POU) technologies for on-site water treatment prior to consumption. Herein, wastewater is introduced from one end and allowed to pass through a thick layer of sand. The sand gets fully saturated with

TABLE 8.2 Merit, demerit and cost of advanced water purification technologies.

Technique	Merit and Demerit	Cost (US$/Million L)	Reference
Ultrafiltration (UF)	Filters solution with colloidal/macromolecules, remove pathogen, can be applied before RO and NF, require low pressure Membrane clogging, cannot remove dissolved salts and viruses	15–400	Gupta et al. (2012)
Microfiltration (MF)	Low operation pressure, filters solutions with solid particle and suspended particles Membrane clogging, sensitive to oxidising chemicals	15–400	Gupta et al. (2012)
Reverse osmosis (RO)	Removes ions, small molecule, dissolved salts, metals and chemicals More water wastage, require high pressure	20–450	Gupta et al. (2012)
Advanced oxidation process	Efficiently degrades organic pollutants, rapid reaction rate, no sludge generation Oxidative by products generation, require high maintenance, cost intensive process	100–2000	Gupta et al. (2012)
Nanofiltration (NF)	Removes ions, small molecule, multivalent salts Require high pressure, cost intensive	1000–6000 (1–6 $/m^3$)	Samhaber & Nguyen (2014)
Adsorption	High surface area, porous, functional and thermally stable Require regeneration of adsorbents, performance depends upon the type of adsorbent	50–150	Gupta et al. (2012)
Electrochemical assisted water treatment	High pollutant removal efficiencies, no additional chemicals for process operation, broad area of applicability, insensitivity to toxic compound Generation of toxic intermediate metabolite, energy and cost intensive process	3300–1760 (0.3–1.6 €/m^3), (1 € = 1.10 $)	Kobya et al. (2009)

water throughout the process as the outlet of the POU is positioned higher than the sand layer. The saturated filter layer and sand enable the growth of microorganisms around them. Excess formation of biofilm in the filter layer forms dirt cover; capable of removing colloids, larger microorganisms and other contaminants from water sources (Pooi & Ng, 2018). The effectiveness of biosand filters depends upon parameters like flow rate, retention time and sizing of biosand filters. An increase in flow rate decreases the contact time of pollutants in water and filter surface, thus comprome the treated water quality. Aging of the filter increases the pathogen removal efficiency, for example, a mature POU filter removes *Escherichia coli* by 98% whereas a new POU filter removes 63% of *E. coli*. Globally, biosand filters have shown success in reducing diarrhea cases. Biosand filters have a long life ofabout 8 years under continuous use as reported in a Cambodian study (Pooi & Ng, 2018).

8.2.1.3 Bamboo charcoal

Bamboo charcoal (also referred as black diamond) is preferred over wood charcoal due to deforestation and environmental issues associated with trees. Bamboo is a fast-growing useful plant and considered as grass. Raw bamboo charcoal and bamboo briquette charcoal have been produced by pyrolysis of roots, culms, and branches. The highly porous structure of bamboo charcoal makes it an excellent adsorbent and filter media in treating wastewater as well as drinking water. Bamboo charcoal has antimicrobial (antibacterial and antifungal) properties. Harmful substances released from pesticides, heavy metals, and other chemicals like chlorine, chloramines, chloroform, and 2,4-dichlorohydroxyl benzene are effectively adsorbed by bamboo charcoal (Dwivedi et al., 2014). This is an eco-friendly and economical approach with locally available resources and minimal maintenance. Regenration of bamboo charcoal can be done by placing it in direct sunlight for 3 h and shedding impurities from it (Dwivedi et al., 2014).

8.2.2 Boiling

Boiling is one of the traditional methods to make water contaminants free. It is the simplest water purification method for marginalized population having limited access to clean water. The practice of boiling water kills disease-causing pathogens (bacteria) and their resting states including spores, cysts, and ova. After 3 minutes of bioling, approximately 100% disinfection is reported (Chaurasia & Tiwari, 2016). Boiling has certain negative impact on water quality like alteration in taste. Use of timber in water boiling practices also introduces pollutants into the air thereby causing air pollution (Chaurasia & Tiwari, 2016). It is reported that the actual use of boiling method to purify water is less as compared to that reported (Brown & Sobsey, 2012).

8.2.3 Sedimentation

Sedimentation process allow suspended large particle to settle at the bottom under the influence of gravity. Sedimentation of suspended solids depends on the size of particles and settling time. It is an effective process for turbid and pathogen contaminated water (Gitis & Hankins, 2018). In drinking water treatment plants, flocculation is typically followed by sedimentation and decantation. However, floc sedimentation through gravitation is relatively slow due to the low floc density, consequently increasing the treatment costs, and lowering process effectiveness. One promising strategy involves replacing conventional flocculating agents with ferrimagnetic iron oxide particles such as magnetite (Fe_3O_4) or maghemite (γ-Fe_2O_3). Clays and iron oxide nanoparticles have also been used in several model systems for water treatment (Housni et al., 2020). The resultant floc has high magnetic susceptibilities and can easily be separated using a gradient magnetic field. Also, ferromagnetic flocs settle faster in magnetic fields versus under gravity.

8.2.4 Solar sterilization

Exposing water to solar radiation potentially destroys disease-causing germs and pathogens. It can be done by exposing a water-filled plastic or glass container to direct sunlight. This method is also known as solar water disinfection (SODIS). Generally, the exposure period is 5 h during midday is reported as suffucient for sterilization. The exposure period should be increased if the water is turbid or the weather is cloudy. Container may be placed on iron or metal corrugated roofs for better sterilization. Water treated by solar disinfection should be stored safely and consumed within a few days as it can get re-contaminated. Solar disinfection requires more time and proper sunny weather (Chaurasia & Tiwari, 2016). Microorganisms possess different heat resistance capabilities. For example, inactivation of *Vibrio cholerae* occurs beyond 40°C whereas *E. coli* inactivates at slightly higher (around 45°C) temperature. SODIS is also effective in turbid water. Bottles and bags made of polyethylene (PE) and polypropylene copolymer (PPCO) outperformed polyethylene terephthalate (PET) due to their higher ultraviolet-B (UVB) transmittance (Pooi & Ng, 2018). Solar water disinfection is an effective and economical disinfecting technique. However, it is not used to remove chemical pollutants in water (Marugán et al., 2020).

In case of water disinfection via ultraviolet (UV, 254 nm) radiation water is passed through tubes lined with UV lamps. Direct UV exposure mutates DNA of microorganisms. Treatment with UV radiation does not alter the taste and odor of water. UV radiation does not leave any residue in treated water (Pichel et al., 2019).

8.2.5 Chemical disinfection

Disinfection of water reduces the risks associated with microbial-contamination as a result of its treatment with chemicals such as chlorine, bromine, iodine, hydrogen peroxide, and ozone (within recommended dose). Chemical disinfectants interact with organic matter and produce disinfection by-products. The chemicals used in the disinfection process may vary in terms of potency and safety (Gitis & Hankins, 2018). International Federation mostly uses chlorine tablets to disinfect domestic water. To use chemicals for disinfection, water must be filtered to make the process efficient. Adding chemicals allows the dirt and mud to settle at the bottom, making watre clear. Chemical disinfection does not ensure the complete removal of biological contaminants from water. Disinfection of harvested rainwater for drinking purposes was done by storing water in a copper vessel for 12 h and 24 h to reduce total bacterial count by 67% and 81% and *Coliform* by 85% and 90%, respectively (Patel et al., 2014).

Chlorine: Chlorine is a commonly used disinfectant to remove water-borne pathogens (especially bacteria) from drinking water. Free chlorine in a liquid, gas, and/or powder form is introduced into almost every water source. It has higher oxidizing potentialis and effective in removing turbidity with minimum residual effect. Despite these benefits, chlorination is associated with some health issues because of generation of disinfection residues and their by-products (Gitis & Hankins, 2018). These by-products are produced from chlorination of natural organic matter, and are known as chlorination by-products (CBPs) or disinfection by-products (DBPs). Hence, the concentration of chlorine for disinfection application is limited (5 mg/L) to avoid possible adverse health issues. Chlorination is simple to use, cost-effective, and robust method (Table 8.1). The presence of cyst, spore, ova and chlorine resistant species of certain microorganism require higher doses of chlorine for wastewater treatment. Chlorination is considered an important step before public water supply (Silva & Sabogal-Paz, 2021).

Bromine: Bromine in the form of elemental bromine (Br_2), hypobromous acid (HOBr), bromine monochloride (BrCl), and bromodimethylhydantoin are used as an alternative of chlorine. These chemicals are used in spas, cooling tower and swimming pools. No asthma related issues are associated with bromine mediated disinfection. However, bromine is not used to disinfect drinking water due to costs and the formation of brominated DBPs. Bromodimethylhydantoin is commercialized in the form of tablets or cartridges which dissolve slowly to release hypobromous acid. Bromine shows germicidal activity and inactivates bacteria, protozoa, and viruses. Hypobromous acid decreases the number of aerobic spore-formers, mold spores, yeasts, and non–spore forming bacteria within 30 seconds of contact time. Application of bromine along with chlorine forms hazardous and corrosive bromine monochloride. The advantages of using bromine over chlorine in disinfection process are: (1) bromine is more effective against microorganisms, (2) bromine is effective over a wide range of *p*H, particularly at low *p*H, and (3) bromine is more efficient for poor quality water. However, brominated DBPs are considered more toxic than chlorinated DBPs (World Health Organization, 2018).

Iodine: Elemental iodine (I_2) and hypoiodous acid (HOI) are used as active disinfectants in wastewater treatment. Iodine within the range of 2.5–7 ppm is used to disinfect potable water. Upon addition of elemental iodine to water, it is hydrolyzed into hypoiodous acid (HIO) and iodide (I^-). Iodine concentrations within the range of 5–10 ppm has been observed effective against various microorganisms with a contact time of 10 min at room temperature. Other species like hypoiodite and iodate (IO_3^-) show mild antimicrobial activity. Iodine works over a wide range of *p*H and has greater chemical stability than chlorine. However, more amount of iodine is required for disinfection to achieve efficacy comparable to chlorine (World Health Organization, 2018).

Alum: Alum–an aluminum sulfate salt has popularly been used as coagulant during 1980s. Later on, in 1965, reports recognized aluminum as potent neurotoxicants and linked alum to Alzheimer's disease (neurofibrillar degeneration due to aluminum salt) (Mitiku, 2020). The disease is a common form of memory loss (dementia) and interfares with the intellectual abilities of a person. The use of alum in water treatment may increase or decrease the aluminum concentration in treated water, depending on the speciation of aluminum in the source water and the presence of Al species (change or distribution) during water treatment. Application of a high amount of aluminum (3.6–6 mg/L) in treated water leads to turbidity, precipitation of aluminum hydroxides, and decreased disinfection efficiency.

Ozonation: Ozone is generated when air or dry oxygen pass through high voltage. Next to chlorine, ozone is a preferred disinfectant. Ozone is a powerful oxidant, requires in less quantity as compared to chlorine and chlorine dioxide. Ozone is the only chemical known to be effective against *Giardia* or *Cryptosporidium* and kills spores or cysts of other bacteria. However, ozone is a primary disinfectant as it does not provide protection against re-contamination because it decays rapidly in water and shows no residual effect. Ozonation process has limitations such as requirement of high energy, onsite generation and higher cost of treatment. It is also important to remove carbon produced during the oxidation process (Pichel et al., 2019).

8.2.6 Coagulation and flocculation

Coagulation is an important step to treat wastewater, based principally on the introduction of chemicals into the feed water. The coagulation process involves the destabilization of smaller colloidal particles (0.01–1 μm) and their aggregation. Coagulant in wastewater produce ionic charge opposite to that present on colloidal particles in water. For example, positively charged protein binds with negatively charged coagulants in wastewater allowing colloids and suspended particles to be converted into a bigger particle followed by their separation. However, coagulation process is unable to reduce *Coliform* levels in wastewater. Coagulation together with membrane filteration effectively removes pathogens like *E. coli, Cryptosporidium*, and cysts of pathogenic bacteria. Manufacturers like Procter & Gamble Co. (P&G) produce small POU sachets of coagulants/flocculants after optimization of coagulant dosage. These sachet from P&G are a combined flocculation/disinfection system containing ferric sulfate (a flocculant) and calcium hypochlorite (a disinfectant) (Pooi & Ng, 2018). In industries, a natural and biodegradable bioflocculant polyglutamic acid (PGA) obtained from *Bacillus licheniformis* and *Bacillus subtilis* has been used. PGA outperforms aluminum sulfate in removing turbidity and produces smaller volume of sludge. PGA is also capable of adsorbing copper ionsin water. Generation of aluminum hydroxide through electrocoagulation has shown potential in treating wastewater. Pathogen and dissolved chemicals (90% of microalgae and 97% of dissolved dye) have been removed within 72 h by wind-powered electrocoagulation system (Pooi & Ng, 2018). As far as flocculation is concerned, addition of chemicals followed by hydrodynamic shear forms particle-particle agglomerates called as flocs formed due to destabilization of particles. These flocs may be in colloidal or macromolecular range. Formation of such flocs is known as flocculation, which includes physical retention of the flocs. Flocs with high density and large dimensions as compared to constituent particle settles at the bottom (sedimentation) whie, low density and small sized flocs are removed by filtration (Gitis & Hankins, 2018). Coagulation and flocculation reduce dissolved chemical species and turbidity of water (Mitiku, 2020).

8.2.7 Aeration

Aeration process of treating wastewater is based on the principle of saturation of water with air. Maximum contact of air and water is allowed in the process. The taste and odor of water are controlled mainly by aeration. This process is also accomplished by the removal of carbon dioxide. Water is passed through the nozzle and sprayed into the air and channelized back into a storage tank. Such tanks may consist of several perforated screens placed over one another, which further improves water treatment efficiency of aeration (Chaurasia & Tiwari, 2016).

8.3 Advance technologies for water treatment

8.3.1 Reverse osmosis

Purification of municipal and industrial wastewater involves membrane separation process such as reverse osmosis (RO), microfiltration (MF), nanofiltration (NF), and ultrafiltration (UF) (Yang et al., 2019b). RO produces potable or near-to-potable water. Reverse osmosis is a membrane technology, highly efficient in removing organic micropollutants in water (Ebrahimzadeh et al., 2021). RO is a pressure-driven process based on the principle of solution-diffusion model, where dissolved solutes are eliminated through semi-permeable membrane. Globally, RO is gaining acceptance in both desalination and water treatment applications. The efficiency of process depends on operational parameters including characteristics of membrane (e.g., pore size and charge), solute (e.g., molecular weight, geometry, charge, size, and hydrophobicity), and feed water composition and other parameters (temperature, *p*H). The main limitation of RO is fouling of membrane and its clogging. The pores of membrane get clogged due to adsorption of solutes or microbial growth on membrane. Colloids, suspended and particulates compact to make cakes on the surface of membrane. RO is considered as the core of ultrapure water producing technology as it supports the majority of impurity rejection. RO is an energy-efficient process for desalination with energy budget of approximately 1.8 kWh/m^3 (Jiang et al., 2017). Benefits of RO membrane include salt rejection, high water permeability, easy maintainence and environmental friendly as compared to bottled water and quality of treated water as per public health standards. Removal efficiency of contaminants is enhanced in presence of hydrophobic-hydrophobic interactions between membrane and compounds. Ebrahimzadeh et al. (2021) reported RO as a robust barrier for the removal of most of the microparticles (based on charge and hydrophobicity). Out of 78 different microparticles, anionic microparticles displayed the lowest passage whereas neutral and hydrophilic microparticles showed the highest passage through the ESPA3 RO membrane. RO membranes are of different types including polymeric membranes (cellulose acetate, aromatic polyamide, cellulose triacetate and thin film membrane), ceramic membranes (metal oxide membranes, carbon-based membranes), and mixed matrix membranes (Yang et al., 2019b).

8.3.2 Electrodialysis

Electrodialysis (ED) is a promising and established technology used for more than 60 years to treat municipal sewage, brackish water, and industrial wastewater. ED removes ionic and non-ionic components under the influence of electric current. It has been driven by the development of ion exchange membrane (IEM) with improved electrochemical and physicochemical characteristics. ED system consists of ion exchange membrane (IEMs), power supply, electrodes, auxiliary materials (spacers, gasket seal), and electrodialysis stack (Al-Amshawee et al., 2020). Between two electrodes (cathode and anode), a voltage passing through membrane (IEM) is applied which is used to separate ions from aqueous solution or uncharged matter. Several cation and anion exchange membranes (CEMs and AEMs, respectively) are present inside the ED stack. Membranes act as a barrier and inhibit the migration of nutrients, thus facilitates the movement of ions according to their charge. Electrolyte solution is circulated throughout electrode rinse compartments. Moreover, ED system is flexible in term to adjust with oscillating behavior of photovoltaic power generation. ED makes it possible to separate selective monovalent ions from divalent ions to produce water suitable for irrigation from feed water (Al-Amshawee et al., 2020).

It has wide applications, such as drugs and food industry (sugar syrup purification), biotechnology, electronics, heavy metal removal, and in other chemical process. In waste water treatment, ED removes potassium, nitrogen, phosphorus, and organic and inorganic matters. ED is highly efficient in case of iron compounds, divalent cations, surfactant, and nitrates. ED has more water recovery rate, long membrane life and easy operation versus RO system. Pre-treatment and post-treatment are not required in ED. Recovery of water and other products via concentration, desalination, dilution, valorization, and regeneration can be done by ED technologies. Chemical-free treatment, high selectivity and separation efficiency make ED an appropriate method for wastewater treatment (Gurreri et al., 2020). Reverse electrodialysis (RED)–an opposite process of ED involves electricity production by converting the mixing free energy of two streams with different salt concentrations (Gurreri et al., 2020).

8.3.3 Electrochemical water treatment

In the industrial sector, electrochemical processes have been proved highly efficient water treatment method, particularly for the heavy metal ions with high degree of selectivity. Electrochemical systems offer a number of benefits, including the ability to operate at ambient temperature and pressure, as well as reliable performance and flexibility to adopt changes in the composition and flow rate of the influent (Tran et al., 2017). Electrochemical process eliminates heavy metals as hydroxide in waste water, produce energy like hydrogen and oxygen and readily enhance continuous process with greater efficiency (97% removal, 20 h) (Tran et al., 2017). An electric current induces metal ions to migrate toward the electrode surface, where they enrich on the electrode's double layer. As a result of a redox reaction on the electrode, pure metal ions bind or precipitate at the electrode surface, allowing in-situ enrichment of metal ions or even the formation of metal products. The electrochemical methods are systematically divided into four major groups: E-adsorption recovery, E-oxidation recovery, E-reduction recovery, and E-precipitation recovery. When an external voltage is provided to a standard electrochemical reaction cell, cations and anions go to the cathode and anode, respectively. E-adsorption recovery is a technique in which an electrical double layer traps the metal ions electrostatically and stores them capacitively. In E-oxidation recovery, heavy metal ions are recovered by the electrochemical oxidation processes where metal anions lose electrons directly on the anode surface or indirectly triggered by active oxygen species that are generated in the electrolyte. E-reduction recovery is the process by which metal ions directly or indirectly receive electrons from the cathode surface before being deposited as metallic elements. E-precipitation recovery is the process of precipitating heavy metal ions in alkaline zone, arising adjacent to the cathode surface. Porous carbon membrane displayed repulsion between polystyrene microspheres and membrane under a negative voltage supply, whereas adsorption and E-oxidation are enhanced under a positive voltage supply (Chen et al., 2020). Heavy metals could be removed electrochemically with a deposition capacity of around 2300 mg/g (Wu et al., 2019). Electrochemical treatment of phenolic wastewater using ultrasound assistance technique showed that the phenol removal efficiency was better at 45 kHz than 80 kHz, as well as directly proportional to the current supplied and favorable under acidic conditions (Zhang et al., 2020).

8.3.4 Advance oxidation water treatment

Advanced oxidation process (AOP) is a chemical method of wastewater treatment which efficiently degrades organic pollutants (bio-recalcitrant and inactivation of pathogens) via oxidation. Initially in 1980s, AOPs were recommended to treat drinking water. Fig. 8.2 represents processes involved in AOP. During oxidation of pollutants, various reactive oxygen species (ROS) (or free radicals) like superoxide radicals, hydroxide radicals, and sulphate radicals are produced in enough quantity to produce reclaimed effluent (Dhaka et al., 2022). Hydroxyl radicals are highly reactive, non-selective in nature, attack a broad range of contaminants, and have high oxidizing capability. Carbon radicals are generated when hydroxyl radicals react with organic contaminants, further producing peroxyl radical (ROO) in oxidizing environment. In tertiary treatment of wastewater hydroxyl radicals are generated via ozonation, hydrogen peroxide, UV irradiation, ultrasound, and catalysts like TiO_2 (Garrido-Cardenas et al., 2020). It is a robust, effective, and economical process to remove organic pollutants without producing secondary waste during wastewater treatment AOP is considered as a green process for wastewater treatment; works without harming human life and environment (Kanakaraju et al., 2018).

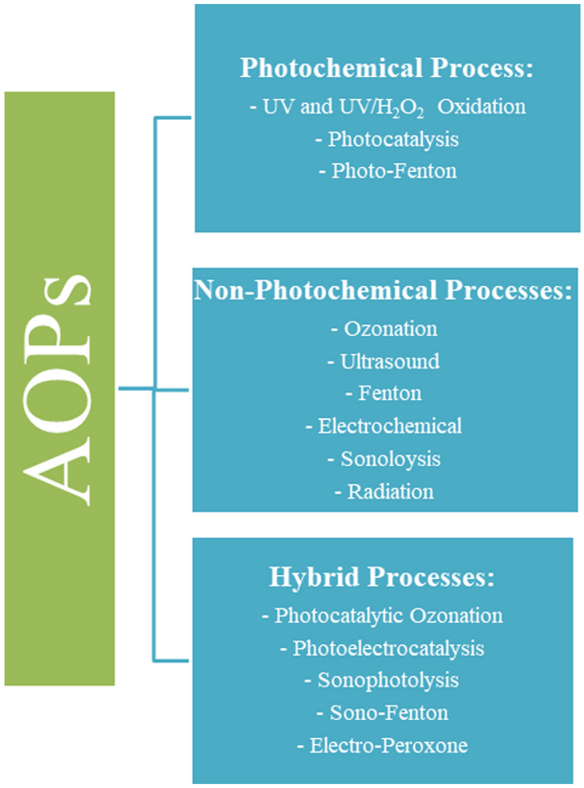

FIGURE 8.2 Processes involved in advance oxidation process.

8.3.5 Membrane filtration

Membranes are thin physical barriers, selectively allow molecules to pass through it. Membranes may work as dead-end filter and cross flow filter. Generally, isotropic and anisotropic are the types of membranes. Isotropic membranes are chemically and structurally homogeneous, e.g., electrically charged membranes (cation or anion exchange membrane), microporous and nanoporous membranes. Anisotropic membranes are chemically and structurally heterogeneous. Anisotropic membranes are of two main types: composite membranes (coated film, thin film) and phase-separation membranes (Loeb-Sourirajan membranes). Reclamation of wastewater can be done by techniques like ultrafiltration and microfiltration integrated with activated sludge which removes particulates,

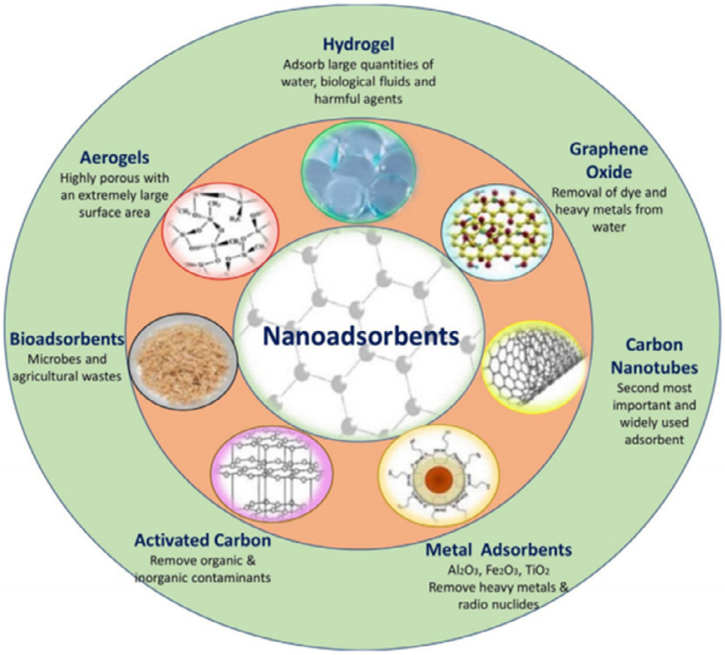

FIGURE 8.3 Commercially available nano-adsorbents.

suspended matter, and biological contaminants. Further, association of reverse osmosis and nanofiltration leads to sustainable water reclamation (Hube et al., 2020). However, wastewater treatment through biological membranes depend upon conditions including oxygen level, feed water composition and temperature. Driving forces such as osmosis, thermal, pressure, and electrical make membrane filtration more efficient along with their reduced price.

Some polymers have been used in membrane filtration for water purification. Polymers are porous and they form layer to provide support for UF, RO, MF, and NF. There are advantages of using polymers in membrane filters compared to inorganic membranes like ease to handle, less expensive, and more flexible. However, there are a few drawbacks like chemical degradation, fouling of membrane, and hydrophobic nature of most polymers (Giwa et al., 2019).

8.3.6 Nanoadsorbents

Nanomaterials are the best feasible alternatives with high surface area and porosity for chemisorption or physisorption. Adsorption is a surface phenomenon used to remove organic and inorganic contaminants from wastewater. Adsorption is an efficient, cost-effective, easy to apply, and versatile unit process to treat wastewater. Sorbents like activated carbon, charcoal, clay, chitosan, natural zeolites, biochar, modified agricultural biomass potentially eliminates the contaminants from feed water (El-Sayed, 2020), thus avoiding the limitation of traditional sorbents. Nanoadsorbents (1 to 100 nm) are preferred due to its multiple adsorption sites, high surface area, high porosity, short intraparticle diffusion distance, functional groups, high surface binding energy. All these characteristics increases the chemical activity and adsorption potential of nanoadsorbents and make them sustainable alternative for wastewater remediation. Nanoadsorbents can be prepared by top down or bottom up approach (El-Sayed, 2020). The criteria for nanoadsorbent selection include (i) non-toxicity, (ii) high sorption capacity and selectivity, and (iii) ease recovery (Gupta et al., 2016). Fig. 8.3 represents commercially available nano-adsorbents.

Polymeric nanoadsorbents: These are composite materials generally classified into carbon polymer/nanotube nanocomposites, graphene nanocomposites, metal/metal oxide nanocomposites and dendrimer-based nanocomposites. Apart from high surface area, polymeric adsorbents have mechanical rigidity, ideal pore size distribution and rich surface chemistry (El-Sayed, 2020).

Metal and metal oxide based nanoadsorbent: Drinking water contaminated with heavy metal are remediated with nanoparticles of silver, gold, alumina and zinc. However, nanometal oxides of titanium oxide (TiO_2), aluminum oxide (Al_2O_3), magnetic nanoparticles, and nano-zero valent iron are highly efficient for the removal of heavy metals and radionuclides (Jain et al., 2021). Goethite is a crystalline and stable oxide of iron which has been used for adsorption of lead, copper, zinc and cadmium. TiO_2 nanoparticles have high chemical stability, high efficacy, lower toxicity to humans, strong disinfectant property, and cost effectiveness as compared to other alternatives, which make them a suitable option for wastewater treatment. Magnetite has been used to remove arsenic from ground water whereas nano-zero valent iron is used against chlorinated hydrocarbon solutions and per-chlorates (El-Sayed, 2020).

Zeolites: These are aluminosilicate minerals possessing large number of electrostatic holes. Nanozeolites (10–500 nm), exhibit more number of adsorption sites, high adsorption rate and more surface area (400–1000 m^2/g) (El-Sayed, 2020). Moreover, zeolites with silver particles have shown antibacterial properties. These have been applied as a fixed adsorbent in the beads or pellets form.

Carbon nanotubes (CNTs): Carbon nanotubes are cylindrical carbonaceous materials composed entirely of hexagonally arranged carbon atoms. CNTs are used to remediate wastewater. These nanostructures have large micropore volume, high surface area with exceptional electrical, mechanical and thermal properties. CNTs are of two types, Single walled carbon nanotubes (SWCNTs) and multiwalled carbon nanotubes (MWCNTs). SWCNTs are expensive than MWCNTs which limits their widespread applications (Jain et al., 2021). Regeneration of CNTs can be done by *p*H modifications (El-Sayed, 2020).

8.3.7 Metal-organic frameworks (MOFs)

Metal-organic frameworks (MOFs) are a fascinating new class of nanoporous inorganic–organic hybrid materials with one, two, or three-dimensional topological structure. MOFs are synthesized by combining organic ligands with metal ions or clusters. In industrial and academic communities, MOFs are among the most promising separation material owing to their tunable physiochemical properties including large surface area, regular porosity, high crystallinity. MOFs containing membranes feature adaptable compositions, tunable structures and extremely good separation capabilities act as promising scavengers in water pollution control, such as oily and micro-pollutant removal, heavy metal elimination, organic dye decontamination, as well as desalination. The quality of MOF-containing membranes is primarily determined by its efficacy, antifouling properties, compatibility, and dispersibility. MOFs have many advantages along with a few limitations such as (i) aggregation of nanosize powdered MOF which blocks the filter during water treatment and reduces adsorption efficiency; (ii) practically powdered MOFs excessive consumption and reduced durability increase the operational cost; (iii) large-scale production of MOFs with high selectivity requires considerable effort as membranes are likely to be engineered more uniformly than other nanocomposite membranes and (iv) MOFs production methods are still immature, life cycle is uncertain, and biocompatibility is low (Yu et al., 2021). A water-stable MOF is generally has strong coordination bonds or significant steric hindrance, preventing the potential degradation of the bond between the metal and ligand in moist environment.

MOFs can be prepared by processes such as solvothermal, ultrasound, microwave electrodeposition, vacuum filtration, and mechanochemistry methods (Li et al., 2020). Size exclusion, electrostatic interaction, π–π stacking, and hydrogen bonding contribute to the removal capabilities of MOF-containing membranes. Linkers are often employed to create different MOFs since they are inexpensive and give MOFs favorable physiochemical features. UiO-66 and ZIF-8 are prepared by using 1,4-benzenedicarboxylate (BDC) and 2-methylimidazolate (MeIM) as linkers, due to their excellent stability and hydrophilicity (Kadhom & Deng, 2018). The performance of MOF based forward osmosis, reverse osmosis, nanofiltration, and ultrafiltration membranes in water purification rely on the synthesis techniques that have a significant impact on configuration of MOF-based membranes. Ultrathin films such as polyamide, polyvinylidene fluoride, polydopamine, polysulfone, polyethersulfone, polyimide, polyacrylonitrile, and cellulose acetate, act as supporting membranes have been used for improving antifouling, permeability, selectivity, and efficiency of MOF based membrane comprising MOFs (Cu-BDC, Cu-BTC, MIL-100, MIL-101(Cr), MIL-101(Fe), MIL-125, UiO-66, ZIF-8 and HKUST-1) (Jun et al., 2020). MOFs containing membranes have frequently been used for water remediation. The maximal adsorptive capabilities of chlorpyrifos were significantly enhanced, 160 mg/g to 356 mg/g using 60% Al-MOF@cellulose acetate (MIL-53-NH_2@CA) versus cellulose acetate only (Abdelhameed et al., 2021). Sm-MOF/GO membrane was prepared through vacuum filtration over graphene oxide layer. As a result of three-dimensional network structure of Sm-MOF, rhodamine B (RhB) was adsorbed and then transferred to GO, enabling the removal of dyes from wastewater quickly and efficiently. In comparison to a pure GO membrane, the permeance was three times greater with rejection rate >91%. Substantial rejection was still present after continuous 5.5 h filtration, confirming long-term stability (Yang et al., 2020).

8.4 Low-cost techniques for water purification for rural area

8.4.1 Bioremediation

Bioremediation process restores environment back to the normal conditions with the help of biological agents such as microorganisms. It is a sustainable and ecofriendly approach to reduce pollutant level and remediate environmental pollution, where an original pollutant is converted into less toxic or non-toxic one. Bioremediation is achieved through degradation, transformation, and mineralization. Large organic molecules are broken down to smaller one, where carbon serve as an energy source for microorganisms. Bacteria, fungi, algae, and plants are capable to detoxify pollutants under specific conditions of temperature, *p*H, and availability of nutrients. Biodegradation of pollutants under aerobic conditions produces carbon dioxide and water whereas in anaerobic conditions methane is produced (Azubuike et al., 2020). Bioremediation of contaminated water depends upon the type and concentration of pollutants present in it. Pollutants may be dyes, agrochemicals, hydrocarbon, chlorinated compounds, medicinal waste, and plastic waste. Microorganisms employed in bioremediation undergo biosorption or bioaccumulation mechanism during wastewater treatment. Bioremediation includes *in-situ* or *ex-situ* approaches. *In-situ* is an on-site remediation approach which employ indigenous microorganisms. These microorganisms proliferate in appropriate nutrient and environmental conditions. *Ex-situ* bioremediation is an off-site remediation approach (Azubuike et al., 2020).

Bacteria like *Bacillus sp., Pseudomonas sp., Arthrobacter, Serratia marcescens, Ochrobactrum sp., Desulfovibrio vulgaris*, transforms toxic Cr (VI) to less toxic Cr (III). *Arthrobacter psychrolactophilus* Sp 313 reduces the protein concentration in wastewater. Cyanobacterial strains of *Synechococcus sp.* strain and *Synechocystis minima* have been used to remove nitrate. *Phormodium sp.* reduces the nitrogen and phosphorus level in water. Heavy metals like Cu, Zn, Co, Mn, and Pb were extracted by *Anabaena subcylindrica* and *Nostoc muscorum. Oscillatoria formosa* removes dye from wastewater. Anoxygenic bacteria like *Rhodobacter sphaeroides* removes pharmaceutical products in water (Ojha et al., 2021).

Phycoremediation, i.e., use of algae such as *C. vulgaris, S. quadricauda,* is an emerging field in bioremediation (Pacheco et al., 2020). Generally, *Spirulina platensis, Microalgae* G23*, Cosmarium sp.* are used to treat wastewater. Fungus, e.g., *Penicillium, aspergillus, Rizopus* and *Saccharomyces* act as a potent biosorbent against various organic and inorganic contaminants (Ojha et al., 2021).

8.4.2 Ceramic filters

Ceramic water filter is a flexible method of water filtration that use natural media to eliminate bacteria and sediment from wastewater. In ceramic filters, water passes through a permeable clay material (pore size 0.3–0.6 μm) which reduces the risk of water borne pathogens. Size exclusion and adsorption onto the filter material serve as the primary removal mechanisms. These filters are flowerpot shaped and have capacity to hold around 8 L of water. Porosity, local availability, and low vitrification temperature of earthenware clay make it the best choice for ceramic filter production. Inner wall of ceramic filter remains impregnated with colloidal silver. These filters are portable, affordable, light weight, and require low maintenance and has long life (approximately 6-24 months). Ceramic filters allow to retain the taste, temperature, and turbidity of water (Akosile et al., 2020).

8.4.3 Natural coagulation and precipitating agents

One of the straightforward processes for effective removal of suspended particles and contaminants from water is coagulation. In comparison to artificial coagulants, natural coagulants are ecofriendly, cost efficient, sustainable, biocompatible, abundant, and safe to use. Natural coagulants can be derived from a number of natural sources, including plants, microbial organisms and animals. However, majority of the studies have been focused on natural coagulants derived from plants and marine biomass. Natural coagulants include Roselle seeds (*Hibiscus sabdariffa), Moringa oleifera, Azadirachta indica,* Hyacinth beans (*Dolichos lablab)*, cactus, chitosan, tannins, and seeds of Nirmali (*Strychnos potatorum*) and watermelon. Plant-based natural coagulants have been reported to be efficient in eliminating turbidity, color, organic matter, and microbes. However, there have been a limited industrial applications of natural coagulants in wastewater treatment owing to their high processing cost and inconsistent performance. As a result, in order to reap the most benefits, researchers frequently concentrate on novel natural coagulants. Nature of coagulating agent, pollutant and mixing procedure affects the coagulation performance. Negatively charged natural coagulant has higher coagulation activity against positively charged suspended particulate and vice versa. Particle bridging depends upon the molecular weight of natural coagulant. Higher the molecular weight of natural coagulant, stronger will be the bridging with particles, which improves settling by generating strong flocs. Another crucial phase in the coagulation process is mixing. Micro flocs are created when coagulants and suspended particles interact more quickly during mixing. The aggregation of small flocs into larger flocs is caused by slow mixing (Nimesha et al., 2022). Charge neutralization and polymer bridging function as the primary mechanisms for regulating the coagulation activity. Chitosan is a positively charged long polymer, present in fungi, yeast, marine invertebrates, and insects, which coagulates negatively charged colloidal particle by adsorption and hydrophobic flocculation. Anionic polyelectrolytes, derived from Nirmali (*Strychnos potatorum*) seed extracts (40 mg/L of dosage) has been reported to remove 93% turbidity from waste water (Alenazi et al., 2020). Water-soluble cationic coagulant proteins are present in moringa extracts. The coagulation efficiency decreases in alkaline water. Natural coagulating and precipitating agents works similar to alum for removing hardness of water. However, water treated with neem and moringa had fewer microbes versus water treated with alum (Asemave & Ayom, 2021). Wastewater treatment can be facilitated by using tannins, containing anionic phenolic groups. Mucilage of cactus leads to coagulation through the formation of chemical bridges via hydrogen bonds or dipole interactions (Nimesha et al., 2022). The extract of Pine cone has 82% coagulation efficiencyand maximum coagulation activity occurred at first hour (Hussain et al., 2019).

8.4.4 Nanobiochar

In comparison to bulk biochar, nanobiochar exhibits superior physicochemical characteristics, such as high catalytic activity, unique structure, and large specific surface area. Nanobiochar act as adsorbents with a high capacity and affinity for micropollutants because of their large specific surface area. Pinewood-derived nanobiochar (with average particle size 60 nm), removed up to 74% and 95% of carbamazepine (CBZ) after 1 and 6 h of contact time, respectively (Naghdi et al., 2019). As compared to other carbonaceous substances (activated carbon, carbon nanotubes, and graphene oxides) nanobiochar adsorbs pollutants more efficiently with less contact time. The prevalence of pharmaceuticals in the waterbodies has negative impacts on human health and ecosystem because of the high mobility and pk_a of drugs. The most persistent pharmaceutical in wastewater is metformin hydrochloride, an anti-diabetic drug. Sodium hydroxide modified artichoke leaves nanobiochar proved effective at removing metformin hydrochloride from tap water, wastewater, and sea water with removal efficiencies of 87.0%, 97.0%, and 92.0%, respectively (Mahmoud et al., 2021). The removal efficiency of tartrazine and sunset yellow dyes by triethylenetetramine and sulfuric acid modified corncob nanobiochar (100 mg/L each) from tap water, sea water, and wastewater were 90.3–92.4% and 90.0–90.4%, respectively (Mahmoud et al., 2020). Wheat straw derived ball-milled magnetic nanobiochar exhibited removal efficiency of more than 99% for tetracycline (TC) and Hg (II) from aqueous solution. The adsorption capacities for TC and Hg (II) were 268.3 mg/g and 127.4 mg/g, respectively (Li et al., 2020). Adsorption of pharmaceutical by nanobiochar has been reported to increase with rising solution temperature, and decreased with raising solution ionic strength. Under the influence of microwave irradiation, nanobiochar prepared from Cynara scolymus leaves does ultra-fast removal of Sm(III) and Cd(II) from aqueous solutions via as ion exchange, precipitation and complexation reaction mechanism (Housni et al., 2020).

8.4.5 Activated carbon

Activated carbon (AC) is a porous carbonaceous material produced by pyrolysis of biomass. It is best suited and highly efficient carbon material used to remediate wastewater. On the basis of average particle size, AC can be of two types: granular (GAC, 0.2 and 5 μm) and powder (PAC, <80 μm). Due to high surface area, it has a greater number of binding sites to interact with contaminants. AC comprise 80% of carbon and the remaining portion is metals, nitrogen and oxygen (Sweetman et al., 2017). Chemical modifications such as acid treatment (using H_2SO_4, HNO_3, and HCl) and alkali treatment using KOH, NaOH, and NH_3) improve the selectivity of AC towards certain pollutants. It increases the acidic or basic functionalities of AC which helps to remove specific contaminants. Modification using microwave heating and steam explosion creates extensive micro, meso, and macro pore (<2 nm, 2–50 nm and >50 nm, respectively), thus improves the adsorption capacity of nanoadsorbent. Most of the POU treatment methods comprised of activated carbon (Sweetman et al., 2017).

8.4.6 Point-of-use water treatment

Adopting on-site water purification and storage is a sustainable approach in areas where water for domestic purposes reaches through extensive piping systems. It is, however, costly to establish a centralized water treatment facility in developing countries and rural areas because of the low density of housing. Point-of-use technology is a system that treats water on-site to remove pathogens. On-site drinking water treatment systems are installed near water taps, showers, and dispensers so that water can be purified before being used for cooking, bathing or drinking. The systems need little maintenance and are easy to operate. The key technologies that are accessible include filtration, disinfection, flocculation, coagulation, reverse osmosis, and remineralization. Removal of turbidity via flocculation and coagulation weakens the framework that supports bacteria, eventually eliminating them from water. POU sachets have been developed through optimization and development of flocculants. Furthermore, a multibarrier strategy should be used to properly assure pathogen elimination. To reduce the possibility of bacterial infection, users can integrate filtration and disinfection process, such as biosand filtration and solar distillation for wastewater treatment.

Lanthanum coated ceramic materials, which are inexpensive and ecologically beneficial, were prepared and tested as a new filter medium for POU water treatment of hazardous waterborne contaminants, As(V) and As(III). These materials showed good adsorption capacities for As(V) (24.8 mg/g) and As(III) (10.9 mg/g) (Yang et al., 2019a). Hence, in underdeveloped nations without centralized water treatment facilities, La-coated ceramic material act as a viable medium in POU domestic drinking water treatment for the removal of arsenic. Treating soda-lime-silica particles with alkali; a portable, non-electric, gravity-driven POU water disinfection system is developed that eliminates 99.5% of *E. coli* OP50, a gram-negative bacteria (Dixit et al., 2019).

Portable POU devices including MSR's Sweet water, SteriPEN, Vestergaard's LifeStraw, HTI's Expedition, Katadyn's Hiker, and disinfectant solutions as well as tablets are also available for the purification of water. These portable water purifiers prices range between $70 and $325, making them expensive for average person in developing nations like India. Cost effective portable POU can be developed via modification of the chlorination process that involves addition of chlorine to the water in a more efficient manner. Chlorine-releasing substances such as sodium hypochlorite, calcium hypochlorite, and dichloroisocyanuric acid and tri-chloroisocyanuric acid are the most often utilized chemicals. One-time-use disinfectant-releasing stirrer and multiple-use pen are used to purify the glass of water whereas stick may be used several times to purify buckets of water within a short period of time (Patil et al., 2020).

For the aforementioned technologies, a number of issues still need to be dealt with. Coagulants and flocculants are recoverable and reusable in drinking water treatment but the recovery procedure costs a lot since it utilizes a lot of alkali and acid. The nanoparticles might be released into the environment through improper disposal. Hence, users should be informed about the proper disposal of nanoadsorbents. Filtration and disinfection-based technologies can get rid of pathogens from wastewater, but cannot remove dissolved pollutants like arsenic and chromium. Therefore, pre-treatment or post-treatment techniques such as adsorption, coagulation, and ion exchange are essential.

8.5 Conclusion

A number of conventional techniques for drinking water treatment including filtration, boiling, sedimentation and decantation, solar sterilization, chemical disinfection, coagulation and flocculation, and aeration have been employed. These techniques, mainly in terms of efficiency, lag behind in comparison to advance drinking water approaches. These methods suffer with issues like inability to achieve desired level of purification and the demand. Advanced drinking water techniques include reverse osmosis, electrodialysis, advanced oxidation, membrane filtration and nanotechnology based approaches. These techniques are effective and efficient in water treatment. However, these techniques inherit drawbacks like poor wide spread accessibility and high operational cost. Conventional methods of water purification may therefore be economically feasible and socially acceptable for the marginalised section of the society. Modification in conventional methods or their integrated application may enhance their efficiency, reduce treatment time and cost. These methods can be used to accomplish Sustainable Development Goal 6 which ensures availability and sustainable management of water and sanitation for all by 2030. Therefore, there is a need for the development of low cost water purification processes.

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Chapter 9

Alternative water resources in rural areas: Smart solutions for a sustainable future

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9.1 Introduction

Water scarcity is becoming a serious global concern, especially in semi-arid and arid regions which in turn traditional water resources are constantly under mounting stress. From the literature, it is evident that there is a huge inequality of access to improved water sources between rural and urban societies due to disparities in economic growth as well as resource distribution (Adams et al., 2018; Armah et al., 2018; Chaudhuri & Roy, 2017). About 2.2 billion people worldwide face unavailability of safe drinking water, 4.2 billion people still do not have access to safe sanitation services and three billion lack basic hand washing facilities (Siegel, 2021; WHO & UNICEF, 2019). Eight out of ten people from rural communities lack safely managed drinking water services in developing and least developed countries (WHO & UNICEF, 2019). This being the case, the Sustainable Development Goal (SGD)—6 on "universal and equitable access to safe drinking water for all" will be difficult to achieve (Küfeoğlu, 2022).

In recent decades, there have been numerous efforts from various governments and non-governmental organizations (NGOs) throughout the world for water management in the rural sector. For instance, National Rural Drinking Water Programme (NRDWP), an initiative by Indian Government was launched in 1999 for providing adequate water for rural communities without compromising water quality (Das et al., 2021; Wescoat et al., 2016). Similarly, Rural Drinking Water Safety Project (RDWSP) was implemented for the period from 2005–2015 for about 500 million rural residents. For a sustainable water supply and sanitation in rural areas, the following components are vital in achieving the success of such programs—(1) a thorough understanding of context-specific knowledge, (2) clear focus or vision, (3) baseline studies, (4) continuous monitoring, and (5) evaluation (OECD, 2012). Factors like inconsistent data, unsystematic water sampling, incomplete spatio-temporal data, simplistic distinctions between rural and urban regions, etc. are often challenges faced in implementing rural water management projects (Wescoat et al., 2016).

The concept of alternative water resources was put forth as a sustainable solution for the aforementioned water shortage issues (Dalezios et al., 2018; Lee et al., 2016). For several centuries, water harvesting has been used for meeting the needs of urban as well as rural communities (Khan et al., 2020; Yannopoulos et al., 2019). In addition to water management, harvesting technique is beneficial for increasing the productivity of rain-fed farming. Owing to the mounting call for water-efficient irrigation technologies such smart strategies can be applied to significantly improve economic and environmental conditions (Casadei et al., 2021). Micro irrigation is a feasible solution for saving water in rural communities. Along with drip and sprinkler irrigation practices, innovative technologies with sensors, watering systems based on artificial intelligence, etc. can be incorporated (Levidow et al., 2014).

One of the most ancient technologies includes traditional water harvesting and storage systems developed and established indigenously (Akpinar & Cecunjanin, 2014; Oweis et al., 2012). Traditionally, water harvesting units like tanks, ponds, lakes, etc. for rainwater storage have played an important role in rural development (Pradhan & Sahoo, 2019). Likewise, these engineered structures had site-specific design and construction in addition to pertinent political and legal frameworks. This argues that in the context of ongoing demands for modernization, traditional water conservation technologies should be prioritized and revived as a sustainable alternative for water supply as well as for integrated development. Based on archaeological studies, it is evident that traditional strategies for water resources management

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are effective for socio-economic wellbeing in rural context (Pani et al., 2021).

Apart from traditional harvesting units, several types of contemporary rainwater harvesting (RWH) strategies have also been developed successfully.

Economically feasible "blue water" (surface and groundwater) can be produced by means of water harvesting (Ahmed et al., 2022; Sauvé et al., 2021). In-situ RWH structures enhance "green water" that is stored in the soil at the roots of plants without a decline in blue water (Worku et al., 2020). Despite the diverse methodologies applied, alternative water resource research is still active worldwide to fill the existing socio-economic and technological gaps (Amos et al., 2018; Liu et al., 2021; Rodríguez et al., 2022; Yerri & Piratla, 2019). Recently, real-time control (RTC) technology incorporated in RWH systems has been developed for enhancing water supply, flood risk management, and sustaining environmental flow in rivers (Liang et al., 2019; Snir et al., 2022; Xu et al., 2020).

Other alternative water technologies include water reuse, desalination, etc. Those strategies are not discussed in this chapter, as their applicability is constrained in rural areas. Moreover, the present methodologies involving greywater reuse and desalination process are still very expensive for a rural region to afford. This chapter gives a brief outline of water-efficient irrigation strategies, traditional water harvesting practices, and other available alternative water resources applicable in rural communities. Also, various possible advantages and disadvantages of these resources are also discussed briefly.

9.1.1 Water efficient agricultural practices

Practicing water efficient irrigation is equally important as other management options viz., artificial recharging, water harvesting, etc. Micro irrigation techniques are recommended internationally to minimize water use. These are a wide variety of techniques that enhances the efficacy of water use in agriculture, in turn assisting farmers in conserving irrigation water. Soil moisture conservation is an important means of achieving agricultural water use efficiency (WUE) (Deng et al., 2006). Although rural communities all over the world have adopted micro irrigation systems at a reasonably high rate over the past 10 years, the overall adoption rate is still quite low. Less than 6% of the world's irrigated land is covered by drip and sprinkler irrigation systems, and in India, they cover 3.88 Mha, with 1.46 Mha under drip irrigation and 2.42 Mha under sprinkler irrigation (Kumar et al., 2022).

However, these approaches are skewed to some extent. Farmers should install these systems in farmlands so they may fully benefit from them in terms of water conservation. But this application is restricted in small fields due to the high capital, operational, and maintenance costs of the pump which is unaffordable for marginal farmers (Nakayama & Bucks, 2012). Instead, the installation of these systems in large farm fields considerably reduces the cost per unit area. Among these techniques, drip systems are the most water-efficient tools (Kumar et al., 2011). In hard rock terrains, pressurized irrigation systems are suitable for pumping for long hours. Lack of extension services and subsidies are often challenges faced by marginal farmers in adopting pressurized micro irrigation systems (Kumar, 2016).

While surface drip irrigation is a viable method in terms of water conservation, it has certain limitations like evaporation loss from the soil surface, the difficulty faced at the field during anchoring laterals and removing before and after each crop, etc. (Jat et al., 2020). In this context, subsurface drip irrigation serves as a better option by limiting evaporation loss and reducing labor costs (Patra et al., 2021). Also, this technique allows the application of water and nutrients directly to the root zone and direct seeding with no-tillage practices (Jat et al., 2019; Zahoor et al., 2019).

Recent studies show the influence of incentives based on farmers' requirements for electricity, energy-efficient irrigation systems, and the adoption of drip systems (Bahinipati & Viswanathan, 2019; Fishman et al., 2016). Besides these factors, the yield increase is highly dependent on agronomic practices, soil type, local weather conditions, geohydrology, etc. (Kumar, 2012). Microtube drip systems and mini sprinkler systems are best appropriate for saving water in horticulture fields (Goyal, 2021).

Water use efficiency is an important parameter to be considered for water conservation and higher yield at the same time. According to FAO (2020), it is the ratio of estimated irrigation water requirements to the actual water withdrawal. At the field scale, there are two commonly used WUE measures of an irrigation system—application efficiency (AE) and requirement efficiency (RE) (Dehghanisanij et al., 2022). These two parameters are estimated using the following equations (Koech & Langat, 2018):

$$AE = \frac{\text{volume of water stored in root zone}}{\text{total volume of water applied}} \tag{9.1}$$

$$RE = \frac{\text{volume of water stored in root zone}}{\text{water deficit prior to irrigation}} \tag{9.2}$$

One disadvantage of traditional irrigation systems is that irrigation water is applied without taking into account soil properties, weather conditions affecting evapotranspiration in crops (Barman et al., 2020; Vories et al., 2021). This results in overexploitation of irrigation water, subsequently leading to fertilizer leaching, deep percolation, and plant stress (Bwambale et al., 2022).

In order to tackle the issues associated with water wastage, the application of artificial intelligence (AI) and the internet of things (IoT) is recommended as an alternative to conventional systems (Tace et al., 2022). Precision irrigation (PI) technologies permit the application of water in the field based on the precise evaluation of crop water requirements (Jimenez et al., 2020). Smart/AI irrigation systems incorporated with soil, plant, and weather monitoring sensors perform well in allocating inputs thus reducing uncertainties (Abioye et al., 2020; Tsang & Jim, 2016). Underground sensors have been used widely in several studies but a few demerits are reported regarding this technique: (1) expensive waterproof materials, (2) slow down setup, (3) impact of soil chemistry on sensor materials interfering signal, and (4) dependence on fixed infrastructure. In this case, proximal sensing is advantageous over underground sensors. Tace et al. (2022) proposed a cost-effective, low-consumption-intelligent, and flexible-irrigation technology based on machine learning algorithms. In a recent study, Cheng et al. (2021) proposed a stochastic programming model with a two-stage mechanism involving increased water prices and water-saving technology subsidy. This method was put forth with the idea of encouraging farmers to minimize water usage and reduce farming of high water-consuming crops.

In short, micro irrigation systems based on AI can have a pronounced effect on WUE and crop productivity. Subsidizing will further persuade farmers to adopt these technically advanced irrigation systems in rural areas.

9.1.2 Alternative water systems

9.1.2.1 Harvesting practices

Water harvesting is one of the ancient water conservation technologies practiced around the globe for several centuries (Akpinar & Cecunjanin, 2014). In past, indigenous RWH systems were constructed and effectively designed for primary water supply, especially in arid and semi-arid regions. These minimally intrusive systems were built often using local materials and adapted to fit the local geographical conditions and regional rainfall patterns (Bhattacharya, 2015).

During ancient times, well-engineered traditional harvesting and storage structures were developed in several parts of the world including the Middle East, Pakistan, India, Thailand, Jordan, Ethiopia, Egypt, China, and so on (Akpinar & Cecunjanin, 2014; Oweis et al., 2012). RWH in specific hydraulic structures including cisterns, rock pits, micro dams, ditches, etc. were practiced in ancient China. Cistern harvesting dates back in the prehistoric period (ca. 3200–1100 BCE) in Minoan villages which were later enhanced by ancient Greeks (Khan et al., 2020; Yannopoulos et al., 2019).

In order to manage the water shortage and flood disaster, it is encouraged that water harvesting techniques be made available to the community (Yannopoulos et al., 2019). Historically, ancient Arabian (Yemen) traditional structures have been looked up as one of the most sophisticated systems (*sayl*) where flash floodwater was harnessed along major *wadis* (Aklan et al., 2022; Harrower & Nathan, 2018). In southern Mesopotamia, RWH has been utilized for irrigation since 4500 BCE, and it is still used today to obtain both drinking water and water for agriculture (Oguge, 2019).

9.1.2.2 Traditional water harvesting: Indian context

Water harvesting structures have been designed and constructed region-wise in India for centuries (Dadhich & Shaban, 2020). A few examples of these systems are cited in this section. *The ahar-pyne* system of Bihar region (Eastern India) is an integrated structure with *ahar*, a rectangular (sometimes U-shaped) tank built at the end of an artificial channel *pyne* through which river water is diverted for irrigational purposes (Kohli et al., 2019; Manu, 2021; Satoh, 2020). In Western Himalayan villages, *Ghul* systems are popular whereas it is the *bamboo pipes* and *Apatani* systems in the Eastern side of the Himalayas (Bhattacharya, 2015; Das et al., 2021). *Khadin* or *dhora* structures of Western Rajasthan is a long earthen embankments constructed across hill slopes and runoff water from these slopes is harnessed using bunds on the valley floor (Dadhich & Shaban, 2020; Yadav, 2022). *Johads* are simple barriers made of stone and mud built across the slope and these systems allow runoff to percolate into the ground, thus recharging water effectively (Yadav, 2022).

In Kerala (South India), the *Surangam* tunnel is used to divert water away from a deep lateritic well and a reservoir at its mouth collect and bring the water to the desired point based on the principle of gravity (Saha et al., 2022; Srivastava et al., 2020). With a history of almost 1500 years, *Eri* tanks of Tamil Nadu (South India) recharges groundwater which can be used for both potable and non-potable purposes (Sivakumar et al., 2021). Other examples of Indian traditional harvesting structures include *Madakas* (Karnataka), *Cheruvu* (Andhra Pradesh), *Dongs* (Assam), *Zabo* (Nagaland), etc. and all these are potential systems for sustainable water management (More, 2020; Srivastava et al., 2020).

A lack of upkeep by the government or society has resulted in the extinction of traditional water harvesting and storage systems like tanks and ponds. Due to unjustified administrative neglect and shifting of socio-economic and practical considerations at grass root levels, many traditional systems have deteriorated over time. Total area under tank irrigation has shrunk significantly from 4.56 Mha (1960–61) to 1.63 Mha (2016–17) causing a substantial reduction of net irrigated area from 18.49% to 2.37% in rural regions of India (Narayanamoorthy, 2022). In addition to the loss of irrigated land, this diminishing tank capacity has also resulted in a significant increase in groundwater irrigation in drought-prone regions subsequently interrupting the ecological balance.

For meeting the potable and non-potable needs, collected water from runoff and direct rainfall will be highly beneficial. In addition to increasing groundwater recharge, water harvesting may also enhance groundwater storage. For the sustainability of water resources management, water harvesting techniques are crucial. Revival of ancient water harvesting systems may serve as an alternate, reliable, and cost-effective solution for the present day water shortage problems.

A considerable shift from community-level sources like tanks to household-level sources has shown a pronounced effect on the decline of traditional water storage systems. Almost 20% of the global groundwater resources are used up for single water source dependent irrigation (Everard, 2015). When the groundwater extraction rate exceeds the recharge rate, it leads to a water resource crisis. In order to resolve this issue, modern-age RWH systems were recommended and accepted globally, especially in rural areas.

9.1.2.3 Contemporary RWH systems

A modern-age RWH system has typically three main components—catchment, conveyance, and storage. Structurally, a modern age RWH system consists of catchments, coarse mesh, gutters, conduits, first flush diverter, filters, storage tanks/cisterns, and recharge structures. The catchment is the structure that receives the input (rainfall) directly and transfers it to the system. The majority of the water collected from paved, compacted, or other treated surfaces, such as rooftops, is used for domestic chores and watering livestock (Datta, 2019; Eludoyin et al., 2021).

Coarse mesh filters out large debris (e.g., dry leaves), dust and bird droppings from entering into the system. Gutters are semi-circular or rectangular channels that circle the edge of a sloping roof to capture rainwater to the storage tank and move it. Conduits are pipelines usually made of polyvinyl chloride or galvanized iron that bring rainwater to the target zone (e.g., irrigation system) from the catchment (Akter, 2022). The first flush diverter is a valve that ensures that runoff from the first rain spell is flushed out and prevents it from entering the system (Haq, 2017).

Suspended contaminants are separated from rainwater accumulated over the roof using a filter unit filled with a filter media such as fiber, coarse sand, and gravel layers to remove sediment and soil from water until it reaches the storage tank or recharge structure (Uppala & Dey, 2021). A storage tank is made of materials like reinforced cement concrete, ferrocement, masonry, plastic (polyethylene), or metal (galvanized iron) sheets (Sendanayake & Eslamian, 2021). Rainwater is charged into groundwater aquifers through recharge structures such as dug wells, borewells, trenches, pits, etc. (Dhakate et al., 2013).

The rainwater harvesting technique has been found to be successful in enhancing groundwater availability, crop intensification, and farmers' profit in different benchmark watersheds (Amos et al., 2020; Garg et al., 2022). Currently, there are numerous methods in practice for RWH. Runoff water harvesting, rooftop harvesting, underground harvesting, and harvesting employing inverted umbrellas associated with the infiltration rate are the major types of RWH. RWH systems are designed and optimized using several types of approaches viz., stochastic approach (Semaan et al., 2020; Torres et al., 2020), linear programming approach (Okoye et al., 2015), nonlinear metaheuristic algorithm (Sample & Liu, 2014), dimensionless analysis (Huang et al., 2015), design storm approach (Snir et al., 2022), rough set method (Palermo et al., 2019), simulation analysis (Zhang et al., 2018), etc. which are also important for performance evaluation.

i) Runoff water harvesting

In the runoff water harvesting method, runoff water is collected and diverted directly to the farming area during rainfall events. Ridges, borders, dykes, gabions, etc. are placed around the farming area to retain the water on the soil surface. Suitable treatment is required for the catchment based on factors like shape, configuration, surface condition, and runoff inducement practices.

Micro-catchment water harvesting involves the collection of surface runoff from smaller catchment areas within a farm boundary ranging from 10 m^2 to 500 m^2 (Rakotovao et al., 2022) where water is stored in the root zone of an adjacent infiltration basin (cultivation area) to meet the water requirement for crops (Eludoyin et al., 2021; Oweis, 2022). The runoff area to basin area ratio should be determined based on climate, soil conditions, and crop water requirements. While a large ratio results in loss due to deep percolation, it improves infiltration by reducing evaporation loss. The ratio of the collection catchment to the target area usually varies between 2:1 and 10:1 (Ali, 2016; Biazin et al., 2012).

Designing a suitable micro-catchment water harvesting system in rural regions is challenging due to the lack of long-term meteorological data. Mishra et al. (2020) devised a micro-catchment system for horticultural crops grown in the humid region of eastern India using a simple approach of storing the soil moisture during the relatively wet period for utilize during the dry period. Medium-sized or macro-catchment water harvesting is the collection of water in larger catchment areas (1000 m^2 to 200 ha), that are located outside the cultivated areas (Oweis, 2022). From there the runoff is conveyed to the adjacent cropping areas using a diversion structure. Although micro-catchment is advantageous in terms of obtaining more specific runoff yield (yield per m^3 of water), medium-sized or macro-catchment favors higher crop yield per unit area.

ii) Rooftop rainwater harvesting

Rooftop rainwater harvesting refers to the technique through which rainwater is collected from roof catchment and stored in a sub-surface groundwater reservoir. This method is applicable to individual houses as well as communities.

The potential of a roof for RWH can be estimated based on local precipitation (P), total catchment area (A), and runoff coefficient (RC) as shown in Eq. (9.3):

$$Q = P \times A \times C \tag{9.3}$$

where Q denotes total discharge from the roof (m^3/s), P is the intensity of precipitation/rainfall (mm), A is the total catchment area, and C is the runoff coefficient.

Runoff coefficient depends on the properties of the roof material viz., degree of imperviousness, infiltration capacity, etc. (Akter, 2022; Anchan & Prasad, 2021). A 10% deduction is applied to account for losses of rainwater due to leakage, spillage, and evaporation of a rooftop RWH system (Karim et al., 2015; Okoye et al., 2015; Zhang et al., 2018).

While considering this method, the quality of the recycled water is equally important as quantity. The primary determinants of the runoff quality in this regard are roof properties (material, age, etc.), rainfall characteristics (precipitation, antecedent dry weather period, and rainfall intensity), environmental characteristics (seasonal variation, atmospheric pollution, and surrounding environment of roof), roof geometry and these factors should be taken into account from a public health point view (Gwenzi et al., 2015; Norman et al., 2019; Ugai, 2016; Zhang et al., 2014). Mao et al. (2021) compared the harvested rainwater quality under different meteorological conditions and roofing materials including asphalt, concrete, ceramic tile, galvanized metal, and found ceramic tile superior to others in achieving high quality recycled water whereas asphalt was found to be the least preferred material. This finding was congruent with previous works of other researchers (Zhang et al., 2014).

iii) Other categories of RWH

Sloped garden harvesting

This method is an extended concept of terrace farming. It is suitable for hilly regions with heavy precipitation where farming is done in a raised plot. Here the water flows from the upper head (raised portion) to the lower head and is collected via valves placed in the lower head. From this section, the water is transferred to an underground tank and subjected to purification by means of filters (Pala et al., 2021).

Inverted umbrella harvesting

An inverted umbrella-like canopy structure with a widely open outer edge as a catchment with a stem is installed into the soil (Hammed et al., 2017). During a rainfall event, the collected water migrates through the stem, reaches underground and recharges the underlying aquifer. Excess water is diverted from the stem using alternate pipes (Pala et al., 2021). In more recent cases, this structure is designed in a way to harness solar energy using solar photovoltaic systems and harvest rainwater based on the meteorological conditions (Maniam et al., 2022). This generated solar energy can be used for electricity in buildings or applied for filtering rainwater.

There are numerous additional strategies for collecting rainwater. RWH is carried out by constructing overhead tanks and simply digging potholes. There are certain advantages and disadvantages while using modern-age RWH systems.

The merits of these techniques are:

- Easy maintenance: Maintenance of RWH systems requires very less time and energy.
- Saves water bills to a good extent.
- Acts as an independent water supply.
- Serves as an alternative source for irrigation in places where accessibility to other water sources is difficult.
- In water-stressed regions especially arid environments, this source can be used as a supplemental during drought.
- Beneficial for the soil environment by reducing soil erosion.
- Collection of rainwater in RWH systems reduces the possibilities of floods.
- Conserves soil moisture and improves crop productivity.

Despite these advantages, there are also a few demerits:

- Its applicability is limited to rainfall-scarce regions. Also, unpredictable rainfall is another hindrance in RWH.
- Initial installation cost is high for this system.
- Harvested rainwater is not applicable for farming at larger scales.
- Regular monitoring and maintenance is required for algal or microbial growth, seep chemicals, animal droppings, animal breeding, etc. inside the system.

9.1.2.4 *Atmospheric water harvesting*

Atmospheric water harvesting is a relatively new technology that has been receiving worldwide attention for the past 2 decades (Jarimi et al., 2020; Zhou et al., 2020). Among different types of atmospheric water harvesting, fog water harvesting is a potentially feasible source of potable water in arid and semi-arid areas where rainfall is scarce (Dodson & Bargach, 2015; Fessehaye et al., 2014). However, there are certain conditions to be satisfied for applying this technique successfully (Domen et al., 2014; Tu et al., 2018):

- Fog events should be frequent in the region.
- Fog concentration should be high with liquid water content ~0.1–0.5 g/m^3.
- Persistent winds (e.g., trade winds) mostly unidirectional (4–10 m/s).
- Enough space and altitude for intercepting fog.

Usually, fog water is collected using a rectangular mesh perpendicular made up of polypropylene mesh nets (Raschel nets or three-dimensional spacer fabric net) to the wind where fog droplets are pushed against the mesh and trapped (Farnum, 2022; Qadir et al., 2018). These droplets grow by coalescence until they are large enough to get pulled by gravitational force, and transferred to a storage tank via a gutter (Montecinos et al., 2018). An ideal system should have sufficient fog immersion time (~40%) and a collection efficiency of ~50% (Tu et al., 2018). However, aerodynamic, deposition, and collection efficiencies depend on the geometry and material of the mesh used (Schunk et al., 2018).

9.2 Shortcomings and recommendations

Designing a site-specific harvesting system requires long-term meteorological data which is unavailable in most of rural areas. More weather monitoring stations need to be installed in such regions for generating data. Lack of awareness among people in economically backward countries is another challenge. The government should provide subsidies, incentives, and proper training regarding water harvesting. Installation of community-scale harvesting systems is more economical and acceptable than household-scale systems. Also, more thrust should be given for developing a smart harvesting system based on RTC technology.

9.3 Conclusion

There is a growing demand for water every year globally and this adversely affects the well-being of rural communities facing disparities to access water and sanitation facilities. Unlike their urban counterpart, these economically disadvantaged regions lack the proper infrastructure and financial setup for implementing large-scale projects. AI-based micro irrigation such as drip irrigation systems are effective in improving WUE and crop productivity. Subsidizing smart irrigation systems and low-water consumption crops will promote farmers to adopt these technologies in rural areas.

Traditional water harvesting systems are eco-friendly and specifically adapted based on geographical conditions and rainfall patterns in a region. The indigenous knowledge derived from these diminishing systems should be preserved for solving real-world problems. The revival of these ancient harvesting structures may aid as a good alternative, viable and economic option for sustainable water management in rural regions. However, relying upon traditional systems alone is not enough to meet the current water shortage challenges. The present day as well as future water demands can be fulfilled by combining traditional approaches with modern technologies.

Currently, there are several alternative water supply strategies including RWH, runoff harvesting, atmospheric water harvesting, etc. Among the technologies discussed in this chapter, harvested rainwater is a feasible option for potable and non-potable applications in rural areas. However, in larger farm fields intelligent irrigation systems should be adopted as modern RWH systems have limitations to provide such high quantities of water. In rainfall-scarce regions where RWH application is restricted, atmospheric water harvesting potential should be assessed. Howbeit, if atmospheric water capture is not applicable due to unfavorable environmental/geographical conditions, other expensive options like cloud seeding could be considered and supported by governmental and non-governmental funding organizations. Also, continuous monitoring and data consistency should be ensured for better performance of rural water development projects.

Novel energy-efficient technologies utilizing small-scale decentralized systems with nature-based solutions are the need of the hour for improved rural livelihoods. Such green approaches with minimal environmental impacts will be beneficial for the conservation of both energy and water resources. Promoting incentives and strengthening the policies further encourage these societies to use unconventional water sources. In short, alternative water resource is a reliable and affordable option for rural communities. Each technique should be selected with utmost care based on the applicability and problem of each specific location to avoid failure of the project.

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Chapter 10

Advancement in technologies of water management in rural areas

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10.1 Introduction

The most critical aspects that determine hygiene and human health are sanitation facilities, hygiene, and water. Together they are referred to as WASH (water, sanitation, and hygiene). Safe WASH not only helps in good health but also grants upliftment in education and livelihood, and creates communities to live in a healthy environment.

Insufficient availability of portable water increases due to natural calamities and anthropological activities such as climate change, water pollution, and floods. Even the water that is available for human consumption gets wasted due to various reasons such as leakage. This lost water does not generate any revenue. Such lost water is referred to as non-revenue water (NRW) and accounts for 35% of the total water supply in 44 developed countries (Liemberger et al., 2019). Additional water needs to be used to compensate for such losses (Plath et al., 2014). Water management techniques are an area of concern in many countries. Smart water systems (SWS) are being adopted by many researchers as they are self-learning systems (Pandey et al., 2021). Many textbooks and research papers have come up to address water loss management techniques namely, analysis of leakage and methods to identify and fix such issues, smart metering, non-infrastructural and infrastructural pressure management in water distribution systems (WDS) (Bhagat et al., 2019).

It has been found that water bodies can be preserved through the use of smart sensor technologies that monitor the content of oxygen, toxicity, and level of contamination. If these levels rise beyond a suspicious point, an alarm is initiated. River waters are always contaminated, so it needs to be treated in water treatment plants before being supplied to consumers. Efficient water treatment infrastructures are thus required for the continuous supply of safe water (Muñoz et al., 2020; Ramos et al., 2020). Such treatment techniques provide value to both plants as well as water.

Rural populations of some countries, by use of SWS, have managed to safely improve water supply and make them free from contamination. According to a database given by World Health Organization (WHO)/United Nations International Children's Emergency Fund (UNICEF) Joint Monitoring Programme (JMP) for WASH (Figs. 10.1 and 10.2) there has been an increased percentage of managing the water safely by using advanced technology in the gap of 5 years Some developing countries like Afghanistan, Bangladesh, India, Pakistan, Myanmar, Congo, Colombia, Ecuador, Ghana, Guatemala, Iraq, Iran, Syria, Yemen, and Ethiopia have improved the quality of water in the time span of 5 years from 2015 to 2020 whereas some countries have not improved in these 5 years According to the data, Myanmar has safely managed the water by 9% from 2015 to 2020 whereas Pakistan has the same percentage in the 5-year gap. India has advanced in making water free from contamination by 13% in these years with the help of advanced technologies. These countries are developing many new methods to improve the water supply and reinitiating ancient techniques used for water conservation by advancing them.

Earlier in many villages, many traditional ways of water conservation were followed but now there are many advancements that are being introduced in many villages for distributing and conserving water. It has been found that water bodies can be preserved through the use of smart sensor technologies that monitor the content of oxygen, toxicity, and level of contamination. If these levels rise beyond a suspicious point, an alarm is initiated. The treatment of this water is then initiated in water treatment plants before being supplied to consumers. Efficient water treatment infrastructures are thus required for a continuous supply of safe water (Muñoz et al., 2020; Ramos et al., 2020). Such treatment techniques provide value to both plants as well as water.

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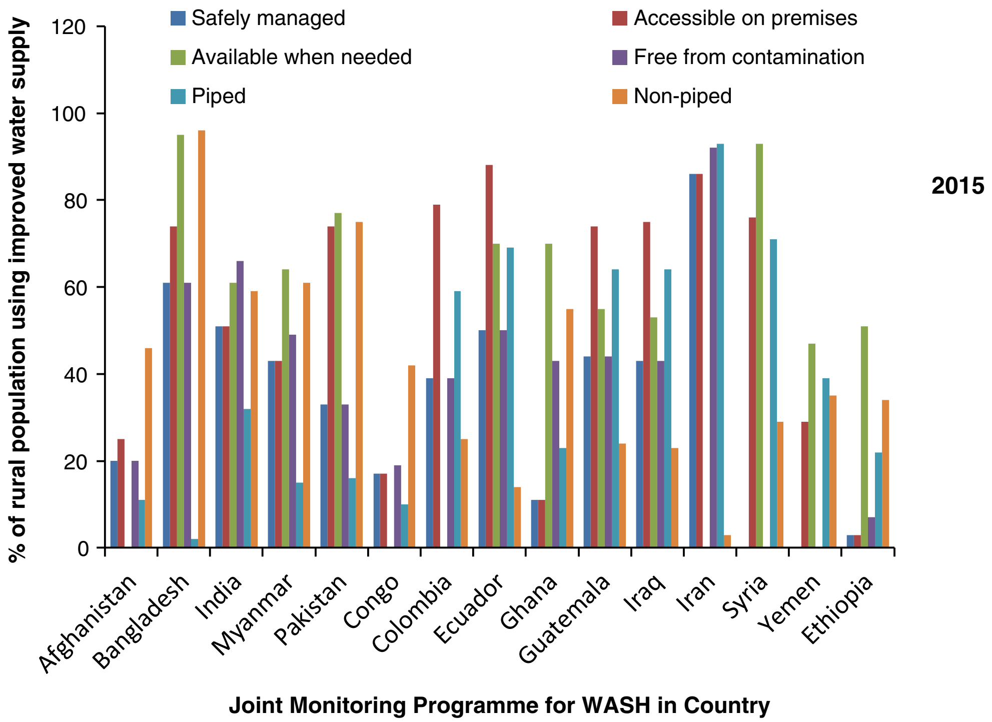

FIGURE 10.1 Estimates on the use of water supply in the year 2015 as WHO/UNICEF Joint Monitoring Program for water, sanitation and hygiene (WASH) in different countries. https://washdata.org/data.

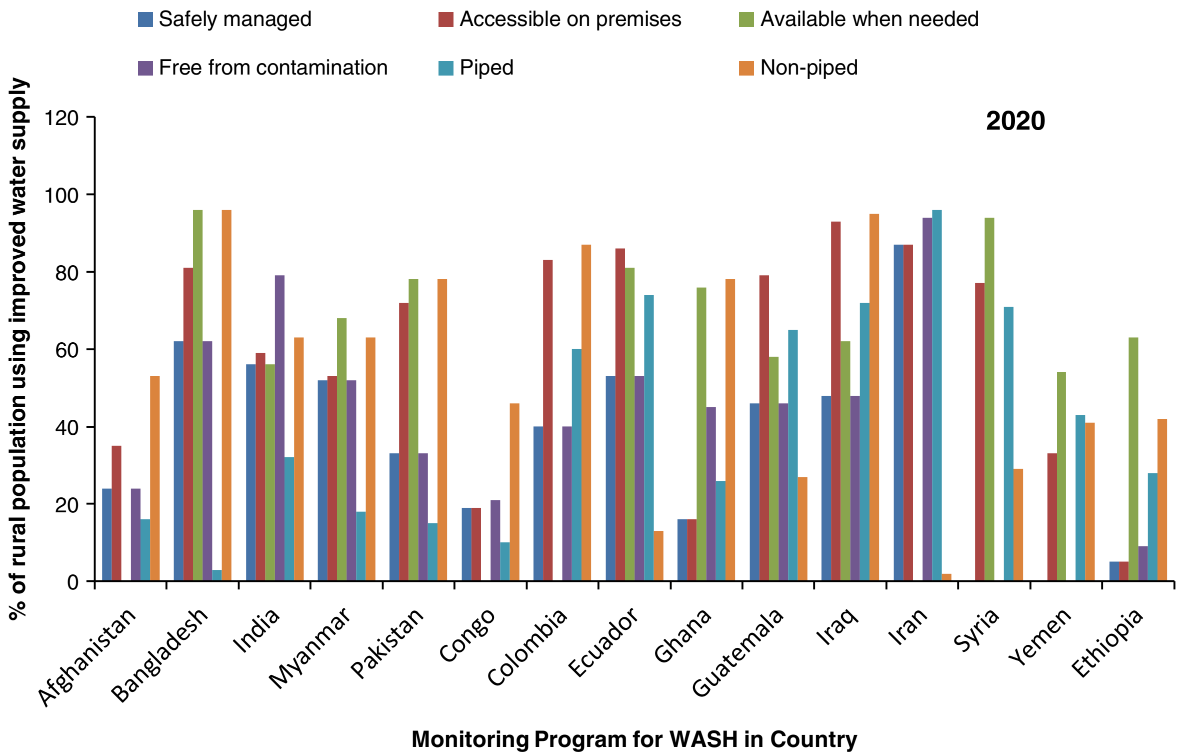

FIGURE 10.2 Estimates on the use of water supply in the year 2020 as WHO/UNICEF Joint Monitoring Program for water, sanitation and hygiene (WASH) in different countries. https://washdata.org/data.

Nowadays, in many villages smart farming is becoming a trend where many sensors have been installed to check the moisture of soil, the fertility of the soil, and many more aspects of the soil. This method of farming is helping a lot in increasing productivity. Many villages have also introduced many motion detectors to detect any water leakage, any contamination in water. In some villages, there are many techniques used to filter out water in an efficient way. Now in many villages efficient ways of doing irrigation are introduced. As discussed earlier, there is a huge scarcity of water all around the globe. There are many efficient ways of conserving water and utilizing water in an efficient manner is discussed in this chapter.

10.2 Advancement in rural water management

It has been found that SWS have been used in many villages for water treatment, water distribution and also for water body monitoring. Some traditional methods are reimplemented for the conservation of water with the addition of new advanced techniques. There are many sensors that are being used for detecting any leakage. Now the water that has been leaked is being treated by the water treatment plant by using bamboo filters and many other treatment systems (Baruah et al., 2011). The use of SWS also includes inspecting the devices that are being used in water body treatment. SWS also helps in irrigation. It helps in scheduling irrigation based on sensors. These sensors like tensiometers, watermarks, granular matrix, time domain reflectometer (TDR), and frequency domain reflectometer (FDR) help in monitoring soil moisture (Francesca et al., 2010). In irrigation, we can also measure plant status with some sensors like a sap flow meter, dendrometer, and infrared thermometer (Doltra et al., 2007). In India due to less labor dependency, automated micro-irrigation (drip irrigation) is slowly being implemented which saves water and energy.

10.3 Water distribution

According to WHO, the basic need for water has not reached around 844 million humans. Among these, rural natives account for 79%. The water from the supply system is not safe for consumption by approximately 2.1 billion people. This data suggests that the system should be improved for the urban population of 14.9% and a rural population of 45.2% to have water that will be suitable for household purposes.

Water shortages are most prevalent in *Kazakhstan*, a Eurasian continent. The future wealth of the nation has been jeopardized by the quality and quantity of water (Bekturganov et al., 2016). There is a huge difference in the amount of water supplied to urban areas (90%) and to rural areas (28%) (UNICEF, 2015).

One more problem faced in water distribution across the world is water leakage (Weifeng et al., 2011). Water leakage involves water that is usually lost due to holes in pipes, uncoupled joints, loose fittings, and even spillage of water from reservoirs. Such incidents are usually hard to notice and so it may lead to huge loss of water over months and years.

To solve these issues, many technologies have been developed and deployed. Some of the most recent technologies in practice are linear polarization resistance, ground penetrating radar, radioactive, acoustics, and pressure metering systems (Poulakis et al., 2003). Few other methods such as geographical information system (GIS) and remote sensing are also used as they are cost-efficient (Faidrullah, 2007). The use of remote sensing technologies over conventional methods can provide lots of details in a short span of time. There are some techniques used for maintaining the distribution of water. In rural areas techniques like Internet of Things (IoT)-based distribution and some leakage-resolving techniques are mostly used. Some examples of these techniques in the rural area are different water distribution techniques using in rural areas.

10.3.1 IoT-based water distribution system

It has been observed over the years that despite having ample amounts of physical water for consumption, a significant amount of water gets wasted by the time it reaches the consumers. The most significant reason for water scarcity in India is a shortage of proper maintenance and infrastructure which leads to the mismanagement of water resources (Maroli et al., 2021).

Kevin Ashton, a renowned scientist in 1999 gave the concept of a network of interconnected "things" and termed it as the "Internet of Things" (Ashton, 2009). It was estimated that 55.7 billion devices will be connected to the internet by 2025 which explains the potential of IoT as a ubiquitous computing network with the capacity to connect everyone and everything (Alam, 2018). One such technique has been used in water management in *Chilka* village of district *Latur* in Maharashtra, India.

The occupation of *Chilka* villagers is mostly agriculture and poultry related, so these people mostly depend upon groundwater available to them through dug wells and borewells. The eight dug wells from different regions of the village and four borewells were observed (Maroli et al., 2021).

IoT devices used in the village are flowmeters, pressure sensors, ultrasonic rangefinders, solid-state relays, and electronic devices with general things like motor pumps and water storage tanks. Two motor pumps are used in a single phase to pump water from the borewell and one motor to pump water from the main tank to the sub-tank. In this distribution, the pressure of 0–10 bars is maintained. The motor of the borewell pumps water to the main tank and the flow of water is measured in between by flowmeters. The flowmeter also detects any leakage. Now, this water is stored in further sub tanks and the level of water is measured by ultrasonic rangefinders/water sensors of 40 kHz frequency. This distribution is maintained by sensors as they communicate real-time information to a central system with IoT networks on Raspberry Pi computers (small computers that run IoT applications like water distribution) (Maroli et al., 2021).

10.3.2 Water leakage detection based on remote sensing

Water leakage has to be dealt with to improve the effectiveness of the WDS since it is a major cause of water loss (Morais et al., 2007). The leakage in water pipes, leakage from joints of pipes and fittings and sometimes overflow from the reservoir tanks are some of the sites for leakage.

In a village named *Pyla*, in *Cyprus* island, spatial resolution is chosen to be the parameter for detecting and mapping leakage zones with the use of remote sensing data (Hadjimitsis et al., 2013). Before, when medium satellite data was acquired it detected only one problematic leakage area (Agapiou et al., 2013)

By analyzing remote sensing data which was recorded from the use of ground spectroradiometers and hyperspectral data at a low altitude, the computer system was able to detect all the known leakages (Agapiou et al., 2016). The remote sensing technique uses a single appropriate high-resolution spatial image. It also uses a satellite with a multi-temporal image for leakage detection and its mapping.

10.4 Water treatment system

A clean and pure water supply plays a major role in public health and safety. Many countries around the globe face issues related to the supply of pure water. There are several techniques of water treatment that are being followed all around the world. Different water treatment methods include filtration, sedimentation, disinfection, and fluoridation. There are several on-site water treatment systems like septic tanks, aerobic tanks, and cesspools. There have been new advancements in water treatment plants in rural areas. According to the WHO and UNICEF, one in ten people does not have access to safe drinking water. In ancient times, boiling water was the most common technique.

There are many rural areas around the globe that are still struggling to get access to pure water. There are many more villages that have adopted different strategies for treating water. In rural areas of Assam people over there are basically dependent on groundwater. In order to purify the water they have been using bamboo charcoal filters. There are many new systems that are being adopted by people in different villages in *Tshaanda* a village in South Africa, they have been purifying water using some gel polymer technique and with the help of solar energy that is hydrogen gel distillation technique. People in rural areas of China and *Shokouhieh*, a village in Iran have been using anoxic/oxic (A/O) membrane bioreactors for the purification of water.

10.4.1 Bamboo charcoal filters

In rural areas of Assam, more than 80% of the population depends on groundwater (Baruah et al., 2011). This groundwater is basically used for drinking and irrigation purposes. The amount of iron present in the water is acceptable for consumption. It is not causing any harm to human health but it causes changes in taste and odor. The people in Assam are using pebbles, gravel, and bamboo charcoal in their filtration techniques. The use of bamboo charcoal helps in removing the excess amount of iron, and other contaminants in the water. It is the most widely used technique in Assam. More than 50% of the total population is using this water filtration technique (Baruah et al., 2011).

There are many villages in Assam like *Chaygaon, Jambari* that are following the bamboo charcoal filtration technique. It is basically a natural filter that is composed of bamboo, pebbles, gravel, and many more adsorbents that are available naturally in the environment (Singh et al., 2015). It is a cost-efficient technique. The use of bamboo charcoal is useful because of its high porosity rate, good adsorption rate, and also consists of harmless microorganisms. Bamboo charcoal has a good mineral content which also makes the water mineral-rich during filtration. This technique also consists of pebbles and gravel which helps in sedimentation. Exposure to sunlight or ultraviolet (UV) light, it helps in killing microorganisms. It has the capacity of purifying 30 L of water per hour by batch process under exposure of sunlight. Bamboo charcoal during filtration produces far infrared rays (FIR) that ranges from 4 μm to 16 μm, which further helps in organic material.

10.4.2 Hydrogel distillation technique

A village in South Africa named *Tshaanda* is following a cost-efficient and eco-friendly technique in the treatment of water, without the use of electricity (Guo et al., 2020). Distillation is the most widely used technique for producing clean water. The method used in this village is a distillation technique that comprises gel-polymer and solar consumption (Zhang et al., 2022). It includes hydrogels which are a chain of polymers with high adsorption rates. These hydrogels consist of both hydrophilic and semiconducting capabilities (i.e., solar absorbing capabilities) which can help in cleaning water from any source.

The hydrogel consists of polyvinyl alcohol which is a water-soluble polymer and polypyrrole with semiconducting properties, which helps in absorbing solar energy (Chauhan et al., 2003). The hydrogel stores the water and after absorbing the solar energy it heats up the water. Once the water in the hydrogel starts evaporating, more untreated water is pulled and evaporated. This removes unwanted salts and other contaminants present in water.

10.4.3 A/O membrane bioreactor

In China, A/O membrane bioreactor is used for water treatment. It consists of two technologies: biological treatment and membrane separation (Liu et al., 2010). Due to the presence of membrane separation, the denitrification factor in the membrane bioreactor is increased. It is most widely used in rural areas. With this artificial wetland sewage treatment is also being used. It is used for removing the phosphorus and nitrogen from the plants, N and P are utilized by the plants and in return make the water free from nitrogen and phosphorus (Lin et al., 2012). This technique is not efficient since the temperature affects its working a lot. It is growing on a large scale in China because of its low cost.

There is a lot of water shortage in *Shokouhieh*, a village in Iran, because of which they have adopted a membrane bioreactor technique for water treatment. The effluents which were earlier discharged from the water treatment plant were not properly removed from the secondary treatment. All the suspended solids and other organic matter are easily removed with this technique (Brookes, 2005). The effluent was collected from different sources like dairy farms, beverage industries, and the metal finishing industry. The material of the bioreactor was plexiglass which had a capacity of 32 L. The ultrafilter membrane which was used was placed in the center. A/O membrane bioreactor basically consists of biological treatment with membrane filtration. With the removal of suspended solids, it is also capable of removing essential nutrients. The configuration of the membrane filter was a flat sheet, width and height were 240 × 200, the pore size was 0.4 micrometer, the material used was EPS, and the surface area of the membrane was 0.0048 m (Hosseinzadeh et al., 2014).

10.4.4 ECOSTP startup

It has been observed that in many villages aerobic bacteria-based water treatment plants have been used. This water treatment plant consumes a lot of electricity. To overcome this drawback of power consumption there is one startup that has treated dirty water using the cow stomach mechanism. The treatment plant basically includes different chambers. All the sewage is collected in the first chamber. Water is transported to the other chamber through pipelines. The other chamber is the second chamber which contains mini chambers. Other than these mini chambers the second chamber also contains a gravel filter. In these filters, water has been traveling using gravity.

Now sewage is being converted into water, gas, and sludge using the catalyst seed. This catalyst seed is made from cow dung and is called an anaerobic bacteria catalyst seed. The advantage of this treatment plant is that it does not consume electricity. It has been using gravitational force. In stage 2, there are many filters that have been inserted in between the way of water. Water is passing via gravel filters in the third stage.

The water which we are getting after the treatment is not basically for the drinking purpose, but it can be used for gardening, washing toilets, or many other purposes.

10.5 Smart farming and irrigation

Crop production is expected to grow by 70% by 2050 to satisfy the demand of a growing population (Lewis, 2016). This will increase water consumption and so will the demand for a timely supply of water. By adopting smart farming, water consumption can be reduced (Gupta et al., 2020).

Technology companies like IBM Inc. came up with smart sensors that can be used in smart farming to reduce the usage of water and its wastage. These sensors analyze weather, moisture in the soil, and relative humidity and suggest when and where to grow crops along with their harvesting time (Lewis, 2016). These sensors can also suggest the number of fertilizers to be used by measuring soil nutrition. This will provide better crop yield, thus increasing the revenue.

Dacom in the Netherlands came up with smart farming devices that use weather stations, a global positioning system (GPS), and moisture sensors to provide information about soil moisture, humidity, etc. (Rinskje, 2020). The farmer can record the water quantity consumed by crops each day. This can save up to 20% of the water in the field by sensing and supplying only the required water to crops (Gupta et al., 2020). Information regarding the timing to harvest crops can help to generate a better quality of crops thus increasing the revenue.

10.5.1 Advancement in irrigation

Irrigation is the technique used for water delivery to farms from groundwater and surface water. It is of great importance in the security of global food but food security faces changes in water supply because of the competition from industrial water needs and less efficient irrigation systems.

In India, 63% of the farming area (195 Mha) is based on rain to be cultivated and the rest is irrigated manually by using flood irrigation, and surface irrigation (have an efficiency of 35–50%). India is an agrarian country but according to a prediction by Organization for Economic Co-operation and Development (OECD), India would face a water crisis by 2050, i.e., 22% of the geographical area of India (1800 million people) will face scarcity of water (Kumar et al., 2014).

Due to poor efficiency in irrigation, groundwater is depleting at a high rate. It is also the outcome of the policy shift by the government in cropping patterns (towards paddy fields), irrigation sources (groundwater or surface irrigation), and energy sources.

It has been observed that there has been a significant decline in groundwater resources in Punjab (Srivastava et al., 2015). It is because of many reasons like there was a change in cropping patterns, the source of irrigation was changed, and groundwater became the source. There have been huge advancements in the agriculture of Punjab, but at the cost of water exploitation (Kulkarni & Shah, 2013). The groundwater draft in Punjab has already increased to 14.56. This reading is exceeding the sustainable limit. This is also contributing towards decreasing the groundwater levels from 8 m (1999) to 15 m (2014) (Srivastava et al., 2015). In Punjab, the groundwater is being exploited rapidly. The groundwater is being exploited in irrigation methods like good irrigation and ground pumps.

In India, there are many villages in northern plains regions where well irrigation is being followed. It can also be observed in the deltaic plains of *Mahanadi*, parts of Narmada and Tapi Valleys, sedimentary and crystalline zones of peninsular India. Well irrigation is cheap, but the only drawback is it requires dependency. It has been found that 63% of the villages are following well irrigation. Well irrigation is used in those villages where drip irrigation and canal irrigation are not in trend. In the ground, a well is dug in order to obtain the groundwater. Usually, the well is not so deep, it is 3–6 m. There are some deeper wells that are 15 m. There are many methods that are being followed to take out the groundwater from wells like *mot, Rent, persian wheel*, and *charas*.

Earlier in rural areas of India, people were using manual irrigation. Manual irrigation like surface irrigation is not an advanced method because it does not include any technology. There are no huge investments in installation. This method is not considered an efficient method for irrigation as it is having many disadvantages. The less efficiency of surface irrigation used might be due to the less or no availability of low-cost gadgets for moisture estimation. Farmers in traditional irrigation either under-or over-irrigate resulting in a loss of crop and a decrease in crop yield. This type of irrigation also involves great demand for labor. In this method, one cannot monitor the amount of water supplied to the crops. It is used in many villages which cannot afford other methods of irrigation.

Nowadays, it is being replaced by other methods of irrigation like canal and drip irrigation.

10.5.2 Canal irrigation

Canal irrigation is an important and effective source of irrigation in perennial river areas like the *Ganga* and *Brahmaputra*, low-level relief areas. So the main concentration of canal irrigation is in the northern plains.

From 2008 to 2009, 82.98 lakh hectares of land was irrigated using canal irrigation of which half land is in the northern plains. Canal irrigation comprises 91.72% of irrigated land in Jammu Kashmir, 64.7% of land in Odisha, and 44.28% of land in Haryana. The maximum canal irrigation is done in Uttar Pradesh. Canal irrigation happens in two ways.

10.5.2.1 Inundation canals

These canals are built to divert the excess water from the river to the fields. Such canals have water only during flood or when the water level rises in the river. So, this type of canal can be used during rainy seasons. These are usually found in the plains and are attached to large rivers.

10.5.2.2 Perennial canals

These canals have water throughout the year. Perennial rivers that are formed from the ice of glaciers keep these canals filled with water. These canals are thus a reliable source of water. Since the quantity of water is enough, these can also be used for agricultural purposes.

It has been found that India has invested 4000 million US dollars in constructing canal systems in villages.

These advancements were carried out between 1991 and 2007 (Dhawan, 2017). During that period there was a significant decrease in canal-irrigated areas. It is due to many reasons, one of them is that the water supply over there was not constant.

10.5.3 Drip irrigation

It is a type of irrigation in which water is delivered to the roots of the plants in the form of droplets. It is observed that drip irrigation has great potential in delivering water to the roots in an efficient manner as compared to surface irrigation (Yadav et al., 2019). A village in sub-Africa named *Sudano-Sahel* has been rapidly using drip irrigation. In Africa, there is a huge scarcity of water. In order to utilize the water in an efficient manner, people in *Sudano-Sahel* have started using drip irrigation. It directly provides water to the roots, thus leading to increased soil moisture and soil fertility. In drip irrigation, only a pressure of 1 m is required to irrigate 1000 m^2 of land (Maisiri et al., 2005). Drip irrigation does not involve more manual inputs. It is the more efficient technique of irrigation, thus it is more sustainable.

A village named *Chandrala* in Gujarat is following drip irrigation. The major crops which are grown there are vegetables, castor, and cotton among which vegetables are grown there in huge quantities. Earlier the village was facing a shortage of labor. There is a huge demand for labor in agricultural practices due to the scarcity of labor. The village was facing problems in agricultural practices. In order to reduce the call for laborers, the village people decided to adopt drip irrigation methods of farming. After the adoption of this technique of irrigation, there is less demand for manual work. The land preparation has been done by the tractors. After adopting this technique there has been an increase in crop yields. The yield of crops has significantly increased thus it also contributes to saving water. But there has been a huge installation cost involved in drip irrigation. Drip irrigation has no doubt reduced the cost of cultivation and increased crop yield at a significant level.

10.5.4 Autonomous irrigation device: IoT based

Irrigation in the fields had always been a constant trouble to the farmers of *Balayapalli*, a village in Andhra Pradesh, India. To make conditions worse, erratic power supply damaged the wiring in the motors which deliver water to the fields. It was difficult to operate these pumps at regular intervals and often resulted in massive loss of water. This problem was resolved by a device named "*Kisanraja*".

Vijay Bhaskar Reddy developed this IOT-based autonomous irrigation device. The farmers have been effectively monitoring and using water since its deployment. Over 34,200 farmers have already benefited from this device. The device is generally installed near the water pumps. A sim card is placed inside the device which allows the farmers to operate it using their mobile phones even from remote places. Simple calls or text messages are enough to make the device work and switch the motor on and off (Gogoi, 2019).

Advanced technologies such as data analytics, AI, ML, and IOT form the framework over which this device is developed. These technologies enable this device to incorporate various features. It contains wireless valve controllers to control the flow of water, wireless sensors for monitoring soil moisture, and wireless controllers.

The wireless sensor senses the moisture content of soil and helps in maintaining an adequate supply of water. The sensors of this device also allow it to collect information on environmental factors like humidity, climatic condition, rainfall, etc. These details get uploaded to the cloud and are sent to the mobile phones of farmers for making new irrigation practices that are specific to the farm. With its feature of interactive voice response service, it can even notify farmers when the need for water arises and when to stop the water supply. Farmers can then regulate the supply of water. They can even communicate with the device in their regional language when they want to operate motor pumps remotely through calls or text messages.

10.6 Traditional water conservation system

There has been an uneven pattern of rainfall distribution in India. During the onset of the southwest monsoon rainfall occurs in many regions. It usually occurs from June to October. The variation is very significant in western Rajasthan, it is 100 mm while 2500 mm in the northeast.

For conserving water, the Government of India has launched several initiatives and projects, one of which is *Jal Shakti Abhiyan* launched in 2019. This nationwide initiation aims at encouraging citizens to participate in the conservation of water at the grassroots level. A campaign was named *Jal Shakti Abhiyan:* Catch the Rain (JSA-CTR) on March 22, 2021. It was on the theme of "catch the rain, where it falls when it falls" and it included all the rural and urban areas of all the districts of India. Under this campaign, the government focused on rainwater harvesting (a method for storing rainwater), modernizing the traditional water bodies like *Jhalaras, Zings, Kuhls, and Zabo* which are small tanks or small water bodies for conserving water.

The problem of water scarcity in India can be solved by the use of water conservation techniques. The Indian government has started to implement conventional methods to harvest water owing to the sporadic nature of rainfall in the nation. These methods do not pollute the environment because of their eco-friendly nature. Ancient India used to suffer from drought and flood conditions frequently and thus developed methods to harvest water. These techniques are unique to each region. The main motive behind each of these techniques was to store water irrespective of place and time of rain. Some of the methods used in India for water conservation are:

10.6.1 Rainwater harvesting

In many villages, rainwater harvesting techniques are being followed. This technique is basically storing rainwater in some tanks or underground reservoirs (natural). All over the country, there are different rain patterns 1300 mm in Maharashtra is the average rainfall reading whereas it also varies from 400 mm to 6000 mm. There is a huge rainfall pattern variation around the state. It has been calculated that per acre the rainwater treatment capacity is 4.4 million liters. If the average rainfall pattern in India is being considered then it is 1120 mm. This technique is more useful, there is no huge investment needed for the setup.

There is one village named *Chinchani* village in *Solapur* district, here in this village rainwater harvesting techniques are being installed. In the village, there were 55 homes where this technique was implemented. The water there was being collected in pits called recharge pits. Afterward, there were many more houses in the village that got inspired and installed this system of conserving water. This technique seemed to be efficient for the village people.

In *Pipriya*, a village in Madhya Pradesh has constructed a rainwater harvesting system. They have been constructed in order to refill the tube well. In the recharge, pit rocks were added so that water could be easily filtered out. This turns out to be beneficial for people over there.

The rainwater harvesting system is a good method of conserving water and it is being implemented in many villages so far.

10.6.2 Use of *Jhalaras*

Jhalaras (steep wells) are rectangular in shape and usually have a well-labeled staircase on its three or four sides. Water is stored in these *Jhalaras*. These structures can be found in *Jodhpur*. It has eight *Jhalaras*. The earliest *Jhalaras* is *Mahamandir Jhalara* which was built in 1660 AD. These are underground water bodies that were built to store the seepages of ponds or other water bodies located upstream. Water collected is then distributed to surrounding areas. These waters were only used for rituals and bathing and not for drinking.

10.6.3 Use of *Zings*

Zing (small tanks) is a water harvesting structure usually built in Ladakh. This structure stores melted water from glaciers which is later used to meet agricultural requirements. This water is brought to the tank through interconnections of guiding channels (Sharma et al., 2000). Water melts from the glaciers till afternoon and is brought to *zings* through the use of these channels and the water thus collected by the evening is used the next day in fields and other activities. Farmers in these dry regions need water for agriculture. The supply of water is taken care of by *Chirpun* which distributes it equally throughout these dry regions and regulates the needs of farmers and households.

10.6.4 Bamboo drip irrigation

This system of irrigation has been in practice in Meghalaya for over 200 years. This system incorporates the use of bamboo pipes to tap water from streams and spring water. It is widely prevalent in *Jaintia* and *Khasi* hills. In a minute, almost 20 L of water enters the pipe system and is distributed across a large area. The water reaches lower regions from the top of mountains due to gravity. This water is drawn from perennial rivers.

10.6.5 Use of *Taanka*

Taanka is also known as *tanka* and *kund*. This system uses conventional methods to preserve water and is used in the Thar regions of Rajasthan. Earlier during 1607 AD, it was built near religious sites to be used by the entire community but currently, most families make *taanka* for their personal use. A cylindrical pit of width 3–4.5 m is dug that is plastered with lime mortar cement. This plaster has a thickness of 6 mm above which cement is plastered which adds another 3 mm. The final structure has the capacity to hold more than 21,000 L of water. The water that falls from the rooftop and flows off from the courtyard is collected and used for drinking purposes.

10.6.6 Use of *Kuhls*

Kuhls are found in the *Kangra* Valley of Himachal Pradesh and are used to store melting water that comes down from the glaciers. 2500 major and 750 minor *Kuhls* are present in this region. Above 30,000 ha of land of this valley is dependent for irrigation on *kuhls.* They were built using donations from the public and grants given by kings, queens, and the government. After constructing *kuhls*, it was given to the *kohli*, a person from the village who had contributed the most to its development for its maintenance.

10.6.7 Use of *Zabo*

Also known as *Ruza, Zabo* is a well-thought ingenious system to conserve water and has been implemented in *Kikruma* village of Nagaland for centuries. The conservation of water has been linked with medicinal practices, animal care, agriculture, and forestry. In this system, various channels are built to stream the rainwater and collect it in ponds thereby preventing it from being flown down to the foothills. These ponds have been constructed to store water in equal amounts on different terraces of the hill. Ponds are also interconnected through inlet channels. The stored water is allowed to flow through the paddy fields used to feed cattle on the lower regions of these hills. The water that flows down from these terraces contains animal excreta that is used as fertilizers for the growth of medicinal plants and in agriculture. The paddy fields are also used to breed fish and add to the profits earned by the farmers. Approximately 50–60 kg of fish can be reared per hectare. This conservative and profitable method has not been implemented elsewhere.

10.6.8 Use of *Ramtek*

There was a model named *Ramtek* which was being introduced in the villages of *Ramtek* in Maharashtra. This network is being handled by the landowners of that village. This model basically includes a tank that further contains the water coming from the canals or groundwater. There is a chain that is being formed between the tank and is extending towards the plains. After the tank is filled water from there is transferred to successive tanks. It has been observed it conserves 60–70% of the water.

10.7 Conclusion

SWS has greatly impacted the lives of people living in rural areas. From drinking water to producing crops, many rural areas have adopted this technology and have seen improvements in their lifestyle. This review paper has covered some statistical data from which it is evident that incorporating SWS techniques in these systems is bound to produce good results. There are still some improvements that need to be made, nevertheless, deployment of such techniques is cost-efficient. At present, 0.5% of the total water on earth is considered freshwater. Only 3% of this freshwater is available to humans for consumption. It has been predicted by the UN that by 2025, water consumption will be increased by 40%. The use of such techniques will not only provide safe water to its consumers but also prevent a possible shortage of water thus making it less scarce.

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Chapter 11

Water efficiency in agriculture as a vital approach toward water management in rural areas

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11.1 Introduction

The history of the earth has revealed events that have led to climate changes owing to natural factors such as Milankovitch influences, plate tectonics, and the growth of mountain chains throughout history. Currently, the main cause of climate change is the increase in the concentration of carbon dioxide in the atmosphere, which has been attributed to a rise in carbon dioxide concentrations in the atmosphere (IPCC, 2007). As reported by the Intergovernmental Panel on Climate Change (IPCC) in 2001, the world's climate is changing due to human activities, which are primarily responsible for the change in climate (Mitchell et al., 2001). It is a well-known fact that temperatures on the surface, precipitation, evaporation, and extreme weather phenomena such as floods, droughts, and cyclones, have all dramatically changed since the turn of the century. It has been found that the 1990s were the hottest decade of the 20th century, and 1998 was the warmest year of the century, and manmade greenhouse gas emissions have been a major factor in this global warming (Houghton et al., 2001). As a result of climate change, we may experience long-term and perhaps substantial changes in the hydrological cycle, which will have an important impact on society and the environment in the long run. Over the past few decades, there has been an increase in droughts and floods all over the world. The agricultural sector consumes more than two-thirds of all fresh water in the world, with the poorest countries using more than 90% of it. Since the end of World War II, the global consumption of freshwater has more than quadrupled, and it is expected that the consumption will climb another 25% by 2030. In order to explain the majority of the increase, it needs to be noted that the world population will increase from 6.6 billion in 2030 to around 8 billion by 2050, and then to more than 9 billion by 2080 (Morrison et al., 2009). As a result, our future depends on how we reduce the impact of climate change, which has a direct impact on both agricultural productivity and the availability of freshwater. It is estimated that the majority of India's population lives in rural areas and relies on rivers and groundwater for their survival. In rural areas, there are more than 80% of the population lives on groundwater, and in urban areas, there are more than 50% of the population lives on groundwater, and around half of the irrigated land is irrigated using groundwater. In India, it is estimated that the value of irrigated produce is accounted for by groundwater to the tune of 70–80% (Mall et al., 2006). There is an estimate that the contribution of groundwater to India's gross domestic product (GDP) is about 9% (Burjia & Romani, 2003). Recent times have seen an increase in human activities driving climate change, which has had a visible impact on groundwater systems, such as the storage, recharge, and discharge rates of groundwater. Global warming is also increasing hydrological variance in various sections of the region. Groundwater quality, water table position, precipitation, and hydrogeology have been significantly affected by variations in drainage density, river geometry, and morphology, water quality, and precipitation in the past few decades.

Several research advancements and applications in the water and hydrological area illustrate and explain the usefulness of integrated descriptive models utilizing system dynamics (SD). Liu et al. (2015), for example, detailed the creation of a model-based SD technique capable of perfectly simulating Beijing, China's economic growth, resource use, and environmental influences on the interaction. The model relied heavily on hydrological, economic, demographic, and environmental aspects. The methodology employed lists the anticipated

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negative effects on human welfare, environmental safety, and public health as well as urban development Statistical analyses, calibrations, and validations, as well as dynamic interactions and comments, will aid in the support of various essential policies, scenarios, and analyses. According to the model, water is the most important component of the sustainable development process. The findings of their SD model will help policymakers comprehend interconnections and impacts on urban areas' economic growth and development. Wang et al. (2011) created an SD-based comprehensive technique for managing water resources while taking into account water availability and demand as well as several socioeconomic factors as well as environmental scenarios. A new index has been created to evaluate the various interactions on water balance, resulting in a thorough and robust representation of the river basin environment. The outcomes of the numerous trade-offs have demonstrated and contributed to the creation of a general theory vision of water security in river basins, which has aided in the development of integrated performance water resource management and paved the way for the notion of water sustainability in basins.

11.2 Climate change and variability's impact on water resources

In many parts of the world, including India, the impact of climate change and variability on water resources will be one of the primary determinants of future food and water security throughout the planet. In spite of the greenhouse effect, nature tends to fluctuate the climate naturally, and the cause of climate change is not the greenhouse effect. As a result of a rise in the concentrations of human trace gases in the atmosphere, the present climate change occurs as a result of the increased greenhouse effects caused by an increase in greenhouse gases. It should be noted that plant cover, land surface texture, or roughness can also have a substantial impact on atmospheric dynamics through their influence on winds; mountains can also have a significant impact on both regional and continental climates (Wang et al., 2004). There has been a noticeable increase in the severity and frequency of water-related catastrophes such as floods and droughts, as well as large-scale changes in evaporation, surface temperatures, and rainfall over the past few years. According to Singh and Sontakke (2002), there has been an increase in summer monsoon rainfall over the western Indo-Gangetic plain (165 mm/100-year, significant at a 1% level), and there has also been a westward shift in rainfall activity over the Indo-Gangetic plain since 1900. Over 40 m ha of land are estimated to be flood-prone in India, and floods inflict damage on more than 8 m ha of land each year as a result of floods. Indian food production as well as South Asian food security have suffered a significant decline as a result of the changing climatic conditions. This is a result of these changes in

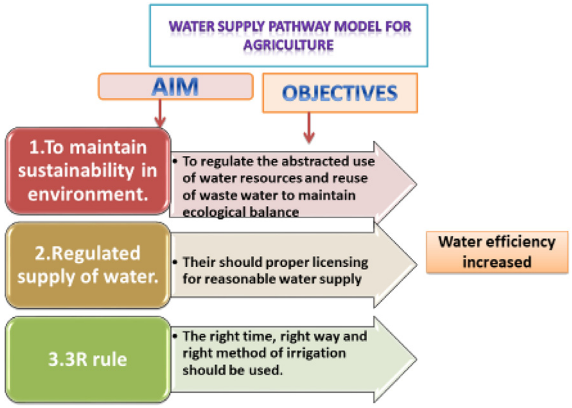

FIGURE 11.1 Climate change model and variability impact on climate change.

climatic conditions. It has been estimated that approximately 80 m ha of India's total net sown area of around 143 m ha do not have irrigation systems and rely entirely on rainfall for the development of agriculture (Kumar et al., 1994) (Fig. 11.1).

Approximately, 70% of the world's freshwater is used for irrigation which makes the agriculture sector as the largest consumer of fresh water (Fischer et al., 2007). It is estimated that from all duty of water only half of the water actually reached the field to reach the crop, the rest of the water is lost through application, conveyance, runoff, and evaporation along the way. The importance of water for agriculture is best illustrated by the fact that in many developing nations, such as India, the proportion used is considerably higher than in other developed countries because of the net irrigated area and poor water conservation technologies (Turral et al., 2010). After deep research, several researchers came to the conclusion that low precipitation threatens to intensify the problem by reducing available water supplies and increasing agricultural water demand. Even though agricultural abstractions in Central and Northern Europe are often very low (1–2%), they can have a significant environmental impact since they are concentrated in the drought catchments during the dry months. The horticultural industry, which relies on continuous supplies of fruit and vegetables for the largest supermarkets and processors, is one where this additional irrigation is especially important (Knox et al., 2010a). Its usefulness is not limited to food production (Knox et al., 2010b). This study discusses the importance of water regulation and irrigation efficiency in a temperate climate, where the reasons for irrigation are very different from those in desert climates. Perspectives on water efficiency are discussed, and a "way to efficiency" is proposed to help farmers and the water regulator incorporate efficiency's broad principles into improved irrigation management and abstraction control. Water auditing and benchmarking are just two examples of other management strategies that are closely associated with increasing irrigation efficiency, and their connections are examined.

11.3 Climate system and changes in climate

As we know, the five components of the climate system, which are the atmosphere, hydrosphere, cryosphere, land surface, and biosphere, together form a complex and interconnected system that can be viewed as several parts working together to affect the climate. We believe that the word "climate" refers to the average conditions of the atmosphere around us, while the word "weather" refers to the variable state of the atmosphere surrounding us, which is determined by a variety of factors, such as temperature, precipitation, wind, as well as many others. There is, therefore, no doubt that climate is the average condition of these variables over a very long interval of time (varying from months to millennia; the standard period of the climate system is 30 years), and it can be most easily defined in terms of its component related to the atmosphere. In order to put it simply, the climate system develops over time as a result of both its own internal dynamics as well as changes to external elements that impact it, known as "forcing." These external forcings can be natural (e.g., solar fluctuations and volcanic eruptions) or artificial (e.g., changes to atmospheric concentrations). Solar radiation is the main source of power for the climatic system. Three factors can influence the Earth's radiation balance:

1. by changing the incoming solar radiation (e.g., due to changes in the earth's orbit or because of changes in the sun itself);
2. by changing the fraction of solar radiation that is reflected or "albedo" (e.g., due to changes in cloud cover, atmospheric particles, or vegetation);
3. by changing the long wave radiation from the earth back towards space (e.g., by modifying greenhouse gas concentrations).

11.4 A case study is based on an interview on rural area patterns adopted for water consumption

According to the findings of the interviews, there appear to be two primary elements that cause variances in water use: the kind and size of the property, as well as the adoption of water-saving behaviors. Regarding rural regions, It would appear that the nature of the property, as well as its dimensions, have an impact on the whole water consumption (Wang et al., 2004, 2011; Weather head et al., 2002; Water Aid, 2008). We were able to determine, through the interviews, that there are three different kinds of consumers who are related to the rural supply: residential users, farmers who raise their animals as a hobby on tiny estates and modest numbers of farmers who own huge farms and a significant number of animals, as well as farmers who have a large number of animals. Farmers and those with bigger scale hobby farms (0.30 ha) that were surveyed have the greatest water consumption rates due to the size of their properties higher quantities of water were needed on account of the increased stock.

As contrasted with residential properties and hobby farms on a smaller scale. Also, the sort of farm matters, because rural customers have different options. A dairy farmer uses the water from the town's supply system to clean his dairy, water the animals in the home, and water the garden according to the needs of his animals. The number of people who use is anticipated to be largest in rural areas, followed by residential users, in addition to various sorts of farmers and hobby farmers because they require a greater amount of water. Therefore, the kind and the extent of the value of the property as well as the quantity of the stock are both key elements in the amount of water that a rural property uses. There are now a greater number of large farms located in high-use regions, which causes. These places are expected to see usage rates that are greater than typical (Agrawala 2005; Arora & Boer 2001; Brouyère et al. 2004; Burjia & Romani 2003; Callaway 2004; Canter & Swor 2011; Cavé et al. 2003; Chadha & Sharma 2000; Christensen et al. 2004; DWAF 2004a).

11.5 Effect of climate change on water resources

There is also the possibility that climate change may also have an effect on the sources and sinks of moisture in the atmosphere, in addition to affecting the moisture content of the atmosphere. There will be an acceleration of the hydrologic cycle as a result of a warmer climate, which will affect the magnitude and timing of rainfall and runoff as a result of a warmer climate. A study has shown that warm air has a greater capacity to store moisture as well as a greater capacity for evaporation due to surface moisture (Mirza et al., 2003). As a result of a higher amount of moisture in the atmosphere, rainfall, and snowfall episodes become more intense, resulting in an increased risk of flooding as a result of the increased amount of rainfall and snowfall. The incident solar radiation, however, increases the temperature when there is little or no moisture in the soil to evaporate, thus contributing to longer and more severe droughts (Gleica, 1999; Goubin et al., 2004; Rosenberg et al., 1999). As a result of climate change, soil moisture, groundwater recharge, the frequency of floods, and drought events, as well as the groundwater level in various areas will be impacted. There have been several studies published in the literature that have assessed the effects of various climate change scenarios on the hydrology of various basins and regions (Arora & Boer, 2001; Evans & Schreider, 2002). As a result of rising temperatures and reduced rainfall, a number of studies have suggested that net recharge may be limited and groundwater levels may be affected. However, little research has been conducted on the hydrological effects of potential climate change on Indian regions/basins. Groundwater is one of the most important sources of water in both urban and rural areas and has been supplying the essentials for more than 80% of rural households and 50% of urban households for the past few decades (Christensen et al., 2004). It also serves as the source of irrigation for around 50% of farmers who irrigate their crops. A majority of India's irrigated produce will be irrigated using groundwater by the time it reaches 80% of the country's total irrigated area. It is estimated that the irrigation of groundwater contributes almost two-fifths of the country's agricultural production. A study conducted by the Indian Bureau of Statistics indicates that groundwater contributes about 9% of the country's GDP economy of the country. Due to the changing climate on the Indian subcontinent, water supplies are going to be under increasing strain. Currently, natural runoff to the sea wastes more than 45% of the average annual rainfall in the country, including snowfall as well (Brouyere et al., 2004). In order to reduce run-off loss based on current rainfall projections, rainwater harvesting techniques are presently being installed throughout the country in order to reduce run-off loss.

11.6 Prospects for long-term water supply

It is clear that we will need to rationalize multiple methods of collecting and storing water in order to meet future water needs. India should be able to meet its future water needs in a sustainable manner through the harvesting of rainwater. Most of the rivers and rivulets within the Indian subcontinent are fed by rainwater, with 80–90% of the runoff being generated during the monsoon season. The monsoon rains are also a major source of replenishment of groundwater during the monsoon season (Mukheibir, 2007; Mukheibir & Ziervogel, 2007). From June through September, the nation receives more than 75% of its monsoon rainfall, with the exception of the eastern coast. In an average year, rainy days range from 12 to 100, and total rainfall durations range from a few hours to more than 300 hours. There is not uncommon for up to 60% of the yearly rainfall to fall in a short period of time, causing severe runoff and causing a high toll on life, agriculture, and property caused by the flooding. As a result of predicted climate change, the interannual variability of the monsoon is predicted to grow in the future, making the monsoon less reliable as a stable source of water in the future due to its increasing variability. Thus, it is necessary to identify, develop, and adapt technology methods for more effective groundwater recharging and rainfall collection in order to make groundwater recharging and rainfall collection more effective (Chadha et al., 2000). By taking advantage of extra monsoon runoff to increase groundwater storage, not only will we be able to increase water availability for satisfying rising demand, but we will also be able to minimize flood damage as well. It is worth noting that subsurface reservoirs can store large amounts of water and that they are an appealing and technically feasible alternative for storing excess monsoon runoff during times of heavy rain. In hydrogeological settings that are appropriate for subsurface reservoirs, both the environmental and commercial viability of these reservoirs can be assured. The advantage of subsurface storage is that it offers the advantage of being devoid of negative impacts, such as flooding of a large surface area, loss of cultivable land, relocation of local people, and substantial evaporation losses as a result of evaporation. A subsurface water storage facility would also have a positive impact on the current groundwater regime by allowing water to be stored subsurface. Several parts of the country may have significantly elevated deep groundwater levels, either as a result of natural causes or due to excessive groundwater development, resulting in lower lifting costs and energy consumption in many areas of the country. In order to recharge groundwater reservoirs, check dams, surface-spreading basins, pits, percolation tanks, subsurface dykes, and other structures may be used, and these structures can be built using local expertise and material, all of which are modest in size and low in cost. As a result, groundwater supplies will have to meet a large portion of future demand. It has been estimated that the water potential of the Ganga Valley (both surface and groundwater) can irrigate 200 ha of additional land, producing an additional 80 metric tons of rice, and supporting an additional 350–400 million people (IPCC, 2007). Water shortages may occur due to climatic unpredictability and change as a result of climate change. Documentation and plans may be available to assist in identifying the extent of the vulnerability. It is also possible to evaluate future resource vulnerability routes by using some techniques, such as scenario planning. Having identified the primary vulnerabilities, it is vital the development of an adaptation plan that incorporates a variety of adaptation measures as soon as the primary vulnerabilities have been identified (Agrawal, 2005). Climate change adaptation activities have to be developed in collaboration with key stakeholders, sector experts, and climate scientists who can provide insight into the nature of climate variability in the local environment in order to be successful. As the sector has a complex institutional framework, this is a necessity in order to analyze the secondary effects of adopting specific adaptation activities and to ensure that these activities are equitable and sustainable when implemented. There is a major problem for water security as a result of the need to reconcile the demand for water and supply over the medium and long term. It can be argued that short-term responses to variability can be seen as coping techniques, while longer-term measures that can be considered to reduce the effects of climate change may be considered adaptation strategies. There are many similarities between the adaptations made

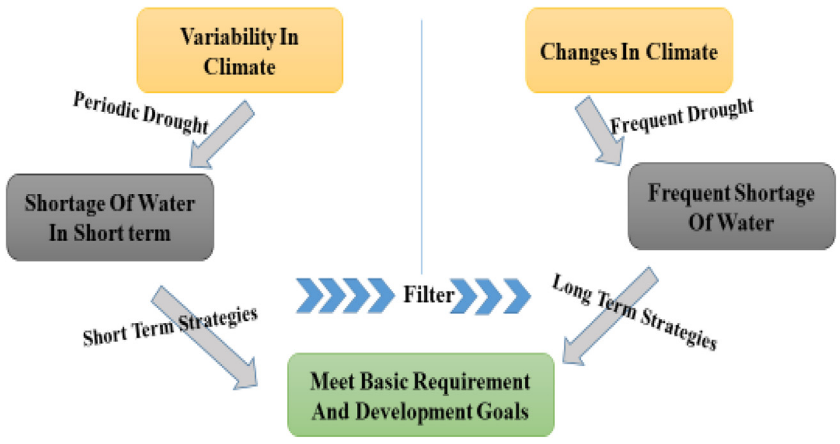

FIGURE 11.2 Relationship between climate variability and climate change.

to deal with the effects of climatic fluctuations and those made to deal with the effects of climate change, which is in agreement with Callaway (2004), who claims that both adaptations have more conceptual parallels than differences. When it comes to preparing for variability in the current environment, it is considerably easier than when it comes to preparing for variability in other climates. Using a qualitative initial screening technique, it can be determined if the responses to climate variability will maintain resilience to future climate effects as well as ensure that local development objectives such as access and employment creation are achieved in the long run by using a qualitative response assessment technique (Schulze, 2000). As a part of establishing comprehensive methods to mitigate the effects of possible water shortages, socioeconomic vulnerability, and adaptive capability should be taken into account along with physical issues. At all sizes, small and large, farmers have highlighted the social, economic, political, and environmental challenges that reveal their vulnerability during times of climate change as well as their susceptibility to it. As a result, it is crucial that these challenges are taken into account when evaluating the risk of farmers and implementing strategies for their assistance and development (Fig. 11.2).

11.7 Availability of water resources

The country is inundated with four main types of rivers that flow through it: the Himalayan rivers, the Deccan rivers, the coastal rivers, and the rivers that flow through the interior drainage basins. There are several factors that contribute to the flow of the Himalayan rivers, such as rain, snow, and the melting of glaciers (Wang et al., 2011; Weather head et al., 2002; Water Aid, 2008). It is estimated that more than two–thirds of the country's water supply comes from three major Himalayan river systems, the Indus, Ganga, and Brahmaputra, which account for two-thirds of the country's water resources. One of the main purposes of managing the flow of the Himalayan rivers is to conserve water and also to prevent damage to civilization and infrastructure caused by floods. This is one of the main goals of managing the flow of the Himalayan rivers in order to preserve water. Three rivers in the Himalayas cross international borders on a regular basis. It is estimated that most of these rivers or significant tributaries of these rivers originate in the countries bordering India. It is imperative to note that these rivers travel through India on their way to the sea before they enter Pakistan or Bangladesh (Schulze & Perks, 2000; Singh & Sontakke, 2002; Srikanth, 2009; Trenberth, 1999). Therefore, one can say that India, at times, would be described as a downstream nation, whereas at other times, it would be described as an upstream nation. A number of rivers are part of the Deccan group of rivers, which also includes the Mahanadi, Godavari, Krishna, Narmada, Tapti, and Cauvery rivers. Due to the fact that all of these rivers are fed by rainwater, they are able to transport far less silt than rivers in the Himalayas. This is due to the presence of rainwater. As far as the peninsular rivers are concerned, there are only two that flow east and enter the Bay of Bengal, the Narmada and Tapti rivers. The catchment areas of many of India's coastal rivers are modest in size and have short lengths. There are very high flows in rivers on the West Coast.

11.8 Issues of variability in water resources

Water availability in India varies greatly over time, resulting in calamities such as floods and droughts. There is a significant regional mismatch between water supply and demand, and demand for diverse purposes is growing quickly while availability is virtually equal. Water withdrawal from the surface and subsurface water bodies is increasing and becoming unsustainable in order to fulfill increased demand.

Over the years, there has been a fluctuation in the availability of water in India, which has resulted in natural calamities such as floods and droughts over the years as a result. During the monsoon season in India, as indicated by

Jain et al. (2007) and Jain (2017), more than 70% of the annual precipitation falls within a period of four months during the period of the monsoon season. There is no doubt that rivers are responsible for transporting more than 70–75% of the flows that occur during the course of a given year, a number that sometimes exceeds their capacity to deliver the water efficiently and in an efficient manner. There is an estimate that 25–30% of the annual flow of a river occurs during the other 8 months of the year, which is why many rivers do not flow during the summer months due to these factors. The amount of groundwater in the ground increases and decreases in a similar way, but with a certain amount of delay. There is no denying the fact that the availability of water varies greatly throughout the world. This causes a wide range of problems such as floods and droughts to arise as a result. It should be noted that apart from the temporal fluctuations in the Indian water supply, there is also a great deal of variation in water availability based on geography. This results in excess water in certain basins/regions and a shortage in others, usually at the same time. Because the tools used to treat both kinds of variations are the same, it is preferable to treat both types of variations at the same time since the tools are the same (Canter et al., 2011). In order to enhance the management of India's water resources, variability management should be one of the cornerstones of the strategy. It is Jain's (2007) opinion that three fundamental principles underpin the country's sustainable management of its water resources.

11.9 Groundwater management

In order to manage groundwater sustainably, it is necessary to manage resources in an environmentally sustainable manner. It is believed that the most effective way to preserve long-term resource use is to keep it mostly within dynamic resources. Management interventions can be divided into two types: those that manage the supply of goods and those that manage the demand for goods and services. The purpose of supply-side interventions is to increase the availability of scarce resources by collecting rainwater, using artificial recharge, recycling wastewater, or even utilizing alternative sources of water in order to increase the availability of scarce resources in order to increase resource availability (Koonan, 2016). Compared to demand management, it aims to increase the efficiency of water use through the use of pressure irrigation, crop variety, plugging of wasteful losses caused by seepage, water loss from the irrigation field, and evaporation at the connection between the well and the irrigation field. It is also important to address the nexus between groundwater and energy in order to achieve a better demand management strategy. As a matter of fact, most states and union territories provide substantial subsidies to farmers, including free power (Mukherjee et al., 2009). It is imperative that the public is engaged in the groundwater management process and that they are aware of the issues involved in the process in order to achieve effective results. Among the various approaches that can be used to promote optimal groundwater use and to enact management actions in the context of India's socioeconomic situation, participatory groundwater management is considered to be the most effective.

11.10 Groundwater quality monitoring in rural areas

Due to the fact that groundwater is the primary source of drinking water in rural India, monitoring the quality of this water has become a key issue and a challenge (IPCC, 2007; Jain, 2017; Liu et al., 2015). Due to the geographical dispersion of Indian villages, there still remains a significant monitoring difficulty due to the geographical dispersion of Indian villages and the fact that many isolated villages are not accessible for regular monitoring by the central agencies due to transportation and communication issues. The dispersion of Indian villages is due to the fact that they are geographically dispersed. The rural population, therefore, bears the most severe consequences of fluoridation, arsenic contamination, and microbiological contamination as a result of fluoridation, arsenic contamination, and microbiological contamination. This is a result of these factors. In order to comply with the Rajiv Gandhi National Drinking Water Mission (RGNDWM) and the sanitation department, through its public health engineering division, state drinking water missions are required to conduct a comprehensive analysis of water sources as a part of the RGNDWM. A national monitoring and surveillance program was set up in February 2006 for the comprehensive monitoring and surveillance of the quality of rural drinking water. There are a number of components in the program, including information, education, communication (IEC), human resource development (HRD), monitoring and surveillance activities such as field testing kits (chemical and bacteriological), as well as the development of district-level laboratories.

The program's aims are as follows:

1. Community monitoring and surveillance of all drinking water sources throughout the nation.
2. Decentralization of water quality monitoring and surveillance of the country's rural drinking water sources.
3. Institutionalization of community participation and engagement of local village institutions (panchayat raj) in monitoring and surveillance of water quality (WQM&S).
4. Raising rural people's understanding of water quality and water-borne illnesses.
5. Increasing the ability of panchayats/village institutions to possess a field testing kit and perform comprehensive

operation and maintenance (O&M) for all drinking water sources WQM&S.

11.11 Planning and management of water resources

To address the country's development objectives, the Department of Water Affairs and Forestry (DWAF) has developed a National Water Resource Strategy (NWRS) to handle water resource management at the national level in order to achieve the country's water resource needs. Our first step is to identify sections of the country where water resources are scarce and inhibit growth, as well as areas where water resources are abundant and help the nation grow. It is also mandatory for industrial users that take their water directly from a water source to prepare and submit a water management plan (DWAF, 2004a) if they take their water directly from a water source. There is a great possibility that groundwater will be the most severely affected by this drought, as the groundwater table will decrease as a result of decreased recharge, especially in the western parts of the country. Strict regulations should be put in place regarding the management of groundwater resources, and early warning measures must be put in place to alert the public when the groundwater supply is running low. As part of the DWAF's long-term objectives, local governments will be responsible for managing the supply and demand of water in their own areas (Krishnan et al., 2020). It is only through the education of the public that they will be able to make the right decisions regarding the potential supply resources, monthly abstraction amounts, water quality, and aquifer levels in order to achieve this (Van Dyk et al., 2005). As part of the planning and management of water resources, it has been proposed that each local government should have the capability of guaranteeing water supply to its constituents, despite current climatic conditions (Van Dyk et al., 2005). It is recommended that the peak demand equals 80% of the resource's available production at its peak. Consequently, it could act as a buffer against droughts and climatic unpredictability as well as provide the aquifer with time to replenish itself after a drought. To prevent reliance on a single source or kind of source, some municipal governments have used more than one type of water supply, such as groundwater and surface water. When groundwater is discovered to be too salty for home usage, this is most often used. There are a number of methods that can be used to improve the supply of freshwater by diluting salty water with fresh water to acceptable concentrations. It is also possible to use saline water to flush toilets, while treated water can be used to consume and cook. In order to install a system of this kind, both water sources would have to be supplied with separate pipes, so the construction of such a system would be very costly. Surface water is transferred into an aquifer in the form of rainfall runoff, treated wastewater, or urban storm runoff (Wang et al., 2004, 2011; Weather head et al., 2002; Water Aid, 2008). It has been shown that artificial recharge can provide security during drought or dry seasons by storing extra surface water from local or imported sources, and this may reverse the negative dewatering trend as well as enhance groundwater quality by replacing the aquifer when river runoff is available, in particular, salinity. As well as the agricultural benefits of surface water harvesting, there are additional benefits that can be obtained by enhancing subsurface water recharge, either through natural penetration of the soil or through artificial recharge. Depending on the type of aquifer, the success of the project will vary. Rainwater collected from rooftops can be used to supplement drinking water, irrigate plants, and fill swimming pools at home as a way to supplement drinking water.

Evidence from temperate, where irrigated agriculture is a relatively modest but economically significant component of land use in terms of productivity, value, and rural employment, is used to set the regulatory background and farmer views (Leathes et al., 2008). Although India's irrigated area (64.7 m ha) is relatively small compared to other countries, the monetary benefit (value) of irrigation water is extraordinarily high due to the supplementary nature of irrigation with shallow water depths applied to high-value crops (Knox et al., 2000). The proposed route is applicable in other temperate and dry regions with well-developed water policies and environmental restrictions, where irrigated agriculture plays a substantial role in the rural economy.

11.12 Systematic water supply regulation

The water regulatory authority, the Environment Protection Agency, issues licenses (permits) for the use of irrigation water in excess of a de minimize level, which is currently established at 20 m^3/d. Working for an organization, there were roughly 10,000 licenses issued for the purpose of irrigating agricultural and horticultural land. For purpose of irrigation alluvial or aquiferous water is taken straight from its original source and distributed by means of aerial spraying equipment, such as portable hose reels equipped with rain guns or booms, stationary sprinklers, linear movers and central axes, hinges, etc. Tumble or drip irrigation (micro watering) is a niche use but getting more and more common on high-value crops. No one uses a sprinkler to water the ground. All simplifications have to be metered, and information is gathered from each farmer's annual return. The Water Act and every license issued since following the implementation of the act (2003), several permits issued before that date have expired. The current government policy is to urge all active license holders to owners to switch to a temporary state. In most cases, these permits are required on a yearly basis, though exceptions may be made. Pertinent to the renewal of time-limited licenses for agricultural irrigation is the passing of three exams. In their catchment abstraction management strategy (CAMS) procedure, farmers may be asked to supply supplementary information. Irrigation abstraction is located near a national or international protected area on a national or international scale (such as a Ramsar wetland, for instance). For the second test, the licensee (the farmer) must quantify a variety of elements that have an effect on the agronomic criteria for continuing to operate irrigation, including specifics on the types of crops that typically benefit from it, as well as factors such as application rates, tools, and scheduling procedures. Previous analysis of data from Knox et al. (2007) established mechanisms that allow local water regulators to determine what amounts of irrigation are "appropriate" on a farm given the kind of crops growing, soil and meteorological conditions, as well as irrigation practice, on a regional scale. In this context, "reasonable need" refers to the practical requirements of agriculture in a hypothetically dry year of the "design" variety and is statistically defined as the irrigation requirements with an 80% confidence that they will not be exceeded. One might say that this is a resumption popular time frame for planning new irrigation systems or reservoirs while still satisfying agronomic needs frequently throughout the years. This concept excludes costs; the abstraction permits. Likewise, total irrigation requirements, which incorporate transport, have to be reflected (Munasinghe & Swart, 2005; Rosenberg et al., 1999; Schulze & Perks, 2000; Trenberth, 1999; Turral et al., 2010; Turton, 1999). This method yields an irrigation efficiency evaluation tool for use by the water authority to evaluate a customer's need and decide if the water volume they have. That farmer of yours is a reasonable person. To what extent the farmer has used previous years' abstract licenses in order to supply further corroborating evidence, despite the fact that irrigation needs change a lot from summer to summer in various climates precipitation and evaporation-transpiration (ET) rates; hence, for the farmer to connect irrigation practices to seasonal climate shifts The farmer bears the primary responsibility for gathering necessary data on how they have been using irrigation water throughout the course of during the length of the license, and then to set up a solid reason to keep the license active. The third and final test mandates that the licensee. Showing that water will be used effectively in the to come, based largely on water use records from the past and future enhancements to administration, infrastructure, and/or Educating the workforce. Genuinely lies, bringing together the farmer's view of what constitutes "efficient use" of water with that of the water regulating body effective Irrigation. Water use is often (but not always) viewed from a financial perspective by farmers. The majority of high-value crop growers have quality assurance in the final product, and thus, contracts and high costs from their clientele, notably in grocery stores. Increasing yield is not worth the high cost of irrigating if premium quality is your goal. Assuming an abundance of water, Water conservation is a key component of every economically viable farming operation. As a result, the marginal advantage was no longer greater than the marginal cost (Christensen et al., 2004; DWAF, 2004a, 2004b).

11.13 Water conserving applications

The initial investment for irrigation in mild climates is part of the equipment, with marginal costs being low in comparison to recurring expenditures. This means that the vast majority of irrigated crops are watered to their full capacity to fulfill agronomic needs while avoiding water waste. Indeed, taking into account the potential risks of disease outbreaks, restricted land access, and fertilizer runoff. If the farmer is concerned about water availability, may not be sufficient, and water for irrigation is mostly limited to the most (financially) crops that can adapt to a variety of climates and watering schedules. Since what we will actually require is highly speculative, a risk assessment yet not always tacitly implied. With some forethought, we could put almost all of the tight margins due to scarce resources. Irrigation return flows are of little relevance, unless when they pose hazards of diffuse pollution due to nitrate leaching; yet, during a typical dry English summer, agricultural runoff does not contain enough nitrate to create any noticeable contamination. No water can be reclaimed from the land because the drains do not work (Trenberth, 1999; Weather head et al., 2002; Water Aid, 2008).

For the most efficient (or least wasteful) utilization of a scarce resource, avoiding both excessive and inadequate watering while cutting down on wasteful runoff (e.g., run-off, leaching). One common way to characterize this is strategically applying water at just the appropriate temperature and pressure, timing, location, and place. More crops would be irrigated with the "saved" water. Alternatively, the Environmental Protection Agency (EPA) has been tasked with regulating the nation's water supply. Whose main goal is to keep everyone's water usage in check every single abstractor with the water ecosystem, often recognized that improving water efficiency would help them save water and advocate for environmental longevity (Munasinghe & Swart, 2005; Rosenberg et al., 1999; Schulze & Perks, 2000; Singh & Sontakke, 2002; Ministry of Water Resources, 1999). For example, in England and other countries, the public) concerns in other European Member states perspective has been mostly shaped by the residential and commercial sectors, where water efficiency measures irrigation water usage have been implemented above a de minimize limit, as established at 20 m^3/d, a permit is needed. No one uses a sprinkler to water the ground. All simplifications have to be local water regulators to determine what amounts of irrigation are "appropriate" on a farm given the kind of crops growing soil and meteorological conditions, as well as irrigation practices, on a regional scale. In this context, "reasonable need" refers to the practical requirements of agriculture in a hypothetically dry year of the "design" variety and is statistically defined as the irrigation requirements with an 80% confidence that they will not be exceeded. One might say that this is a resumption popular time frame for planning new irrigation systems or reservoirs while still satisfying agronomic needs frequently throughout the years. This concept excludes costs; the abstraction permits.

11.14 Sustainable water supply strategies in future

To counteract their country's dwindling water supply ("virtual water"), wealthy nations have the option of desalinating water and importing food from well-watered places in order to counteract their country's water scarcity ("virtual water"). Supply-side management is the first step in addressing the demand for water that is driven by population growth and social upliftment, even when water availability becomes scarce as a result of population growth. There is no doubt that supply-side management does not satisfy the demands of the water market, so when supply-side management is not successful, the 2nd phase of water management, referred to as demand-side management, takes over to satisfy the demands of the water market (Turton, 2006). In order to be able to deal with the problem of increasing water shortages, a series of changes within a social unit will have to be made in order to solve the problem. Traditionally, in the management of water resources, the focus has been on increasing the supply of water (Cave et al., 2003) rather than increasing the demand for water. There has been a shift in recent years from the quantity of water that consumers are requesting to reducing the amount of water that consumers are using, as the focus has shifted from quantity to quantity (Houghton et al., 2001). In order to optimize water supply alternatives, it is imperative to plan and manage a wide range of water sources, as well as adopt a range of new approaches like groundwater recharge and rainwater collection (Mukheibir & Zievogel, 2007). As well as reducing leaks and removing alien plants, it may be possible to reduce water losses by reducing leaks and removing alien plants, which may help to prolong the life of the existing sources of water. It may be possible to provide early drought warnings and enable proper preparation through the use of reliable and sound information systems (Munasinghe & Swart, 2005). Analyze strategies done by the effect of the intervention on water supply via increased yield and/or financial savings. Intervention technology is easily accessible. Intervention necessitates extra capital outlay. The present level of institutional capability in relation to the intervention. The extra cost and convenience of this action are acceptable to the consumer. The impact of the action on the area's water supplies and ecology.

11.15 Conclusion

Climate change presents a problem to water resource engineers. Hydrological research is required to be undertaken for the assessment of water resources under changing weather situations To forecast future climate, and to logical variables affecting the micro, meso, and macro watersheds. A thorough general circulation model is re-created at various scales giving serious consideration to be created for India in comparison to global circumstances. Because of the fast industrialization as well as the increased use of fertilizers and pesticides, the quality of surface and groundwater resources is declining. Pollutant transport in rivers, lakes, and streams in the groundwater aquifers must be managed. Regarding this a frequent water quality monitoring procedure is required undertaken in order to determine the locations that are likely to be affected because of water quality issues In order to keep water quality management, freshwater quality Strategies must be developed and implemented. Rivers must maintain a minimum flow in order to meet the EFR criteria. The eco-hydrological method According to the notions of blue and green waters considered an essential component of artificial water resources through balancing water amongst human beings, aggement methods. Also included is the concept of virtual water transfer. To address potential climate change impacts, it is necessary to distinguish between responses to climate variability and responses to climate change. Climate change has an impact on water resources. Droughts occur on a regular basis, resulting in short-term water shortages at the municipal level. To resolve these issues, Short-term methods are used to address fundamental home needs when there are shortages. Much of the academic literature. Furthermore, to yet, policy attention has been focused on the impact of climatic variabilities, such as droughts and floods, notwithstanding frequently reactive. Climate change, on the other side, is expected to increase the frequency. Droughts will become more common, resulting in more frequent water shortages. The application of long-term adaptation methods is needed to lessen vulnerability to future frequent droughts to achieve development objectives This method of dealing with natural climatic fluctuation and the prerequisite for dealing with the extremely unpredictable repercussions of global warming and climate change. Adaptive water management can have a positive influence. By dealing with current climate variability in water resource management, which is already a challenge tremendous task, resilience to any future effects of climate change will be enhanced. Adaptive water management practices used in the face of climate change food trading require policy changes to be implemented. Agriculture and water management capacity development and user awareness programmers could be organized and the general public for encouraging active engagement in water management techniques and the development of ethical standards and ideas for making better use of water resources capac-water resources necessitate the construction of city managers and developers for knowledge updates.

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Author contributions

In addition to contributing to the outline, the author is responsible for leading the draft and editing of the manuscript. It was L.S., K.S., and P.K. who conducted an extensive literature search and contributed to the writing of sections and the construction of figures and tables. In addition, they contributed to the construction of figures and tables. In addition to providing professional advice, P.K. helped revise the final version of the document and participated in its revision. In the end, all authors read and approved the final version of the manuscript.

Conflicts of interest

None.

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Chapter 12

Integration of water resources management in rural areas

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12.1 Introduction

Aside from its fundamental role in preserving the natural environment, water plays an essential role in driving economic along with social development as well as preserving the environment. Despite this, water is just one of a number of essential natural resources, so it is not appropriate to look at water problems in isolation. When it comes to deciding how to allocate water resources to the public and the private sectors, managers both in the public and private sectors are faced with a series of challenging choices when it comes to making decisions. In order to meet the ever-increasing demands, they are increasingly forced to divide every resource among ever-increasing demands as a result of ever-increasing demands. With current population growth and current water usage patterns and practices, the World Bank predicts that by 2030, the world will face a deficit of nearly 40% between projected demand and available usable water. To feed the world's nine billion people, we need to increase agricultural production by 60% by 2050. This could use up to 70% of the available water resources, leading to a 15% increase in water withdrawals. According to the World Bank, "estimates imply that 40% of the world population live in water-scarce areas, and around 14% of the world's GDP is susceptible to this risk." Approximately 1.8 billion people would be residing in areas with absolute water shortage by the year 2025.

Changes in population and weather patterns, for example, contribute to the already high demand for water. Since the old gradual method of managing water is no longer efficient, there is a need for a more comprehensive approach to water management. A wide range of organizations has recognized that integrated water resources management (IWRM) is the most effective way to ensure the future of the world's limited water resources (Afghan National Development Strategy (ANDS), 2007). Most natural disasters, like floods and droughts, are caused by water (IFRC, 2016), and this trend is likely to continue. The frequency and intensity of these water events are expected to increase as a result of climate change problems (for instance, IPCC, 2007, 2014). Therefore, one of the risks associated with climate change is the failure to adapt largest threats the planet is facing. This is because IWRM takes into account all of the different needs and how they affect each other. From the semiarid deserts to the wettest tropical rainforests, water availability varies greatly around the globe. It is important to note that seasonal changes, as well as inter-annual fluctuations, play a role in the variation of supply over time. Managers of water resources as well as societies as a whole are often faced with significant challenges as a result of the uncertainty of the resource, given that both the magnitude of variability as well as the timing and duration of periods of high and low supply are often unpredictable as a result of this uncertainty.

In spite of the high costs and negative impacts on the environment, and sometimes on human health and livelihood, it is not surprising that most developed countries have artificially overcome natural variability through supply-side infrastructure in order to guarantee reliable supply and reduce risk despite the high costs and negative impacts on the environment and sometimes on human health and livelihood. Because there is an insufficient amount of water available in many less developed countries, as well as in some of the developed countries, these countries are taking steps to treat wastewater, recycle water, and control the demand for water (GWP, 2004a). Also, population growth and other demographic changes (especially urbanization), as well as agricultural and industrial expansion in response to shifting consumption and production patterns, are driving up demand in many regions. In some areas, as a result, it has resulted in a situation where demand consistently exceeds supply, while in many others, it only occurs during particularly dry seasons or years (Bearden, 2010).

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This chapter's overarching goal is to determine if and how rural communities may accept and implement sustainable, cost-effective, and environmentally friendly water resource management strategies. Manpower capability, the ideology of stakeholders, and "social solidarities" were the primary areas of attention. Water resource management capacity-building and economic and social research management of water resources in terms of technology and ecology (White, 2002).

In view of the findings of Braga and Lotufo's (2008) investigation into the definition of IWRM, it becomes apparent that water resource planning and management must take into account the varied uses of water within a river basin along with economic, social, and environmental goals. Furthermore, it should involve collaboration between different levels of government as well as stakeholders in order to ensure an inclusive decision-making process. There are very few people within the water industry who would disagree with the premises and concepts of the paradigm described above as illustrated by Braga (2008) and Biswas' (2005) definition of integration. Hence, it is imperative to take into account not only quantitative and qualitative factors, but also supply and demand, as well as engineering, economic, social, ecological, and legal considerations (Wolman, 1980).

12.2 Water management potential in Rural India

In 2009, a dry spell badly damaged Chellapur, which is located around 150 km from Hyderabad but had little to no effect on the neighboring areas of Mahbubnagar and Anantapur in Andhra Pradesh. Villagers in Mahbubnagar and Anantapur joined together to share groundwater with their neighbors in Chellapur as part of a pilot project funded by the World Bank and implemented in partnership with the Andhra Pradesh drought adaptation initiative (APDAI). Those who did not possess borewells were nevertheless able to access the community's common water supply thanks to an underground network of pipelines that stretched for about 2 km (World Bank 1993).

Multiple towns in the Panchgani district of Maharashtra benefited from an effort that began in 2010 to restore several springs vital to the region's water supply. Borewells and these revitalized natural springs allowed local communities to meet their water needs when pumping water from dams wasn't an option owing to distance and high prices (World Bank 1996).

Constant usage of groundwater has resulted in serious depletion of water levels, and excellent quality water was accessible only below 1000 feet or more in 2015, leading to the catastrophic failure of the borewells at Sandharsi, Patiala, Punjab. The people banded together to address this issue by constructing ponds in and around their agricultural areas. There were two benefits to this, in times of drought, the ponds' water was used for agriculture, while in times of monsoon, the ponds helped to prevent flooding by holding the extra water.

12.3 The "ideal" IWRM scenario

In order to guide the water sector in a more effective way of managing its resources, the framework proposes a hypothetical "ideal" IWRM scenario in order to develop a framework for implementing IWRM. It is believed that a truly effective IWRM system would be able to manage water sustainably at the sub-basin level. It is important that when we are making decisions about water, we take into consideration everyone's needs and values when making those decisions. Each of the parties involved in the project understands the potential of the water source, as well as how their actions will affect the other parties in the project (Warner, 2007). Decisions regarding the use of water as well as the costs associated with the provision of these services are made in a collaborative manner. This is based on criteria that are accepted by all the parties involved. A number of effective mechanisms are in place in order to ensure that IWRM is implemented in an efficient and transparent manner and at the lowest possible cost. According to IWRM theory as well as internationally accepted and applied water policy principles, it is possible to develop an ideal IWRM situation based on IWRM theory. Several IWRM-focused regional and municipal water policies have been implemented throughout the world (Asian Development Bank, 1996; Imperial Order of Beavers, 1997; World Bank, 1993). It is important to note that there is no such thing as an "ideal" scenario when it comes to IWRM. Based on the specifics of each area, there may be a different best course of action depending on the specifics of the specific situation. This is depending on the specifics of each area. I would like to take a moment to explain why it is essential to establish an ideal scenario in order to provide some direction for formulating the ideal IWRM scenario that will work best for your organization when it comes to formulating an IWRM plan. If one wishes to depart from an ideal situation and deviate from it, then one must make a deliberate decision in order to do so. The fact that people feel more invested in the final product as a result of this not only makes them feel more invested in IWRM, but they also get a deeper appreciation for what IWRM is all about (van Hofwegen and Schultz, 1997).

12.4 Concepts of integrated water resources management

The concept of IWRM is a practical theory that is derived from an actual body of work done by a number of experts over the past few decades (Thompson, 2003). In accordance with the global water partnership, the definition of IWRM that has been put forth by the organization is one that is generally agreed upon by those involved in the field. Having said that, in accordance with the document, the term “IWRM” can be defined as “the process by which water, land, and related resources are managed in a coordinated and equitable manner with the goal of optimizing the resulting economic and social well-being without compromising the sustainability of vital ecosystems” (Fulazzaky et al., 2009).

The WHO’s worldwide sector guidelines for water supply and sanitation are currently being followed, but it is highly advised that a more integrated strategy is needed to solve the problem of water supply and sanitation (Morita, 2014; Olokesusi, 2004; Pena, 2009; Rahaman & Varis, 2005). Therefore, it was proposed some future policy suggestions, such as an integration of the technical, operational, financial, and health concerns right from the start of the planning process will enhance outcomes. Improvements might also result from prioritizing community input at all stages of the project’s development, with a focus on the important role women play and should play in ensuring adequate water and sanitation services for their local communities. Maintenance and manufacturing should ideally be organized on a local level. Rain collecting should be encouraged, and the proper equipment for classifying the water gathered should be made available in both urban and rural locations.

Suitable technologies, such as solar panels and wind turbines, have already been implemented. They need enough money for the results to be shared with member states so that good ideas can be used in different places (Sivakumar, 2014; Soncini-Sessa et al., 2007).

“Integrated Water Resources Development and Management” is what is meant by the term “Integrated Water Resources Development and Management” in these guidelines when it refers to implementing IWRM for the provision of water services at the river basin level. In terms of IWRM, the global water partnership (GWP-2000) defines it as “a process that promotes the coordinated development and management of water, land, and related resources with the objective of maximizing the resulting economic and social benefits on an equitable basis while maintaining the sustainability of vital ecosystems.” It is an all-encompassing method that seeks to integrate environmental management with broader social, economic, and political structures. As a result of the river basin approach, it is intended to promote more effective implementation of IWRM principles through improved coordination between operating and water management entities within a river basin, with a specific focus on the equitable allocation and delivery of services that rely on a steady supply of water (Brils, 2008).

The river basin approach is used in IWRM with the aim of gradually decentralizing activities to river basins and sub-basins and making extensive use of the available water resources. As a result, in order to achieve integrated water resource management, the following common policy principles must be adhered to:

- It is important to take a long-term, sustainable approach to develop and manage our water resources as part of an integrated strategy.
- Stakeholder participation is crucial for the effective management and development of water resources.
- All parties involved in the water sector should be consulted and invited to participate in all development activities.

As a result, the strategy intends to manage and develop water resources in this country in order to improve the livelihoods of present and future generations. In order for this to be achieved, it will be necessary to ensure that people in both rural and urban areas have access to hydropower, as well as a reliable supply of clean drinking water. A reliable water supply is essential for industrial development and growth to be successful (MEW, 2004a).

12.5 Consumption stranded

Each of the three socioeconomic categories of the population is taken into account while planning for water and sanitation infrastructure. If you live in a rural area with between 150 and 5000 people and you need water, you may be assured that you will have access to at least 30 L per person, per day, within 250 m of the nearest water station. Having a population between 5000 and 20,000, semi-urban (small town) water supply refers to communities with a minimum supply norm of 60 L per capita per day by reticulation and a restricted number of full home connections as specified by the beneficiaries or government. If a city has a population of 50,000 or more, it is required to provide each resident with 120 L of water per day. Complete reticulation and consumer premise connections will be available to more than 20,000 residents (Thompson et al., 2003).

12.6 Principles of integrated water resource management

In order to develop a more holistic and integrated approach to water management (2001), a country’s water policy must be reevaluated in order to make the necessary changes. The process of creating a water policy is commonly begun by outlining a handful of guiding principles and objectives, for example, the importance of achieving sustainable development as well as the development of a thriving economy, which is standard practice when creating water policies. As Postel (1992) points out, there are three essential parts of making good policy, or what he refers to as the “three E’s”:

1. **Equality**: It is crucial that people have access to safe drinking water. There is an absolute necessity for humans to have access to a sufficient supply of potable water in order to survive. All people should be assured that they have free and unrestricted access to potable

water in order to fulfill their basic needs. There is a very strong correlation between the widespread recognition of water's value as a public good and this principle of public policy. Because of how crucial water is to human existence, society has a duty to protect the public interest when it comes to the use of water resources. Many other problems, such as safety, can be derived from this (protection against floods, droughts, famine, and other hazards).

2. **Ecological integrity**: Unless water resources are located in a natural setting that is capable of replenishing adequate supplies of clean water, it will not be possible for water resources to be used sustainably. Using water cannot be allowed if it is not sustainable, so future generations will be able to enjoy the same benefits from it as we do today.
3. **Efficiency**: There is no doubt that water is a valuable resource, but it is limited, which is why it is essential to conserve it efficiently. In order to ensure that the full cost of providing water services is recovered, institutional arrangements need to be put in place. By doing so, we will ensure the long-term viability of essential infrastructure and institutional frameworks, but we must not compromise the principle of equity in the process. In this context, the question of whether or not to price water according to its economic value arises. The important part of water resource management is to find fair solutions that take into account the different facets (dimensions) of IWRM with these policy principles, which can be at odds with one another at the same time. There are three pillars on which IWRM is based, namely social justice, economic viability, and ecological sustainability. It is important to take these guidelines into account so that we can then address the following issues:
   - **a.** How will my choice or action affect the rights of others to use water, or their ability to reap the benefits of doing so?
   - **b.** Will, what I'm about to do or decide lead to the "best use" of the available money and water?
   - **c.** How will my choice or action influence the health of ecological communities.

There is a need to ensure social equity by ensuring that all users, especially those from underprivileged backgrounds, have access to the minimum amount and quality of water that is necessary to maintain a normal lifestyle. In order to decide who should receive how much water, it is also important to consider who should receive what share of the benefits as well. In addition to the simple pleasure of using a resource for recreation, water can also be converted into useful products for monetary gains, thus bringing a range of benefits. Economic efficiency can be defined as a measure of how much money and how much water can be spent in order to provide the greatest possible benefit to a large number of people at the same time. In order to make the most cost-effective choice, it is imperative that the best decision is made. As part of the monetary value of an asset, the social costs and benefits of the present, as well as those of the future, should also be considered as part of the monetary value. In order to attain ecological sustainability, aquatic ecosystems must be recognized as users and provided with the resources needed to ensure their continued, natural functioning. This criterion cannot be met unless land uses and developments that have a negative effect on these systems are either restricted or eliminated in order to achieve compliance with this criterion. As a result, IWRM can be viewed as a thorough, collaborative planning, and implementation tool that assists in managing and developing water resources in a way that strikes a balance between social and economic needs while safeguarding ecosystems for future generations (Sivakumar, 2014). The multifaceted importance of water in modern life-for food production, maintaining ecosystems, sustaining human life, and sustaining livelihoods requires a concerted effort if we want to protect it. Integrated water resources management (IWRM) is a transparent and adaptable process that brings together decision-makers from all sectors that have an interest in water resources as well as other interested parties, in order to formulate policies and make well-informed, well-considered decisions in response to the unique water challenges that each sector has to deal with (Biswas, 2005; Rehman, 2005).

Since water is a limited resource, the Dublin Declaration (ICLEI, 2008) stipulates that the management of water also needs to take into account affordability and equity criteria, in order to treat it as a "finite and valuable commodity". As an essential resource for life, development, and the environment, water is neither abundant nor secure, but a scarce and vulnerable one (Fig. 12.1).

12.7 Development of integrated water resources management in rural area

Given these problems, Nigeria's water supply and sanitation sector are in dire need of a service definite strategy for building water and sanitation infrastructure, with the goal of making the market more orderly within a certain time frame. So, the method should establish a respectable national policy. It will establish a framework for planning, studying, and training new employees, as well as a framework for new government agencies, legislation, and a method of funding to accommodate the country's monetary and social needs.

The policy's main provisions are as follows:

Nigeria's water and sanitation policy's primary tenet is the delivery of adequate supplies affordable and sustainable access to clean water and sanitation for all Nigerians through

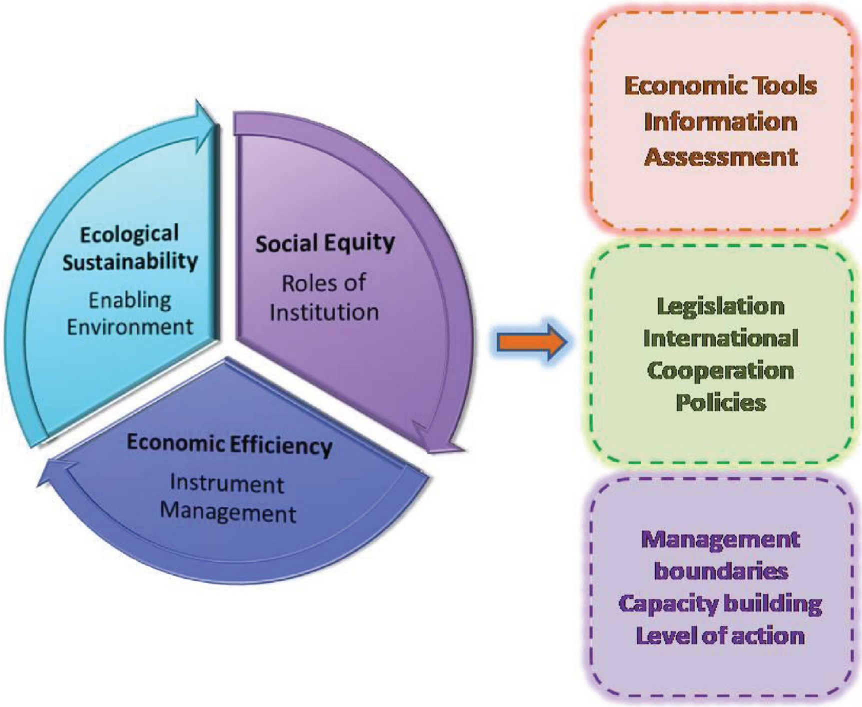

FIGURE 12.1 Principle and need for integrated water resources management.

the involvement of all three levels of government, the corporate sector, and the intended recipient as investors.

The term "integrated" is frequently used to convey the idea that policies need to be taken into account in order to be effective. The integrated management of water resources has roots in the same ideas as "integrated planning," "integrated environmental management," "integrated risk management," as well as "integration with other policy sectors." As time has passed, there has been a number of related terms that have come and gone over the years, with some being fads and others sticking around. In Fig. 12.1, we can see in part how the development of modern IWRM can be visualized. The question that arises is, "For how long has this term been around?". Since similar ideas have likely developed as society has grown and as public affairs have become more complex, the question may be moot. As per Biswas (2004), it has been in use for more than 60 years now. In the United States, the Flood Control Act of 1917, which was passed in 1917, mandated a "comprehensive study of the watershed" with similar goals (Holmes, 1972, 1979). During the new deal era in the United States, planning progressed substantially, and efforts to build on those gains culminated in the Water Resources Planning Act of 1965, which mandated comprehensive, coordinated, and joint planning in all water resource areas. These concepts, as well as other integrated planning and management concepts, were the forebears of IWRM. The integration of IWRM across a variety of disciplines is crucial to its success. The 1960s Water Resources Research Act sparked the establishment of the Universities Council on Water Resources (UCOWR), an organization that encourages researchers from a variety of academic disciplines to conduct research on water resources. Civil engineers and others recognized the need for an interdisciplinary approach to the planning and management of water resources during the 1970s, which led to the founding of the Water Resources Planning and Management division of the American Society of Civil Engineers (ASCE). Coordination is one of the most critical components of IWRM. According to a study conducted at Harvard, coordination is one of the three main pillars of federal water policy, along with development and regulation, and has been identified as one of the three main areas of federal policy. Further, they mentioned that the issue of the coordination of policy has been discussed by a variety of study groups a number of times over the years (Morita, 2014). In a term coined by the American Water Works Association (AWMA), the term "Total Water Management" (TWM) refers to the process by which the water supply industry strives to make sure that water resources are managed in a way that is advantageous to the community and the environment and that participants from all segments of society are equally engaged in this process. In the past few years, similar ideas have been proposed under the banner of "TWM" as an alternative to IWRM under the banner of "TWM." A variety of approaches have been proposed for describing water management frameworks, including the use of the term "holistic water

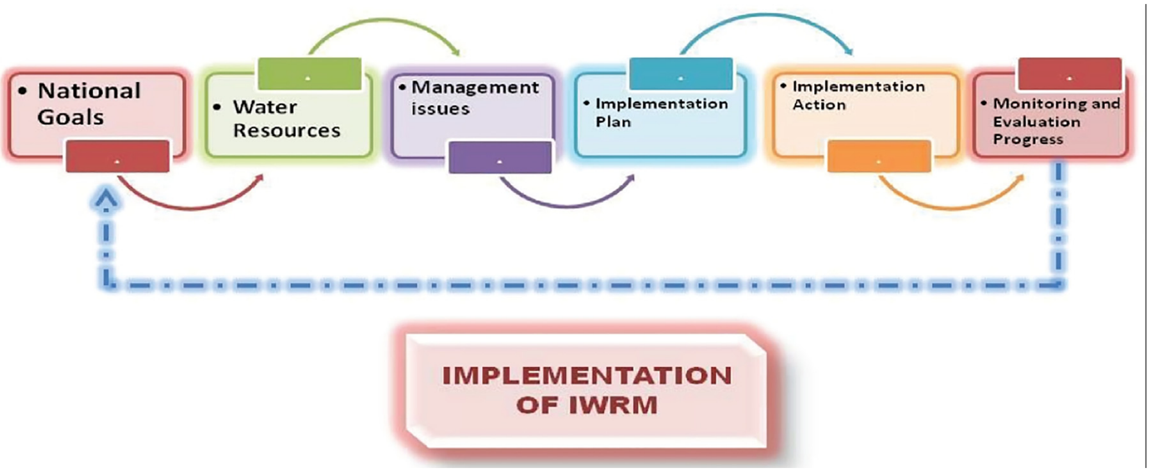

FIGURE 12.2 Developmental objectives and implementation of integrated water resources management.

management" (Kirpich, 1993). In addition to various elements that have been emphasized by IWRM, the "comprehensive policy framework" that has been promoted by the World Bank (1993) emphasizes a number of elements that have been emphasized by IWRM.

12.8 The IWRM framework

It has been suggested that in order to get from the current state of water resource management to the ideal state of integrated water resource management, it is necessary to develop an analytical framework that is based on the concept of cyclical development in order to get from the current state to the ideal state. In my opinion, it is important to keep in mind that implementing IWRM fully and immediately is not feasible and even unwise. In terms of IWRM, therefore, an ideal situation would be one in which there is a middle ground in terms of the current situation as well as the ideal situation as it pertains to IWRM (Braden, 2014). Fig. 12.2 shows the main steps in the process of achieving the desired IWRM situation, as well as the main conditions that will need to be changed. There are three tiers of the framework and guidelines, which includes the constitution, the organization, and the operational tiers, all of which are taken into account throughout the framework and guidelines (Warner, 2007).

12.9 Implementation of integrated water resources management in rural area

The objective of IWRM is to improve the catchment basin conditions and establish long-term water security within existing constraints within the catchment basins. There are a number of key requirements that must be met for the introduction of IWRM to be successful (Rahaman et al., 2004).

Political will and commitment: With the right amounts of political will, all parties involved in the process will be able to come together and the process will be able to move forward. The fact that there may already be controversies and conflicts among stakeholders, or that the resulting plan or arrangement would require changes to legal and institutional structures, makes this step especially significant if there are already controversies and conflicts among stakeholders. For the implementation of IWRM, it is necessary to have access to actors outside the box in order to gain governmental support, sector support, and public pressure relief.

Basin management plan and clear vision: It is essential for the coordinated development of water resources to have a master plan that takes into account the plans of the various sectors and users and ensures the most efficient and effective use of the resource.

Mechanisms for participation and coordination: Meetings and interviews are two effective methods to help you find the people who really matter in your project and can help you promote the free flow of ideas and data. A way in which stakeholders can be involved can be defined in a way that is appropriate for the given context, and the process can then be refined over a period of time.

Capacity development: In the United States, there is a need for a top priority to be put on capacity development and training. In order to engage people who are at risk of being negatively affected and/or socially marginalized, consensus-building strategies can be effective (Soncini-Sessa et al., 2007).

Well-defined, flexible, and enforceable legal frameworks and regulations: The need for compiling and reviewing the full spectrum of existing laws and regulations that apply to water-related activities needs to be undertaken in order to be able to determine how existing legislation can be better adapted to accommodate sustainability and integration with respect to the management of water resources.

Water allocation plans: As a shared resource, it is important that the plans that are used to allocate water are flexible enough to be able to adapt to new circumstances as the situation changes. As explained by Lenton and Muller (2009), in order to maximize the use of a basin's resources and improve the coordination among all the different sectors within a basin, it is important to develop a basin management master plan that takes into consideration the plans of each sector.

Adequate investment, financial stability, and sustainable cost recovery: In order to effectively coordinate the implementation of IWRM, all of the long-term costs must be considered so that the project can be implemented effectively (Pena, 2009).

Good knowledge of the natural resources present in the basin: An in-depth understanding of the basin's natural resources, including its water supply and its human population, would be preferable to a superficial understanding of the basin's natural resources.

Comprehensive monitoring and evaluation: In order to ensure that the current process of managing water resources is being carried out correctly and to discover whether there is a need to adjust management strategies as a result of the current management practices, it is important to perform regular monitoring and evaluations of the system, in order to ensure that it is continuing to function properly.

12.10 IWRM requirements for the functional levels

In the context of an IWRM program, tasks are delegated to water systems, guidelines are developed, guidelines are enforced, and water resources are managed through the development of guidelines. The process of determining the availability, development, and use of water resources includes the analysis of physical and socioeconomic processes, weighing interests, and taking decisions concerning their use, development, and availability, all of which are a part of the decision-making process (Afghan National Development Strategy (ANDS), 2007; Bearden, 2010; Biswas, 2005; Braga & Lotufo, 2008; Brils, 2008).

12.11 A role of the constitution functional in IWRM in a rural area

As far as water policies and legislation are concerned, the primary purpose of the constitutional function of the IWRM platform is to set the boundary conditions for the successful implementation of both the organizational and operational functions of the platform, by establishing appropriate legal and policy frameworks for the implementation of the platform's functions. In order to fulfill our constitutional duty, policymaking, normative and executive lawmaking, and the development of human resources are all items that are considered a part of the constitution-making process. At this level of organization, it is imperative to take into account the extent to which the private sector is involved at all three functional levels. This is in order to achieve a successful outcome at all three levels of the organization (Fig. 12.3).

12.12 Management of rural water resources as an organizational function

The occurrences of these events are influenced by the time and place in which they occur. The project has been highly interdisciplinary, involving environmentalists, ecologists, lawyers, economists, sociologists, agriculturists, politicians, and representatives of interested parties, pressure groups, and water users, in addition to engineers with expertise in hydrology, hydraulics, construction, water supply, sanitation, hydropower, and irrigation, as well as engineers with expertise in hydrology, hydraulics, construction, water supply, sanitation, hydropower, and irrigation. In order to achieve success in terms of developing the capacity and capability to manage water resources integrated, both a top-down approach as well as a bottom-up approach needs to be taken in order to achieve success in this regard. Because of the government's efforts to fulfill its role of caring for the people, a hierarchical order has developed as a result of the government's efforts to make sure its responsibilities are met. In order to accomplish this objective, the government needs to take steps to protect society's resources, ecosystems, and socioeconomic well-being in order to achieve this objective. A government is responsible for developing policies and creating legal and institutional frameworks to ensure that water resources can be used and managed efficiently by the government in order to achieve this task. The bottom-up strategy emerges from the operational level of a company in order to safeguard varying and often competing uses and controls (Biswas et al., 2005; Braden et al., 2014; Braga, 2001; Braga & Lotufo, 2008). For this bottom-up process to be successful, an enabling environment must be created by the government in order for it to be successful. It is imperative that the constitution provides sufficient space for the refinement and adjustment of the constitutional frameworks so that they can be adjusted and refined as part of a lifelong process of learning, adjusting, and refining. This is a lifelong process of learning, correcting, and adjusting. To put it another way, the law regulates only the major policies and major concepts of the government. This is in order to give interest groups the opportunity to formulate their own ways in which they wish to coordinate and operate in accordance with their own interests in accordance with the law in the way they see fit. In order for this activity to take place, it is without a doubt that the state must supervise it in order for it to be allowed to proceed.

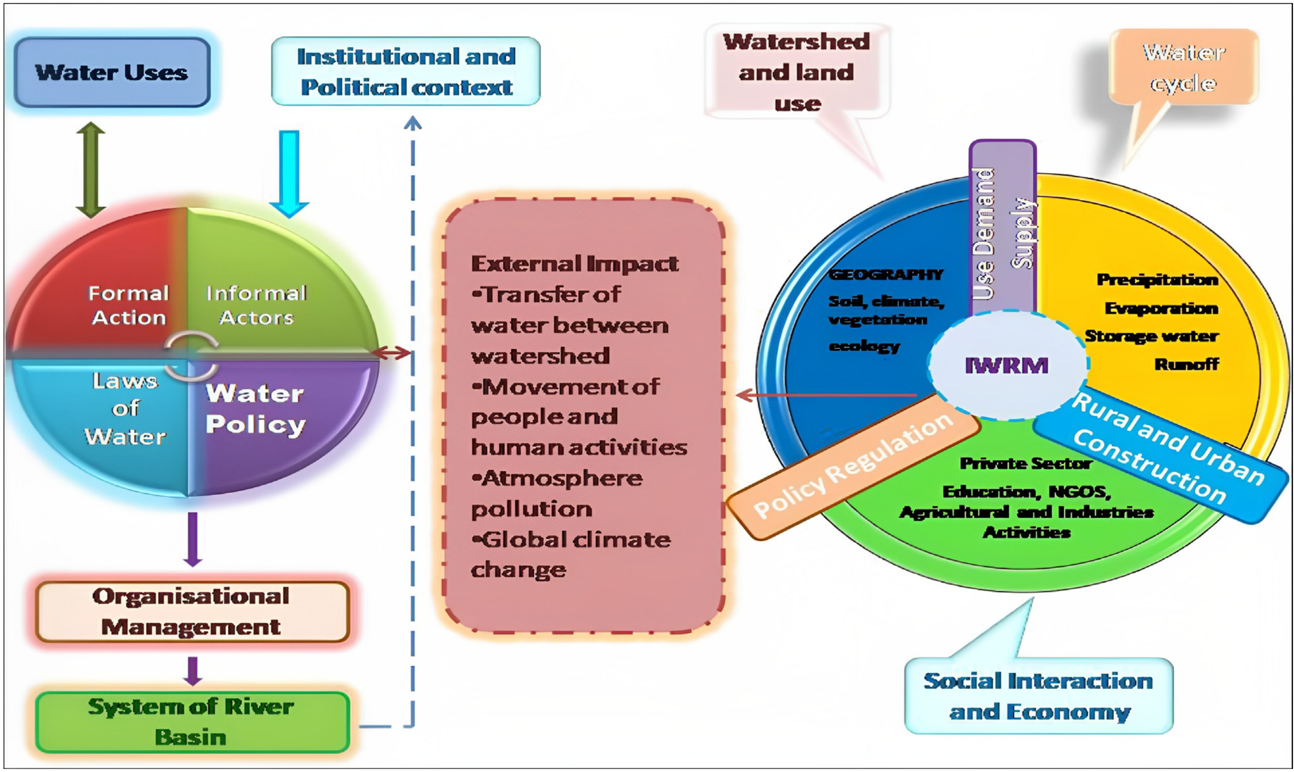

FIGURE 12.3 Interaction and developmental framework for the implementation of integrated water resources management.

- **A centralized location for group collaboration and policy formulation:** It is crucial that the current development work is focused on providing a mechanism for balancing conflicting interests in order to ensure the success of the project. In this way, we will be able to make decisions regarding the allocation of water resources based on the balance of competing interests, which will allow us to make informed decisions. The achievement of a balance between competing interests in a balanced manner is vital if a balance is to be maintained between them in the long run. Because of the nature of these forms of oversight and responsibility, there is a need for legal frameworks that can govern them as a consequence.
- **Data availability:** For effective interventions related to the development and use of water, it is imperative to have easy access to this information. This will enable us to analyze alternative courses of action for interventions related to the development and use of water. IWRM has to be capable of meeting the demands of planning, management, control, and development of trees and forests. They could have a high stake in its success. In order for the development and operation of the platform on a long-term basis, the legal and institutional framework will have to be developed at the constitutional level in order to establish the long-term legal and institutional framework. On an institutional level, policies are established for the training and encouragement of competent and enthusiastic employees at all levels of government.

12.13 Evaluating the institutional framework: methods and resources

We believe that an assessment of the underlying institutional framework must be conducted as the first step in order to move from the current state of water resources management to the ideal state of IWRM in order to move from the current state to the ideal state of IWRM in order to move from the current state to the ideal state (Biswas, 2004, 2005; Braga & Lotufo, 2008; IPCC, Core Writing Team, 2014; Kadi, 1997; Soncini-Sessa et al., 2007; Thompson, 2003).

12.13.1 Step 1: The water management system as it currently stands

Firstly, in order to be able to set the necessary priorities, there is a need to gain a full understanding of the water situation in order to be able to assess the organizational structure of the water system so that we might be able to identify (possible) conflicts over the use of water between stakeholders and set the necessary priorities accordingly. As a starting point for the institutional assessment process, we felt it essential to start with a foundational document that outlines the current situation. It has been assigned to a group of experts the task of writing a report that would provide an overview of the current water management situation as well as any issues that have been reported (in terms of quantity, quality, and the impact on the environment). This report needs to be widely disseminated in order to provide the necessary context for the subsequent procedures to be undertaken. This report can be widely disseminated as soon as possible.

- **Physical condition:** When assessing physical conditions, it is imperative to take into account the availability and consumption of water on a time and spatial basis (quantitative as well as qualitative) as part of the assessment process. As part of this analysis, it is necessary to collect data on the local weather, hydrology, hydrogeology, aquatic ecosystems, abstractions, influents, and storage capacity in the area. There is no doubt that if IWRM is to be implemented effectively, there must be access to observation networks and databases. In addition, there must be information regarding whether these datasets are of high quality and whether they can be easily accessed in order to achieve this.

12.13.1.1 Interested stakeholders

In the case of a private entity or body as a stakeholder, the interests of that entity or body are codified in the bylaws of that organization. Interest groups and stakeholders are two separate entities that need to be distinguished from each other. As a result, different interest groups represent different types of interests, such as public interest, private interest, environmental interest, social interest, etc. It is considered that stakeholder documents are the governing documents of organizations such as governments, non-governmental organizations, professional societies, businesses, and user groups if those organizations have governing documents, such as statutes or bylaws, that govern the actions of the organization.

- **Developing a list of water issues:** As a result, the inventory of water issues has been limited in this area. In order to be included in the inventory, only the issues that are widely known and that have been registered with the most influential stakeholders have been taken into account. Among the many problems of this nature, there are those that are related to navigation, recreation, and other uses, as well as those that are related to water quantity, quality, and environmental issues (erosion, siltation, salinity, etc.). Based on the inventory of these issues, the second phase will then take place, in which the issues will be further analyzed and additional interest groups and stakeholders will be identified.
- **Water rights and water allocation:** There is a general perception that water is a resource that is shared by all. It is true that there is customary law that allows the acquisition of private rights to water supplies in many countries. A good management system is of great importance, both in terms of the management of water market systems as well as the approval process for water transfers, since both systems are directly related to the management of water markets. Unless there is a proper plan for water management, there can be no doubt that a nightmare will ensue if there is no planning.
- **Indicators of the financial and social economy:** In addition to the problems that have been mentioned above, there are a number of problems that can be attributed to the current economic and social climate. Often, the lack of sufficient financial resources is attributed to a lack of adequate infrastructure and maintenance, poor management, and ineffective cost recovery, a result of poor management and ineffective cost recovery, as a result of poor management and ineffective cost recovery, as a result of poor management and ineffective cost recovery, as a result of poor management and ineffective cost recovery, as a result of poor management and ineffective cost recovery.
- **Existing water policies and strategies:** This issue, as well as the government's commitment to implement the outcomes of international conferences, has resulted in discussions regarding the water sector taking place in many countries today as a result of these issues. Despite the fact that many countries' policies have still not been fully formulated, they are still in the process of being put together. By taking an inventory of these policies, one can get an idea of the level of understanding and dedication at the constitutional level to the implementation of these policies.
- **Legal structure:** The existing water laws (as well as other relevant environmental legislation), water regulations, and relevant governmental regulations, decrees, and bylaws regarding the water authorities and river catchment agencies must be cataloged, and the principles that govern them must be outlined.
- **Institutions with a stake in the water sector:** A government, a semi-government agency, or a private company are all examples of relevant water institutions at a national, basin, or user level. This is because all of these organizations have some sort of role related to water and water management. There are several factors that can be identified in a water use flow diagram, including the users, service providers, and coordinators involved.
- **Experience with IWRM in the past and present:** Having a clear understanding of what has been done in the past in order to address specific challenges, as well as how effective those efforts have been, is crucial to addressing these challenges in the future. As a result, it would be beneficial to have an explanation of the successes and failures of past and present interventions in the area of integrated water resource management in the local area, along with the factors that have contributed to their success and failure.

12.13.2 Step 2: Identify the appropriate parties

As a first step, we are planning to take note of all the parties that are relevant in the first place. The most obvious examples of these parties are the water utilities, coordination agencies, and policymakers who are involved in water management. In order to avoid unnecessary work, it is necessary to narrow down the pool of potential participants in the order of the next steps to avoid unnecessary work being done. As a matter of fact, it is possible that some relevant perspectives may have been overlooked in the original study. Water policymakers are not the only ones that can be considered potential candidates for inclusion on the independent team referred to above.

12.13.3 Step 3: Involvement of stakeholders

As part of the evaluation process, experts conduct in-depth interviews with the selected stakeholder groups in accordance with a set of established interview protocols. This recommendation takes the form of a questionnaire, in which stakeholders are asked about their thoughts on the current IWRM landscape and what they would like to see changed in the future. In their study, van Hofwegen and Jaspers (1999) have developed some rules for conducting interviews that should be followed at all times during the interview process. By conducting these interviews, it would be possible to get a better understanding of the current state of the water management system, the nature of the conflicts involved, and even the extent to which the various parties involved agree or disagree with one another. There is no doubt that this is an extremely crucial step.

12.13.4 Step 4: Evaluation of stakeholder feedback

Every row in the table represents a set of questions that are tailored specifically to a particular stakeholder group and it is pertinent to note that each row represents its own set of questions. In order to contextualize the findings from the interviews, it was decided to provide stakeholders with a report and assessment of the institutional frameworks (van Hofwegen & Schultz, 1997) in order to place the findings into a broader context. For the purpose of ensuring the success of the process, it is imperative that these parties are included in the workshop that follows the process in order to ensure that it is successful.

12.13.5 Step 5: The initial problem-finding workshop

There will be a first workshop, to which all relevant parties have been invited. This workshop will be aimed at assessing the current state of water resources management and identifying problems from the point of view of the stakeholders. In the previous steps 1–4, it was essential to identify and understand the needs and priorities of each stakeholder. In the analysis report presented in step four, you can see that the "experts" interpretation of their agreement and disagreement has been reflected in the analysis report in a way that you can clearly see. So, it is crucial that everyone involved acknowledges not only their own issues but also those of others. This strategy was found to be highly effective in identifying the most pressing issues among the participants in the test (Kadi, 1997). Accordingly, it would seem that the result would need to be incorporated into the formulation of policy, the implementation of policy, or the operationalization of the management of water resources.

12.13.6 Step 6: Development of the preferred rural IWRM situation and interventions

Several months after the first workshop, a second workshop will be held to explore in more depth the principles of IWRM in a more in-depth manner. At the first workshop, these principles will be discussed in more detail. Despite the fact that there is no doubt that the results of this workshop are illustrative, they can also be used to guide future constitutional, organizational, and operational interventions as well as help guide upcoming discussions.

12.13.7 Step 7: Preliminary country, basin, or sub-basin

It will be conducted in such a way that a preliminary document will be drafted for the country based on the following sections: an assessment of the current water management situation and the development of an exhaustive list of issues and desired conditions in the management of water resources in the country.

12.13.8 Step 8: Provide and receive feedback

When the country/basin/sub-basin draught report has been disseminated to stakeholders at all levels, a thorough procedure is followed in order to collect feedback from all stakeholders at all levels as soon as the draught country/basin/sub-basin report has been distributed to them.

12.13.9 Step 9: Report on sub- and country-level basins

During the development of the strategy and/or during the implementation of specific water-related projects in a country, the government and funding agencies will receive a final country/basin/sub-basin report, which has been prepared by

TABLE 12.1 Different problems related to integrated water resources management and their possible ways to resolve them.

S. no.	Problems of IWRM	Solutions to resolve it
1	There is no consensus on essential concerns like how by whom, or how to combine certain parts even though such incorporation in a the more practical sense possible.	IWRM should not be viewed as a "bundle of reforms," but rather as a philosophy.
2	Integrated water resources management (IWRM) does not focus on people enough.	Projects and programs should incorporate IWRM principles.
3	IWRM does not sufficiently apply adaptive management concepts.	IWRM should start with local laws and customary institutions. There should be stronger connections made with local government and its planning procedures.
4	Local IWRM is not included in reform packages for IWRM.	IWRM ought to be constructed top-down.
5	Obtaining legitimacy may be difficult for watershed authorities or river basin organisations.	Even if this means enhancing "sectoral," rather than undertaking a comprehensive redesign, IWRM reforms must build upon the current structures for the participation and organisation of stakeholders around water management.
6	Catchment agencies frequently are unable to perform even the most fundamental tasks.	More likely to be effective entry points are "light" approaches that aim to apply IWRM concepts at all phases of the project cycle (e.g., visioning, assessment, planning, implementation, monitoring, and assessing, etc.).
7	IWRM initiatives disregard politics.	As a form of local IWRM in and of itself, supporting the current local arrangements should be promoted as it is more likely to succeed than beginning from scratch at the local level catching capacity.
8	IWRM participation rates are low.	Even if regional IWRM efforts frequently have been limited they still have the potential to contribute to the growth of IWRM and are significant at the basin scale because of the ways to start using the IWRM framework.

experts, for approval and incorporation into the strategy and/or into specific water-related projects in that country

12.13.10 Step 10: Verifying the status

With the use of a tracking system, we are able to monitor the implementation of our interventions and the realization of the desired outcomes resulting from those interventions (Table 12.1).

12.14 The possibilities and challenges of true integration of IWRM in rural areas

India's water management and administration agencies are struggling due to the large sums of money needed to launch initiatives in the country's rural areas. The availability and use of electricity are the second challenges. In order to implement effective, equitable, and sustainable water management, it is important to recognize formally the requirement to include and integrate the various sectors, governance structures, people, and environments that are involved with, as well as influenced by, the water in the decision-making process. Access to information is obviously one of the most important factors for the achievement of this goal, and it goes without saying that it is vital. Though there have been many solutions proposed, some of them come with their own set of challenges that need to be overcome despite the fact that many of them have been proposed (Braga, 2001; Braga & Lotufo, 2008; Chinchill, 1988; Fulazzaky & Gany, 2009; van Hofwegen & Malano, 1997; Wolman, 1980; World Bank, 1993; Global Water Partnership (GWP), 2004a; GWP 2004b). It is, of course, essential to keep in mind that there are real-world difficulties that need to be kept in mind, such as the lack of available data to measure the appropriate variable over a sufficiently long period of time and space, to name a few. If water managers are going to be able to make sound decisions when it comes to managing water resources, it is essential that they have access to data that can be reasonably trusted in order for them to make sound judgments. As there is an immense amount of literature in the field of GIS science, it is evident that many conceptual issues, such as dealing with uncertainty in the data, the accuracy of the data, the propagation of errors, and recognizing the impact of scale on data and process representation, are not discussed in the current discussions on IWRM methods and information. However, the positivist, empiricist, and technocratic approaches to analysis and information development are often cited as the sources of the most contention, suggesting that the central controversy lies elsewhere. As a result of all of these approaches, we now have a rather scientific and technical set of approaches to the development of water resources, with the greatest gaps occurring in the description, analysis, and understanding of the influences of water development ideas on, and their effect on the many structures of society in general. In spite of this, the methods for developing information over the last two decades have largely ignored the work done in social theory over the past two decades (ADB, 1996; Afghan National Development Strategy (ANDS), 2007; Bearden, 2010; Biswas, 2004, 2005; Biswas et al., 2005).

12.15 Conclusion

Not all actions have to be done by the government, though people and businesses like Rite Water Solutions (RWS) can also step forward to help. Clean water in rural areas is difficult to come by due to high startup costs and power usage, but Rite Water Solutions has developed a number of programs to address these issues. Water security is a top priority for us at RWS; therefore, we work hard to see that appropriate water management practices are put into practice across rural India. Rite Water Solutions is a water disinfection company that only focuses on providing rural and urban areas of the country with effective and affordable water disinfection and purification solutions. The importance of water management in land consolidation plans has grown throughout time. Water management has become more flexible and participative as a result of climate change worries, and modifications have been explored in rural regions. There were recommendations made to enhance future IWRM in rural areas, including improvements to the management approach, integrated planning, the water pays for water principles, the coordinating model, and the interaction between stakeholders based on a seller-buyer approach to water pricing for rural areas. In order to move away from theoretical ideas toward practical implementation, it is necessary to use clear and precise language, despite the risk of oversimplifying complex issues, in order to avoid misunderstandings.

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Author contributions

In addition to contributing to the outline, the author is responsible for leading the draft and editing of the manuscript. It was P.D., S.R.D., and P.K. who conducted an extensive literature search and contributed to the writing of sections and the construction of figures and tables. In addition, they contributed to the construction of figures and tables. In addition to providing professional advice, P.K. helped revise the final version of the document and participated in its revision. In the end, all authors read and approved the final version of the manuscript.

Conflicts of interest

None.

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Section 3

Role of society, NGOs and Government in rural water management

Chapter 13

Sustainable management of eutrophication and problems associated with the algal toxin in ponds and lakes of rural areas

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13.1 Introduction

Surface water and groundwater are the two important sources of water for human use. Precipitation in the form of rain and snow is sometimes collected and stored to fulfill the above purpose. Water quality and its suitability for human use always depend on sources of water. In rural areas, people mostly depend upon surface water sources like reservoirs, lakes, rivers, and streams to fulfill their water demands. However, due to increased anthropogenic activities in recent years, the tremendous decline in quality, as well as quantity of surface water, has been experienced in both rural and urban sets up across the globe. Surface water as such cannot be used for drinking purposes without prior treatment because of the presence of various toxic water pollutants in variable quantities originating from different sources. A recent survey conducted in India shows that more than 42.9% of households in rural areas use hand pumps as their principal source of drinking water. The groundwater extracted through the bore well hand pump could produce water contaminated with fluoride or trace metals originating from the leaching of the parental rock bed. It may also be adulterated by agrarian flow or the disposal of surface, subsurface fluid waste, and solidified waste dumping leachate. Sources of freshwater such as rain and spring water are of diverse quality and may require processing to rest their portability. The percentage of individuals with access to a drinking water facility increased from 81% to 89% between 2000 and 2015 as a result of achieving the target set in the millennium development goal (MDG) (UN-Water, 2018). But a flaw in the MDGs monitoring was a lack of focus on water safety, which was a crucial component of the source work for water and hygiene services once the sustainable development goals were created (Sustainable Development Goal 6 [SDG 6]). United Nations Resolution 64/292 states that "the human right to water allows everybody to adequate, harmless, suitable, materially available, and inexpensive water for individual and domestic usages" (UN, 2010). SDG 6.1 calls for the provision of sustainable access to safe drinking water for all by the year 2030. The three following requirements are part of the "safely managed drinking water" indicator: readily available on-site, accessible when needed, and uncontaminated. This objective presents a significant challenge to all nations, not just those with low and middle incomes. Rural areas must be prioritized because of the commitment to "leave no one behind," which is typically disregarded (Kabeer, 2016). Over the globe, 844 million people still lack basic potable water, and 79% of them live in rural areas (WHO, 2017). On the other hand, 2.1 billion individuals lack access to a system of drinking water that is safely managed.

Pond habitats are extremely important to human civilization because they provide water for household, agrarian, and industrial use, as well as food. Even though vital to living beings, the nature, and role of all these freshwater systems have been presently endangered by a slew of anthropogenically caused disruptions. Humanoid development actions can degrade the water quality of ponds through the gathering of noxious contaminants (for instance, pesticides from farming runoff) and sedimentation, providing pond use unproductive and dangerous. Extreme loading of nutrients, a degenerated buffer zone, contaminated influxes, and atmospheric progressions all have an impact on ponds. Pond evaporation is caused by human activity activities such as sewage removal and fertilizer runoff from agronomic

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lands. Rural ponds can be crucial sources of water used for household activities, and fishing. On the other hand, a pond-centered cholera outbreak in rural West Bengal was defined in detail by Mukherjee et al. in their survey (Mukherjee et al., 2011). Ponds used for a variety of purposes may become contaminated by the environment, which can spread cholera. *Vibrio cholerae* manages to survive longer in environments with high levels of organic nutrient content, such as sewage (Bhuiyan et al., 2007). Ponds used for waste disposal may later develop into a natural fertile ground for mosquitoes, spreading diseases carried by vectors throughout the neighborhood. Pond conservation is crucial for the community's sustainable development because ponds that are contaminated with pathogens can no longer be used for domestic purposes. Water directly withdrawn from rivers, reservoirs, and lakes cannot be considered a cleaner source fit for human consumption until treated properly. Even water extracted from underground aquifers requires some level of treatment. Mixing of nutrients such as phosphorus and nitrogen with the freshwater aquatic bodies causes deterioration of water quality by the production of algal bloom. The sudden uncontrolled growth of algal mass in nutrient-rich lentic aquatic bodies is generally known as the eutrophication process which sometimes inhabits a larger fraction of algal species capable of producing algal toxins. Algal toxins such as mycrocystins, Anatoxin, and Saxitoxin are known to cause numerous health hazards because of their toxic nature. It is therefore significant for us to understand sustainable management practices to control eutrophication and algal growth over non-sustainable management methods when drawbacks like persistency, carcinogenicity, and environmental degradation are considered.

13.2 Significance of lake and pond in rural water management

The aquatic ecosystem such as ponds and lakes plays a crucial role in the life and livelihood of the rural populace. Apart from being the source of water for bathing, washing clothes, and other household uses, ponds also satisfy numerous other purposes such as use for irrigation, fisheries, nontimber forest products, water supply, and recreation. Ponds and lakes provide ecological services to rural communities by sequestration of carbon, control of floods, groundwater recharge, and biodiversity conservation (Turner et al., 2000). Ponds are the major site for fish aquaculture in most of the village setup. Additionally, they are also a source of water for household needs and nutrient-rich soils, collection of grass for feedstuff, and manufacture bricks. These usages have greater worth in terms of household income, nourishment, and wellbeing for the underprivileged (Kumar et al., 2013). They are equally important from the ecological outlook as they help in the conservation of soil, water, and bio-diversity (Balasubramanian & Selvaraj, 2003). Lakes can provide us with major prospects for recreation, cottage or residential living, and tourism. They are also valued by many people for their historical and traditional values and may be used as the source of raw drinking water for a municipality. Lakes can also be used as a water source for industry and an irrigation source for cultivation.

13.3 Degradation of water quality for lentic aquatic bodies of rural areas

Rural ponds are the primary source of water for almost all household purposes; thus, this ecosystem broadens as a basic provisioning service. However, non-segregated numerous, unstructured, impulsive use causes water pollution, affecting the wellbeing of users, particularly the poor, who have no other source of water. In recent years, freshwater aquatic bodies have experienced the greatest decrease in quality as well as quantity in every zone, with lentic ecosystems being primarily influenced by anthropogenic activities in rural settings. Agriculture, household garbage, and poultry waste production are the primary drivers of environmental change, resulting in serious habitat destruction in ponds and lakes across the globe. The growing effects of climate alteration and invasive species have put additional strain on these systems. Pollution from quickly decomposable organic compounds from point sources is the initial form of large-scale water contamination identified by civilization. To protect, conserve, and maintain the natural environment prevailing in and surrounding the pond area and its diversity proper filtration method, regular assessment of hydrological, physicochemical, and hydro-biological features, application of disciplinary, rigid rules and regulations for the locales residing near the ponds, strict prohibition of washing, bathing, gazing, and so on should be taken as an urgent initiative by the governing board. Microbial breakdown of organic material deteriorates oxygen in the water, negatively impacting the biota. Heterotroph lifeforms are affected by an absence of oxygen, while prime growers are primarily influenced by lower water clarity and mineralization of nutrients from organic matter (Friberg et al., 2010). Due to human population growth and a total absence of treating wastewater, contamination of aquatic bodies prevalent impact on rivers in the early days of biological assessment which is why all evaluation schemes focused on organic contamination. Eutrophication created by dispersed sources is a common disturbance of aquatic habitats, and nutritional mobility in channels has been expansively studied (Fig. 13.1).

The growth of algae in eutrophic freshwaters is common in rural, agrarian, and town areas. In a broad sense, eutrophic waters are thought to be crucial water resources that must be properly recycled to meet future drinking water demands (WWAP, 2017). The majority of the ponds and lakes in rural areas which are used for livestock watering demonstrated little degradation in water quality indicating that extended

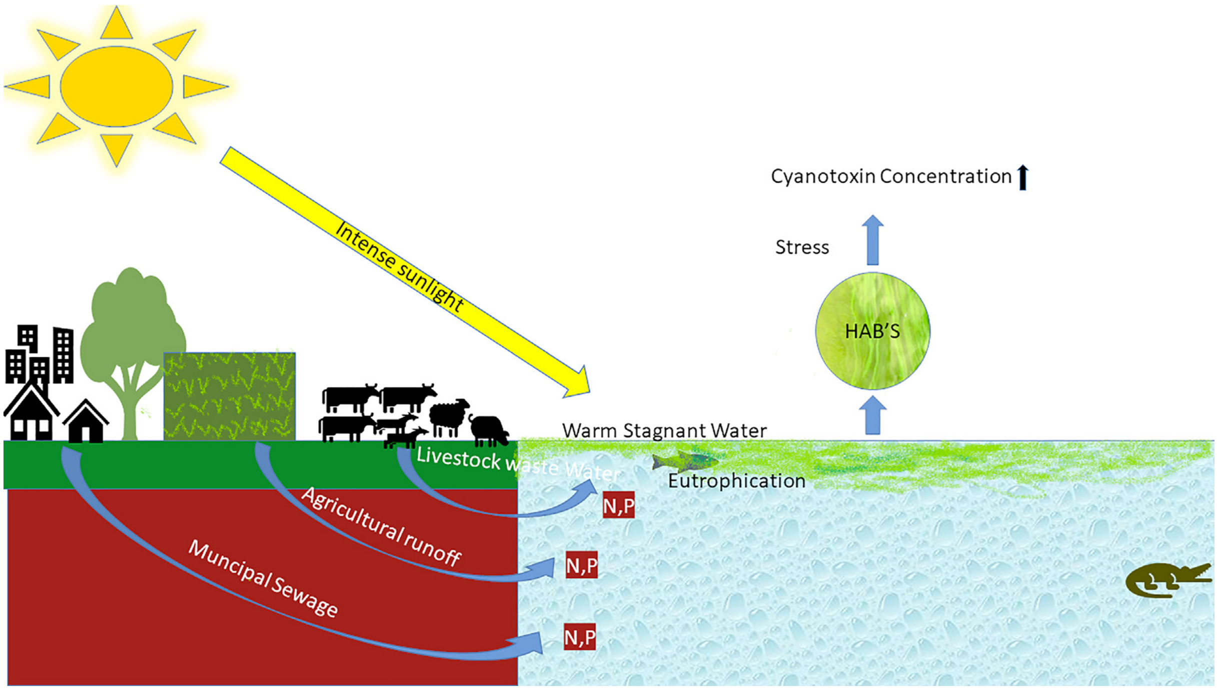

FIGURE 13.1 Eutrophication and factor affecting cyanotoxins level in lentic aquatic bodies in rural setup.

use of aquatic bodies keeps the water quality high. Similarly water quality in aquatic bodies where aquaculture practices are followed showed good water quality which could be due to better water management practices. Unused aquatic bodies near agricultural fields or near the villages where drain water mix directly with water bodies reportedly showed poor quality of water and rapid eutrophication.

Several reports focused on the organic pollution of aquatic bodies in rural India have been conducted in the last decade. Pond pollution and eutrophication were primarily caused by wastewater discharge into them. In their study of the Tapti ponds in Madhya Pradesh, Gajanand et al. (2013) discovered a significant organic load (BOD: 4.8–9.2 mg/L). They observed that both idol immersions and the addition of non-biodegradable and biodegradable materials can hurt the water quality of ponds, including the development of eutrophication. Because it received a lot of untreated wastewater from neighboring densely populated habitation (Gajanand et al., 2013). Mahajan and Billore also investigated a crucial source of potable water in the Khandwa district, a pond water body. Freshwater quality was steadily declining, and tests for chloride, phosphate, and nitrate revealed that eutrophication was on the rise in the water body (Mahajan & Billore, 2014). Hydrochemical analysis conducted by Manoj et al. on ponds in the Santiniketan-Bolpur-Sriniketan zone revealed that organic pollutants and phosphate were the utmost significant pollutants, both of which were detrimental to the ecosystems of the ponds (Manoj et al., 2013). In the holy city of Varanasi in Uttar Pradesh, ponds had alarmingly elevated amounts of nitrate (as high as 52 mg/L) and phosphate (as high as 7 mg/L), according to Mishra et al. (2014). From an urban pond near Vadodara, Soni and Bhatt recorded the highest BOD up to 50 mg/L and total phosphate as 1.49 mg/L. The main cause of the decline in water quality was the disposal of untreated sewage. Eutrophication brought on by effluent and surface runoff was also discovered in a study of urban ponds in Vadodara (Soni & Bhatt, 2008). According to Dhanya et al. the Pallipuram area's ponds have experienced nutrient enrichment and algal blooms because of phosphates from fertilizer runoff, detergents, residential area effluents, and the area's poor sanitation system. Several ponds that were surveyed reported blue-green algal blooms. A primary cause for concern was the discovery of possibly toxic species of Microcystis and Oscillatoria in the ponds that produce hepatotoxins (Dhanya et al., 2012).

13.4 Eutrophication and factors responsible for the growth of HABs

There exist specific environmental conditions in aquatic bodies that can intensify algal growth with the potential to harm human health. The sudden and rapid growth of algal mass consisting of harmful algal species is denoted as harmful algal blooms (HABs). Particularly in freshwater ecosystems, cyanobacteria earlier known as blue-green algae are microorganisms that can manufacture HABs. A few HABs in suitable conditions or during stress produce toxins as a secondary metabolite or as a mode to defend themselves. Which have the potential to harm humans, aquatic organism, recreational activities like swimming, commercial economic activities like fishing and drinking water qualities as a hole. They might cause odor complications depletion of dissolved oxygen and other alternation in water quality parameters. Concerns about water quality, public health, and safety are becoming more widespread due to an increase in the production of cyanotoxins such as microcystin, cylindrospermiopsin, anatoxin, and saxitoxin from cyanobacteria (Graham et al., 2020). The two most significant physical variables are temperature and light intensity, and in many situations, an ideal level for each of these variables has been noted. The key chemical components that frequently result in toxic algal blooms and the development of microcystins are nitrogen and phosphorus. Different forms and concentrations of nitrogen and phosphorus influence how well algae absorb nutrients and carry out metabolic processes, and leads to the production of microcystins. Temperature, light and nutrient input, periodic drought, and heavy rains all have an impact on tropical cyanobacterial blooms (Baldia et al., 2003). Tropical blooming can come at any stage of the year and are typically visible for a few weeks, unlike temperate bloom events, which take place during the warmer months and last the entire summer.

One of the more crucial elements in the growth of tropical blooming of *Microcystis* is an increase in total nitrogen concentrations. High temperatures and other elements also have a role in the development of *Microcystis* blooms, but their influence is not as great as that of total nitrogen content. According to certain studies, elevated temperatures encourage the blooming of Cylindrospermopsis (Figueredo & Giani, 2009), however high total nitrogen concentrations cannot be as crucial given that Cylindrospermopsis are nitrogen-fixing plants. *Cylindrospermopsis* blooms are more common in reservoirs than in natural lakes, but Microcystis blooms are more common in natural lakes. This might be caused by how reservoirs and tropical lakes are built differently. Natural lakes typically have low extreme variations in water level with limited control over discharge depth, in contrast to most reservoirs, which may undergo extreme changes in water level based on water demand. More *Cylindrospermopsis* blooms could result from increased mixing and turbulence of the mixed layer in reservoirs, especially during droughts (Bouvy et al., 2000). High nutrients may cause *Microcystis* blooms to develop more frequently in natural lakes with steady water conditions and little variation in discharge depths (Baldia et al., 2003). In shallower tropical lakes, cyanobacteria outnumber other kinds of algae; they are greatly competitive in high turbid conditions.

13.4.1 Light

Studies show that cells require active photosynthesis to create more toxins, and therefore light intensity is a key factor regulating photosynthetic activity. The effect of increased light accessibility on *Microcystis aeruginosa* (MCs) levels may be connected to the processes governing gene expression and control (Sevilla et al., 2012). It was observed that under limited conditions, the MCs content per unit cell was associated pronouncedly with light intensity, but below sufficient light conditions, it was negatively correlated (Wiedner et al., 2003). According to a recent study, the rate of electron transport and redox potential of photosystem II (PSII) were the two mechanisms used by photosynthetic light reactions to modify MCs yield at the cellular level. When *M. aeruginosa* was subjected to high photon irradiance, it was hypothesized that PSII reaction centers maintained a more reduced state. Under low light levels, a rise in photosynthetic light-dependent reactions predominantly encourages the synthesis of MCs, but under relatively high light levels, algae are stimulated to produce MCs for resistance to photo-oxidation in response to the high-intensity light radiation.

13.4.2 Temperature

Another significant element that influences algal growth is temperature. MCs yield increases directly with temperature in the measure of 15–20°C and peaks at 20°C, but that yield reduces dramatically after the temperature reached 28°C (Westhuizen & Eloff, 1985). *M. aeruginosa* produces MCs potentially best at a temperature of 25°C (Sivonen, 1990). However, even though temperature favors algal growth, some reports demonstrate temperature does not affect the generation of MCs. There can be two theories for how increased temperature encourages the formation of MCs. First, a temperature rise can encourage the growth of cyanobacteria, with Microcystis as the dominant species, which will then cause a bloom of MCs. Second, hazardous Microcystis may produce more microcystin as the temperature rises further. Therefore, even if the process by which temperature influences MCs production cannot entirely be determined by the available studies, it is likely that temperature does affect MCs production. The differences in culture methods, growth environments and experimental designs, and analyses may be the cause of conflicting data about whether temperature increases the production of MCs.

13.4.3 Nutrients

For the metabolism of algal cells and the formation of MCs, nitrogen (N), and phosphorus (P) are crucial components. In algal cells, nitrogen takes a role in the synthesis of protein and deoxyribonucleic acid. The manufacture and transformation of adenosine triphosphate (ATP) in cells, as well as the enzymatic activities involved in cellular metabolism procedures, depend on phosphorus. N is not only a requirement for the development and reproduction of an algal cell,

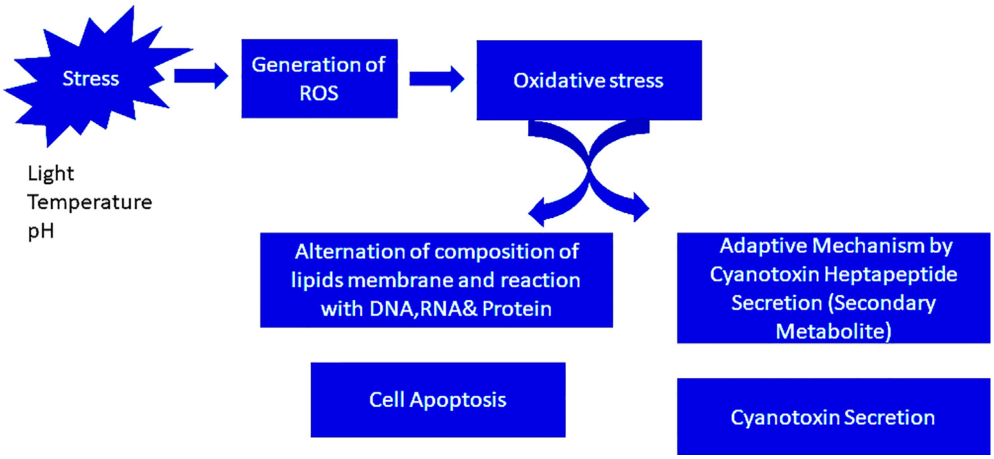

FIGURE 13.2 Schematic diagram showing mechanisms involved in production and release of cyanotoxin by algal species to aquatic bodies.

but it is also an important part of the fragments that make up MCs. Nitrogen is thus frequently regarded as the factor that determines the synthesis of MCs. Algal growth and the generation of MCs are compromised by a very low or high N concentration. Organic and inorganic N make up the majority of the nitrogen in the water. The most prevalent inorganic forms in water are ammonium and nitrate, and *M. aeruginosa* can digest them in a variety of ways. They are therefore expected to be crucial to the generation of MCs. The majority of laboratory studies revealed that inorganic N at high concentrations could increase the formation of MCs (Pimentel & Giani, 2014). However, several further works have advised that organic N, notably amino acids and urea, may also encourage *M. aeruginosa* to produce MCs and trigger algal blooms.

13.5 Mechanism for cyanobacterial toxin release into aquatic bodies

In fresh and marine waters ecosystems, cyanobacterial harmful algal blooms (CyanoHABs) are increasingly common, among them hepatotoxic nodularin and microcystin are the two cyanobacterial toxins that are most frequently found. The genetic products of the toxin genes cluster mcy and nda, respectively, synthesize these cyclic peptide pentapeptides and heptapeptides non-ribosomally. This is maintained by a current study signifying that toxin manufacturers are healthier enough to resist stress situations and increase toxin production under stress conditions (Kurmayer, 2011). The most frequent growth limiting factor for cyanobacteria is the availability of nitrogen. In the non-nitrogen-fixing unicellular cyanobacterial species *M. aeruginosa*, studies have shown conflicting results regarding the impact of nitrate levels on microcystin production. Some studies show a rise in toxin production with growing nitrate availability, while the rest show an intensification under nitrogen-limiting situations (Long et al., 2001). The close relationship between the protein concentration of microcystin in *M. aeruginosa* revealed that the N:P ratio of the growth media and associated nitrogen acquisition are key factors in the synthesis of microcystin (Fig. 13.2).

13.6 Community health issues on cyanotoxin exposure

Among several toxins formed by cyanobacteria, MCYSTs are one of the major familiar forms. The progress of hepatic cancer in China was associated with chronic exposure to these toxins. Amongst cyanotoxins, the widely studied class is that of liver toxins, which consist of about 100 diverse congenerics of circular peptides. The chronic outcome, known as MC-LR, comprises tumor-developing action, as a result of which IARC has designated MC-LR as a probable human cancer-causing agent (class 2B) (IARC WHO, 2010). When Microcystin is consumed through drinking water, the bulk of the MC from the GI region is resorbed into the portal bloodstream and transported to the liver (Falconer & Yeung, 1992). The organic anion-transferring polypeptide superfamily (OATPs) facilitates MC absorption into hepatocytes well as crossing the blood–brain barrier (Lu et al., 2008). Dependent on the dose and length of contact, this causes morphologic and functional variations in the hepatocytes, inducing autophagia, programmed cell death, necrosis, or cell growth. Low dosages of MC are linked to cell proliferation, but sublethal amounts can cause apoptosis by releasing reactive oxygen species (ROS), and extremely high concentrations can cause cell death or necrosis. Typical signs and symptoms of MC poisoning consist of failure of hunger, nausea, stomach cramps, diarrhea, vomiting, headache, illness, weakness, joint and muscle pain, general whiteness of the mucous membranes and skin, lacrimation, dermatitis, cold extremities, nasal discharge, and raised levels of liver enzymes (Bell & Codd, 1994). In freshwater

TABLE 13.1 List of cyanotoxins and their toxicity to human health.

Chemical composition	Cyanobacteria genera	Cyanotoxin produced	Primary target organ in mammals
Cyclic peptide	*Microcystis, Anabaena, Planktothrix (Oscillatoria), Nostoc, Hapalosiphon, Anabaenopsis*	Microcystin	Liver (Codd, 2000)
	Nodularia	Nodularin	Liver (Guzmán-Guillén et al., 2014)
Alkaloids	*Anabaena, Planktothrix (Oscillatoria), Aphanizomenon*	Anatoxin-a	Nerve synapse (Corbel et al., 2014)
	Anabaena	Guanitoxin	Nerve synapse
	Cylindrospermopsis, Aphanizomenon, Umezakia	Cylindrospermopsins	Liver (Neumann et al., 2007)
	Lyngbya	Lyngbyatoxin-a	Skin, gastrointestinal tract
	Anabaena, Aphanizomenon, Lyngbya, Cylindrospermopsis	Saxitoxin	Nerve synapse (Su et al., 2004)
	All	Lipopolysaccharides	Potential irritant; affects any exposed tissue
Polyketides	*Lyngbya, Schizothrix, Planktothrix (Oscillatoria)*	Aplysiatoxins	Skin
Amino acid	All	β-N-methylamino-L-alanine (BMAA)	Nervous system

recreational surroundings, exposure to cyanotoxin in various concentrations induces indications like fever, severe headache, pneumonia, vertigo, myalgia, and blistering in the mouth (Funaria et al., 2008). A few allergic feedbacks to cyanobacteria have also been reported, probably because of the activity of cyanobacterial LPS endotoxins (Stewart et al., 2006). Cases of skin inflammation and flu-like indication have been proclaimed on subsequent recreational activity in waters comprising cyanobacteria.

13.7 Cyanotoxins showing neurotoxicity

Neurotoxins (e.g., anatoxins, anatoxin-a(s), and saxitoxins), are formed by the breed of the genus *Oscillatoria, Phormidium, Aphanizomenon*, and *Anabaena*. Anatoxin acts upon the neuromuscular junction by obstructing bones and respirational muscles and triggering respiratory collapse. Anatoxins (ATX) are powerful pre- and post-synaptic depolarizing mediators, competently combating with acetylcholine for nicotinic receptors in neuromuscular junctions and the central nervous system (Campos et al., 2006). Anatoxin(s) irreversibly inhibit acetylcholinesterase (AChE) in the neuro-muscular junctions in the peripheral nervous system alone. Saxitoxins (STXs) are a group of over 30 natural alkaloids, manufactured through both freshwater cyanobacteria and marine dinoflagellates (Stucken et al., 2011): they obstruct Na-channels in nerve cells and Ca^{++} and K^{+} channels in the heart cells, hence avoiding the multiplication of electrical communication inside the peripheral neural and skeletal or cardiac muscles (Wang et al., 2003) (Table 13.1).

13.7.1 Nephrotoxicity

There are few epidemiological studies on MC nephrotoxicity. In Brazil, there have been cases of acute renal injury, after hemodialysis with water-containing MCs renal insufficiency (Hilborn et al., 2007). Liyanage et al. surveyed the higher incidence of chronic kidney disease of unknown origin (CKDu) in the Girandurukotte area of Sri Lanka and reported that the existence of MCs in the area's well water would have been the cause behind it (Liyanage et al., 2016). In addition, Chen et al. found alternation in blood uric acid (UA), creatinine (SCr), and blood urea ammonia (BUN), implying that MCs are involved in the renal disease of fishermen (Chen et al., 2009). which was confirmed by an association between the serum of fishermen with MCs and abnormal kidney function.

It is well acknowledged that the urinary system is enormously reactive to oxidative stress and lipid peroxidation (LPO), anyhow, their substantial rise may give rise to renal toxicity. Kidneys are abundant in unsaturated lipids; thus, they are sensitive to peroxidation impairment. On the one hand, protein carbonylation is extensively used to estimate the level of oxidative deterioration of proteins in several biological organisms. In vitro studies also displaced that the level of oxidative stress by MCs might encourage renal toxicity. Gaudin et al. on the other hand, discovered that MC-LR causes DNA damage irrespective of the path of delivery in the kidney (Gaudin et al., 2008). If these growing lesions appear in the kidney, the normal proliferation of renal cells would be hampered, thereby raising the risk of renal carcinogenesis. The expression of c-jun, c-fos, and c-myc in the kidney was found to be one plausible machinery for the tumor encouraging and starting activities of MCs. Hao et al. (2010) also discovered a link between tumor-associated stathmin and MC levels in the kidney (Hao et al., 2010). Thus, changes in tumor-allied genes or DNA may deliver a clue to MCs in the kidney's tumor-promoting capability.

13.7.2 Hepatotoxicity

The MCs are dominant hepatotoxins formed by the cyanobacteria genera Planktothrix, Microcystis, Aphanizomenon, Nostoc, and Anabaena and the most prevalent variants noticed in the environment are microcystin-LR, -RR, or -YR (Ettoumi et al., 2011). These cyclic heptapeptides have high empathy for serine/threonine protein phosphatases (PPs), making them a restraint of this enzyme family. A series of circumstances accountable for the microcystis (MC) cytotoxic and genotoxic effects in animal cells may occur as a result of this interaction. Furthermore, MCs cause oxidative stress in animal cells, which, along with the hindrance of PPs, is thought to be one of the main machinery of MC toxicity. Microcystin-LR (MC-LR) is the utmost toxic and frequently comes across members of the family MC (Bogo et al., 2011).

13.7.3 Cancer

Based on a tolerated daily intake (TDI), the World Health Organization acclaimed a temporary specification standard for MC-LR in drinking water as 1 mg/L in 1998, which is equivalent to 0.04 mg/kg body weight. The International Agency for Research on Cancer (IARC) recently categorized MC-LR as a probable human carcinogen (Group 2B); however, there is insufficient knowledge to classify other MCs. It has been identified that MCs primarily promote tumor growth by inhibiting protein phosphatases 1 and 2A, which have been linked to both cytotoxicity and tumor-encouraging activity (Humpage et al., 2000). In the last decade, proof has been collected that signifies MCs cause DNA damage, implying their genotoxic nature and therefore acting as tumor promoters. These toxins along with microcystin in particular are responsible for inhibiting activities of serine-threonine phosphatase, enhanced oxidative stress, and their genotoxic properties, involved in the pathogenesis of host cell injury and gastrointestinal and liver tumor, carcinogenesis (Svircev et al., 2017).

Previous investigation examining whether gastrointestinal tumors are more prevalent in human populations exposed to cyanobacterial toxicant contaminated with drinking water (Levesque et al., 2014). Zhou et al. found that consuming water from ponds, wells, ditches or tap water with higher (>50 ng/L) microcystin-LR (MC-LR) levels were associated with a 7.9-fold increased risk of developing gastrointestinal cancer over time as compared to consuming MC-LR free water (Zhou et al., 2002). These conclusions were validated by in vitro investigations in which it was shown that human colorectal epithelial cells underwent a malignant transformation after being exposed to MC-LR (0.0001–1.0 g/mL) for 28 days. Additionally, the growth-promoting proteins Akt, LNK, P38, and mitogen-activated protein are constitutively expressed in MC-LR transformed cells. It has been reported that MC-LR facilitates tumor progression by inducing rapid cell division and growth, epithelial-mesenchymal transformation (EMT), relocation, and infiltration of liver cancer and colorectal cells. MCs in water have a great potential risk to higher trophic level species, including humans by getting direct exposure and distribution into diverse environmental sections such as residue, aquatic and terrestrial plants in the aquatic ecosystem, and animals. Epidemiological studies have concluded that cyanotoxins are risky for the high prevalence of primary liver and colon cancer in some areas of China, where cyanobacterial-contaminated water from the ditch and ponds is taken.

13.8 Non-sustainable management of eutrophication and their drawbacks

13.8.1 Synthetic algaecides

Eutrophication of aquatic bodies can be controlled by using algaecides such as $CuSO_4$ and herbicides. For more than 110 years, copper sulfate ($CuSO_4$, $5H_2O$) has been the substance most frequently used to regulate the tremendous algal growth in lakes and reservoirs (Kenneth & Harold, 1952). Single copper sulfate additions do not affect a long-term reduction of algal blooms and need a frequent periodic application to control populations. In the end, copper is a trace element that is crucial to the biochemical processes that transpire in photosynthetic organisms. However, it can alter or inhibit basic enzymatic activities as well as electron transport through the photosystem. In particular, high levels of copper sulfate can encourage the emission of toxic microcystin compounds, which have a potent algaecide effect on cyanobacterial physiological stress and cellular membrane damage.

However, Algicidal chemicals could also end up causing secondary pollution of water bodies, though chemical methods can quickly and efficiently remove algal blooms. As most algicidal chemicals' inhibition not only target dangerous cyanobacteria, other beneficial organisms or non-harmful algae may also be killed off or adversely impacted by chemical administration and exposure. Aquatic ecosystems frequently collapse when concentrated chemical algicides are introduced into water bodies. In addition, copper sorbs to suspended solids or precipitates from the water column, accumulating in bottom sediments. Numerous research on aquatic algae and cyanobacteria species have also focused on copper toxicity. Copper bioavailability is interrelated to speciation, which is most likely related to pH, redox potential, alkalinity, and concentrations of organic and inorganic ligands.

13.8.2 Inorganic coagulants

Since the beginning of the 20th century, aluminum sulfate and ferric chloride have been regularly used in the coagulation procedure of algal blooms from polluted freshwater. These salts have significantly contributed to the elimination of a variety of impurities, such as suspended algal cells, colloidal particles, and dissolved organic substances (Dawah et al., 2015). By charging negatively charged colloids with dissolved cations to neutralize their charges and integrating the particulates into an amorphous metal hydroxide precipitate, these salts' primary mechanisms for eliminating algae are carried out. The selective chemisorption of cationic species from solutions is straightforward machinery for the destabilization of negatively charged particles. The hydrolysis products' cationic Al and Fe ions balance or lower the negative charge on the suspended solids comprising anionic cells in the flocculation/coagulation process. However, there have been worries expressed that the usage of such coagulants could raise the levels of aluminum in treated water. Although water treatment facilities typically set a stringent standard for finished water (e.g., 0.05 mg/L), the drinking water guideline for Al in Japan is 0.1 mg/L. Al is acutely hazardous to individuals when consumed orally, and long-term exposure to it intensifies the risk of developing Alzheimer's disease (FAO/WHO, 1989). Since ingesting Al through drinking and eating is the most frequent way that people are exposed to it, the gastrointestinal tract serves as the primary route for Al absorption (Kimura et al., 2013). Maintaining Fe and Al residuals of less than 100 g/L was specifically recommended, which was officially recognized in the water quality regulations of 1989, which directed less than 200 g/L Fe or Al in tap water. In the case of water supply, coexisting chloride anions with these metal cations produce corrosion products in ferrous and non-ferrous metal components such as storage tanks, pumps, piping, valves, and concrete. Corrosion products degrade water quality, provide habitat for microbial growth, and interact with disinfectant residuals (Slavková et al., 2013).

13.8.3 Sediment dredging

Removal of sediment and debris from bottom of the pond, lake or river or any other aquatic bodies called sediment dredging is a general measure to deal with the issue of sedimentation in any waterway. The intensity, frequency and rate of dredging mainly depend upon the turbidity and sedimentation rate. Physical elimination of substratum and related biota from the sediment bed and burial due to succeeding deposition may pose risk for ecosystem functionality of the water bodies. Dredging events often interrupt sediments by decreasing visibility and smothering benthic organisms.

13.9 Sustainable management practices and their advantage over non-sustainable methods

Normally algaecides must be used only when cell density is lower to prevent massive discharge of cyanotoxins or traces succeeding cyanobacterial cell breakage (Chorus & Bartram, 1999). For decades, copper sulfate ($CuSO_4$) has been applied to regulate cyanobacterial blooming. It is equally efficient and simple to implement. Though cyanobacteria are especially vulnerable, $CuSO_4$ is a vast-spectrum biocide. It will affect other lifeforms, such as fish and zooplankton, and be liable to a concentration level that accompanies rising floodplain levels, macrophytes quickly became potent, and phytoplankton biomass remains low.

13.9.1 Food web intervention

Direct food web intervention could have a remarkable effect on aquatic biota. If the nutrient status allows it, such initiatives must be competent to shift a lake ecosystem from an unstable to a steady clear state. Food web measures, if successful, can cause a rapid transition to a clear state with high efficiency. Measures include direct involvement of macrophytes, freshwater mussels, and fish such as seeding, stocking, or removing species. Active macrophyte culture through stocking or seeding can provide immediate outcomes in lake reclamation, decreasing phosphorus release from sediments.

13.9.2 Biomass removal using physical method

One of the effective characteristics of several species of the genus cyanobacteria within the physical removal process is their capability to control their buoyancy, lowering their deposition loss rate. Under suitable weather conditions, when the turbulence is low cyanobacteria form a highly dense scum. Wind-impulsive accumulation of scum on nearby shores could even cause a health risk due to the elevated cyanobacterial as well as hence cyanotoxin concentrations. Scum can be eliminated by skimming the surface (vacuum cleaning). Large lakes may cause a long-term transfer of biomass to the shorelines. As a result, smaller bodies of water (e.g., urban ponds) or compartmentalized are efficient and effective for this technique. Moreover, the concentration of the scum layer influences its efficacy. The potentially highly toxic one gets to reduce their choices to be wiped out of their biomass. It might be treated in a community wastewater treatment plant or predisposed to a fermenter. Following the application of a flocculating agent, entrapped particles, containing cyanobacteria, sink to the bottommost sediment. The treatment works better in deeper lakes since wind-induced mixing can cause cyanobacterial cells to resuspend in shallow lakes. Clays are effective in the flocculating *M. aeruginosa* for numerous clay types, including bentonite and kaolinite.

13.9.3 Flushing and mixing

Cyanobacterial bloom in lakes, ponds, or reservoirs can be prohibited if the residence time of the aquatic body can be deduced in association with the development rate of the cyanobacterial cells. Some of the rapidly growing cyanobacterial species are Microcystis, Anabaena, *Cylindrospermopsis raciborskii, Planktothrix agardhii*, and *Aphanizomenon flosaquae*. The growth rates ranged from 0.1 to 1.0 per day (Lürling & Tolman, 2014). This produced a doubling time fluctuating from 0.7 day to 7 days and suggests that to regulate harmful algal blooms by flushing, residence times must be decreased from weeks to days.

Dilution-based horizontal mixing, generally prevents scum development. Vertical blending will spread the buoyant cyanobacterial cells across the total lake depth. This will reduce cyanobacterial predominance and dilute the remainder of the cyanobacterial population by limiting sunlight penetration for cyanobacteria and decreasing sedimentation losses of other phytoplankton. Vertical amalgamating is only successful in a deeper lake than an average of 16 m or an extreme of 30 m for Microcystis, or fewer for other species. This means that it is not appropriate for small lakes.

13.9.4 Artificial circulation

Artificially stimulated combining of anoxic water bodies can help control eutrophication. Typical rotation methods fall into two classes: destratification, where water or air is pressured into the bottommost of the water depth, boosting blending and destructing the temperature grades, and hypolimnetic aeration, in which water is eliminated, aerated, and returns to its normal depth; the later intends to truly hinder coupling and reserve the water body's natural biochemical cycling (Henderson-Sellers & Markland, 1987). Although destratification is an effective method of preventing cyanobacteria blooms, experiments also showed that it may encourage diatom progress while slightly decreasing the total algae populaces. Hypolimnetic aeration techniques are well-approved and potent at reducing oxygen-deprived situations, but they are ineffective in preventing intrinsic phosphorus loading from P deposited in lake sediments (Gachter & Wehrli, 1998). Because many of these configurations rely on aerial techniques, the related total costs and energy utilization rates are quite greater, limiting the potential application of artificial rotation to minor overland water forms such as ponds, lakes, and dams.

13.9.5 Artificial destratification

Artificial destratification entails boosting the flow of water that cycles between the reservoir's lower and deeper strata. This can be accomplished by creating a plume of bubbles near the reservoir's bottommost or by putting a propeller or impeller in or around the reservoir wall. A circulation sequence is established to lessen temperature, oxygen, and nutritional disparities in the middle of the topmost and base of waters. Manual destratification can inhibit algal development by lowering the sediment phosphorus loading access to the water strata, depriving algae of nutrients by either intermixing algae deeper into the water level and starving them from light or dropping the nutrient concentration in water storage.

Once nutrients arrive at a reservoir, they are very tough to remove. Hence, the utmost effective approach is to avoid entering nutrients from the reservoir in the first place. There are numerous procedures that can be used to decrease the intake of nutrients in water reservoirs:

- Artificial swamps, marshes, or reservoirs located upstream of the water storage operate as a nutrient descent, preventing nutrients from entering the storage. These systems frequently necessitate extensive maintenance and their efficiency in developing water quality have varied.
- Managing the entire watershed just above storage by lowering fertilizer use and fencing off rivers to restrict stock access will reduce soil erosion and the number of nutrients invading a waterway.

13.9.6 Water treatment

A variety of treatment procedures can be used to eliminate algae from the water. Filtration, coagulation with aluminum and salts of ferric iron or organic polymers, and the application of algicides are some examples. Short-term control measures for drinking water sources include moving offtakes away from areas where the accumulation of algal cells occurs, as well as using barriers to inhibit scum movement. Activated carbon filtration is the most dependable method of algal toxin removal. This method employs either powdered activated carbon absorbers, which can be applied occasionally as needed, or granular activated carbon absorbers, which are utilized continuously. As a result, while granular activated carbon is costlier than powdered activated carbon when used infrequently, it is also additional operative and dependable for the continuous elimination of soluble organic complexes.

13.9.7 Constructed wetland

As compared to the conventional treatment system, constructed wetlands are cost-effective, efficient, can be maintained, and operated environment friendly. This method has been used frequently for the elimination of nutrients from degraded lakes of developing countries and to work out on the addition of nonpoint nutrient sources into aquatic bodies. The main drawback of this method is of sluggish operational rate. They may be affected as a result of the limitation of space and waterlines in lakes and rivers. Whenever environmental conditions like pH, and temperature are altered, precipitates formed by chemical reactions are discharged. Thereby increasing the contaminated area and cost of processing.

13.9.8 Aquatic phytoremediation

It has been verified that in aquatic bodies diverse species of plants have different effects on the rate of elimination of pollutants. Plants are commonly selected based on their efficacy and cost, among them frequently selected are *Canna*, cattail, *Scutellaria*, water hyacinth, duckweed, *Vetiveria zizanioides, Acorus* calamus, and *Cyperus alternifolius.* Available literature indicates that, *Canna* shows better effects on DO levels, hydraulic efficiency, and percentage of nutrient elimination attributable to plant uptake as compared with other plants (Bu & Xu, 2013). Moreover, the elimination rates of TP, TN, and COD are enhanced in *Canna*, calamus, and mixed canna–calamus systems (Wang et al., 2011).

13.10 Microorganisms-based methods for HABs control

Methods for rapidly reducing the density of algal cells in water, among prevailing methods, flocculation can significantly reduce cell quantities in water in a short period, restricting future development of algal cells and fulfilling the goal of HABs regulation. Though chemical flocculants could effectively suppress HABs, their widespread usage has been steadily prohibited due to their neurotoxic and cancer-causing qualities (Dearfield et al., 1988). Bioflocculants have mostly been explored in the laboratory for HABs regulation due to their superior effectiveness, nontoxic, and biodegradability when equated to standard flocculants (Jiang, 2015).

Bacteria play critical functions in the blossoming and death of toxic algae. In the elimination of HABs, bacteria increase algal cell accumulation by (1) promoting the secretion of extracellular polymeric substances (EPS) by algae, hence quickening algal cell aggregation and (2) generating bioflocculants that directly cause algal cell gathering and subsiding. Bacterial populations in natural aquatic environments can have direct and substantial contributions to algal aggregation (Alam et al., 2016). By boosting *M. aeruginosa* EPS release, the aquatic heterotrophic bacteria Porphyrobacter and Flavobacteriaceae play important roles in the establishment of *M. aeruginosa* blooming in natural water habitats. The released EPS forms a microenvironment that connects cyanobacterial cells with bacterial cells in a mutually advantageous relationship. The major mechanisms underpinning bacteria-associated bioflocculation include bio-adsorption, ion bridging, and charge neutralization, which may be assisted by 10 proteins and flagella upon that cell wall (Powell & Hill, 2014). Palletization is an adequate method for assisting fungi in the elimination of algal cells. Algae can be removed from bodies of water by the precipitation of fungus-alga pellets, which are formed when algal and fungal cells interact during the fungi's palletization process. Starting with the inflammation and germination of spores, accompanied by the development and branching of hypha, the establishment of fungus-alga pellets, spherical, oval masses, or elliptical intertwined hyphae with sizes ranging from numerous hundred micrometers to a few millimeters, begins. The hypha then intermingles with the algal cells, resulting in the generation of the pellets.

One of the primary organisms involved in the severe extinction of HABs in water habitats is algicidal bacteria. They can destroy algal mass directly or indirectly. Interaction among algicidal bacteria with algae results in direct algicidal activity. Myxobacteria was the very first described algicidal bacterium, capable of killing single cellular and filamentous Cladophora when in close contact with the myxobacteria. A newly discovered chitinase-producing bacteria (strain LY03) has an algicidal effect on *Thalassiosira pseudonana,* which is also a straight interface effect. Strain LY03 demonstrated chemotaxis into algal cells by bacteria sticking to algal cells with their flagella and subsequently generating chitinase to break down algal cell walls, resulting in algal rupture and mortality (Li et al., 2016). Some fungi can also destroy algae directly. Han et al., (2011) recovered four fungal genera (*Tramete shirsuta* T24, *Irpexlacteus* T2b, *Bjerkandera adusta* T1, *Tramete shirsuta* T24, *T. versicolor* F21a) that destroyed algal cells directly.

13.10.1 Biomanipulation

Biomanipulation refers to ecosystem reformation that uses the trophic cascade concept as a method to improve water characteristics and reduce the phytoplankton populace. Biomanipulation strategies often include reconstructing the nutrient-enriched food web by replenishing the number of fish eaters to regulate zoo planktivorous fish and relieve strain on algal eating zooplankton abundance (Jeppesen et al., 2007). Filter-eating fish like as tilapia have also been introduced in the anticipation of directly controlling the algae populace. Strategies that have ratified outstanding in temperate climatic aquatic bodies do not continually have the alike degree of achievement when employed in tropical settings; in fact, some cases of additional water depletion due to exotic species and nutrient defecation degree of defined fish species have been documented. Biomanipulation is an appealing alternative for addressing the consequences of manmade eutrophication due to the low operational cost and use of underlying natural systems, but there are some possible downsides.

13.10.2 Nanosilicate platelets

Nanosilicate platelets (NSP) are a regulator approach derived from the scarp of natural clay materials that have been determined to have little mammalian toxicity and thus do not harm other creatures. According to one study, NSP can effectively suppress the growth of cyanobacteria while also absorbing the toxic microcystin (Chang et al., 2013). NSP also reduces turbidity by promoting cyanobacterial settling. This improves water transparency and encourages the development of macrophytes and other phytoplankton, potentially leading to a better lake or dam ecosystem. More NSP tests on a larger range would be advantageous in determining their feasibility as a lake supervising technique.

13.11 The integrated ecological floating bed

The integrated ecological floating bed (IEFB) is a little extra progressive structure that, like the artificial floating island (AFI), uses macrophytes as a controlling regime for a lake or dams while evading factors that can typically limit macrophyte development, like waves, turbidity, and water depth. Li et al. (2010) propose a novel IEFB design. The floating-bed system comprises hydroponic terrestrial and aquatic plants that grow on floating frames floating on top of a lake or dam. Floras absorb required nutrients from the water column, while the plants' submerged exterior and a biofilm sustenance system assist as a foundation for the adhesion of microbes that disrupt down organic materials and trap floating particles. The plants may also be cultivated for nutrition or biomaterial purposes. Furthermore, filter-feeding bivalves could be added into the arrangement to feed on phytoplankton in the water and be aggregated for nutrient and food elimination. However, the nutrients that bivalves can remove from the system by feeding plankton must be adjusted with the nutrients that they add to the system via excretion. Even with the presence of the bivalves, studies have demonstrated that the IEFB system reduces TN and TP when compared to a control.

13.12 Use of natural plant-based organic algaecides

Some physical procedures such as artificial mixing and sonication, chemical substitutes, such as hydrogen peroxide and some metals (copper sulfate, iron, and aluminum), and some organic methods, such as algicidal bacteria are been used to avoid the development or direct killing of cyanobacteria. However, the fixing, process, and cost of energy are comparatively high, and most of these constituents can be a reason for secondary pollution of aquatic ecosystems. Currently, an advantageous substitute for conventional methods is the use of organically acquired ingredients from floras, which is described to be an eco-friendly and promising method for regulating cyanobacterial blooms in water bodies. Several studies have been done on controlling cyanobacteria blooms using extracts from aquatic and terrestrial plants (Zhao et al., 2019). Due to its lower toxicity and reduced risk to the environment, this technique appears to offer a fresh and favorable alternative for controlling harmful algal blooms. Hence, in this work, we chose ten well-known plants as algae suppressor source plants. These plants include *Cinnamomum camphora, Ginkgo biloba, Firmiana platanifolia, Salix babylonica, Euphorbia Humifusa, Erigeron annuus, Solidago canadensis, Alternanthera philoxeroides, Thalia dealbata*, and *Eichhornia crassipes*. They are also rich in antibacterial compounds and phytotoxic compounds (Chen et al., 2018).

Allelochemicals may be responsible for the inhibition effect of plant abstracts on algae. The best algicidal activities were found in the extracts from *S. babylonica, E. humifusa, S. canadensis*, and *A. philoxeroides* when comparing the inhibitory actions of the ten plant extracts. This might be caused by various allelochemical compounds present, each of which has different water solubility. Polyphenols and flavones are probably the primary phytotoxic compounds among the four plant species that developed inhibition rates higher than 70.00%. According to several researchers, phenols are crucial for inhibiting algal growth.

13.13 Suggestions for decision-makers and water supply authorities

A complex interaction between human activity and the environment leads to harmful algal blooms. Previous HAB investigation has mainly been ecological in nature, with little community science examination that has protected to concentrate on how social practices and knowledge affect health outcomes after exposure to HAB toxins. Anthropogenic factors are the primary for the increase in HAB occurrence, and these factors go far off the regional human populace that lives in and around the actual sites of HABs. Future investigation on HABs should concentrate on community members, sociodemographic and health hazards, and awareness programs to lessen contact and approach regional applications that affect the occurrence and prevalence of HABs. The local stakeholders do not have significant impact or regulation over the fundamental sociocultural, and political aspects that promote HABs, it is thereby unlikely to neglect to broaden spatiotemporal dynamics affecting bloom formation. Long-term land use patterns, rising population densities, shifting ways in which natural resources are used, and increased production of a variety of hazardous waste into soils and waters are a few of these.

Scientific direction is required to avoid and check algal blooms, including the efficiency of various techniques for various kinds of algae at varying densities and treatment intervals. The inactivation of algae cells through the use of physical, chemical, biological, and ecological procedures should be the main goal of methods for controlling algal blooms whenever the algal density is less than 107 cells/mL While some of these techniques can stop the growth of algae in a short time interval, majority of them have the effectiveness of less than 95%. The key to control is quick inhibition and a slowdown of growth when algal concentration is less than 107 cells/mL.

1. Regular and periodic inspection of water quality should be performed.
2. Risks correlated with an expense that harmfully upset the natural purity of rivers, lakes, aquifers, and wetlands, their hydro morphologic situations, and the natural water retaining dimensions of the basins or ecosystem working should be detected and evaluated and appropriate action should be taken.
3. Actions to decrease pollutants of surface waters succeeding in eutrophication, concerning the transport of nutrient-loaded waters over boundaries or to the ocean should be taken.
4. Utmost cost-effective actions should be promoted for developing water quality while making contaminators and users responsible as much as probable over.
5. Machinery to monitor should be established and impose consent with regulatory plans. Enforcement should be targeted, using accessible data sources. It must be shaped on clear, translucent and balanced implementation, guidelines, measures, penalties, and mechanisms to accomplish governing objectives.
6. Actions should be taken to defend, re-establish and endorse sustainable use of aquatic ecosystems, halt and reverse deterioration, and stop loss of biodiversity.
   a. Harmony between water policies and other sectors should be ensured such as industry, energy, the environment, drinking water, health care, and agriculture. Identify and minimize any harmful incentives and practices that have negative environmental or water-harming effects to the greatest extent possible for the latter (e.g., subsidies for fertilizer and pesticides that are harmful to water).
   b. The necessary monetary, managerial, and technical safeguards should be adopted to guarantee that wastewater treatment systems are constructed and operated cost effectively, take into account topography and projected population trends, contribute to the goals of improving the quality of the water, and enable resource recovery, energy and water efficiency, and reuse to save water.

13.14 Source protection

Available drinking water and freshwater resources should be safeguarded by implementing the total sanitation movement to promote villages' open-defecation free and keep a clean environment, by properly discarding liquid and solid waste, by conforming to the regulation and treatment of industrial effluents, and by educating people about the effects of using high concentrations of fertilizers on water. The Central Pollution Control Board (CPCB) regulatory authority, State Pollution Control Board (SPCB) and the water quality assessment authority will be implemented to safeguard the drinking water quality sources contaminated by effluent released from industry and raw discharge.

13.15 Generation of awareness among people in the community

Periodically, the concerned authorities should organize campaigns to raise awareness for citizens, local welfare associations, local organizations, activist groups, green organizations, political organizations, educational institutions, and government agencies to protect water bodies. They should also make sure that electronic media in local languages is available.

Limiting or reducing nutrient loads to the body of water from sources in the watershed that contribute the most of the "biologically available" kinds of nutrients should be the first regulating priority. The drainage basin's point and/or non-point nutrient sources can both be the targets of the control effort. Large amounts of phosphorus and nitrogen are present in human and animal effluents in chemical forms that are readily utilized by algae blooms. At least up to a specific advanced level of treatment, treatment to lower the level of nutrients in these effluents is typically a financially sensible method of preventing them from trying to reach surface waters.

13.16 Conclusion

People living in rural areas across the globe face acute shortages of water every day. In some parts of the world, though the water is available in sufficient quantity, the quality of the water available is not suitable for human use. In India, there is a complete absence of a structured water supply system in rural areas. The dependency of the larger populace on ponds and other lentic aquatic bodies makes them vulnerable to numerous diseases that are transmitted through contaminated water. Most of the ponds in rural India are eutrophicated because of the mixing of nutrients through wastewater amalgamation resulting in the growth of numerous harmful algal blooms. Cyanobacteria such as microcystis can secrete toxins that are known to cause diseases related to the kidney, liver, and brain. Appropriate treatment measures to reduce the eutrophication of ponds can prevent such diseases being percolating into the community in rural setups. The generation of awareness among people living in rural areas and the development of low-cost sustainable treatment modalities to make pond water free from toxic algal species is the need of the day that ensure the health and well-being of the rural populace in the country.

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Chapter 14

Toxic, non-toxic, and essential elements in drinking water: sources and associated health issues in rural Asia

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14.1 Introduction

The quality of surface and groundwater sources is equally important to fulfill the water needs (especially household, farming, and industrial) in rural and urban areas around the globe (Carrard et al., 2019). On an average, about 63% of the inhabitants in Asia (Southeast) and Pacific countries use groundwater in rural as well as urban areas to fulfill their daily water needs (Carrard et al., 2019). In most countries (worldwide), more than 72% of the freshwater is used for agriculture, 15% in industries and the remaining in domestic applications (Fig. 14.1). The health risk posed by elevated levels of toxic substances in the water used for drinking is at an alarming stage at many places in Asia and requires urgent attention and planning to prevent future health predicaments (Choudhury et al., 2022). The improper discarding of liquid, as well as solid waste, is one of the main causes of water pollution in rural areas.

The ground and surface water are polluted in rural locations by the direct or indirect release of domestic sewage into or near the water sources, open excretion, runoffs from agriculture fields that contain chemical fertilizers and pesticides, and runoff from agribusiness (Laskar et al., 2022). Due to the unavailability of tap water supply in some rural households, people have to obtain water from unhygienic sources in order to fulfill their daily needs (Daud et al., 2017).

Increased application of insecticides and insect killers in farming, modernization of society, and industrialization greatly affects the natural composition of groundwater in rural areas. Groundwater quality is also strongly influenced by the geological and topological development of the area (Bux et al., 2022). Various heavy metals have been introduced into the ecosystem by smelters and mining activities. Industrial and hospital wastewater also contains organic pollutants that complicate wastewater treatment. Metals are considered the most important pollutant for marine environments which, if mingle with the groundwater source, can modify groundwater chemistry (Edwards et al., 2022; Ghoochani et al., 2022; Mishra et al., 2023; Mukhopadhyay et al., 2022). According to the World Health Organization (WHO) report 50% population around the world would face severe water stress by 2025 (Ravanipour et al., 2021). More than 2 billion people still struggle in rural areas to fulfill their daily water needs. It has been estimated that around 159 million people around the world obtain water directly from surface water sources and use it for drinking purposes without any treatment (WHO, 2017).

Normally, water pollution is associated with urban and suburban sprawl and the expansion of manufacturing units and agricultural practices involving different types of harmful substances to improve agricultural production. This leads to a range of noxious inputs including nitrates, phosphates, pesticides, and heavy metals into natural hydrosystems (Hayder et al., 2022; Kumar et al., 2022). Environmental contamination with toxic heavy metals is a widespread problem through the straight or evasive release of these toxic metals into the aquatic environments, especially in developing countries (Fig. 14.2) (Poonia et al., 2021; Sall et al., 2020; Vardhan et al., 2019).

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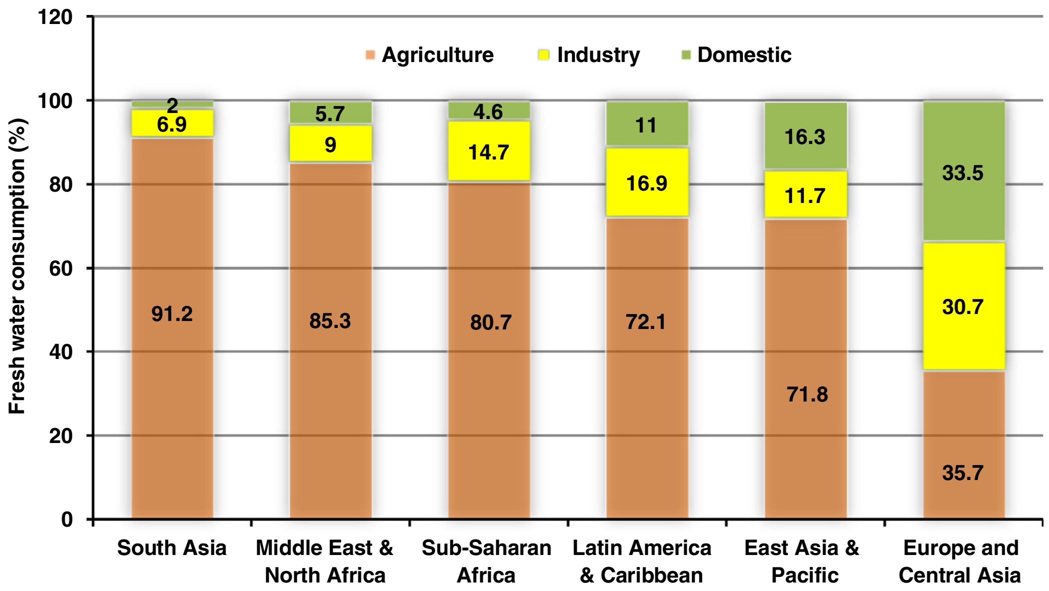

FIGURE 14.1 Annual freshwater consumption in agriculture, industry and domestic applications around the globe (Water, 2015).

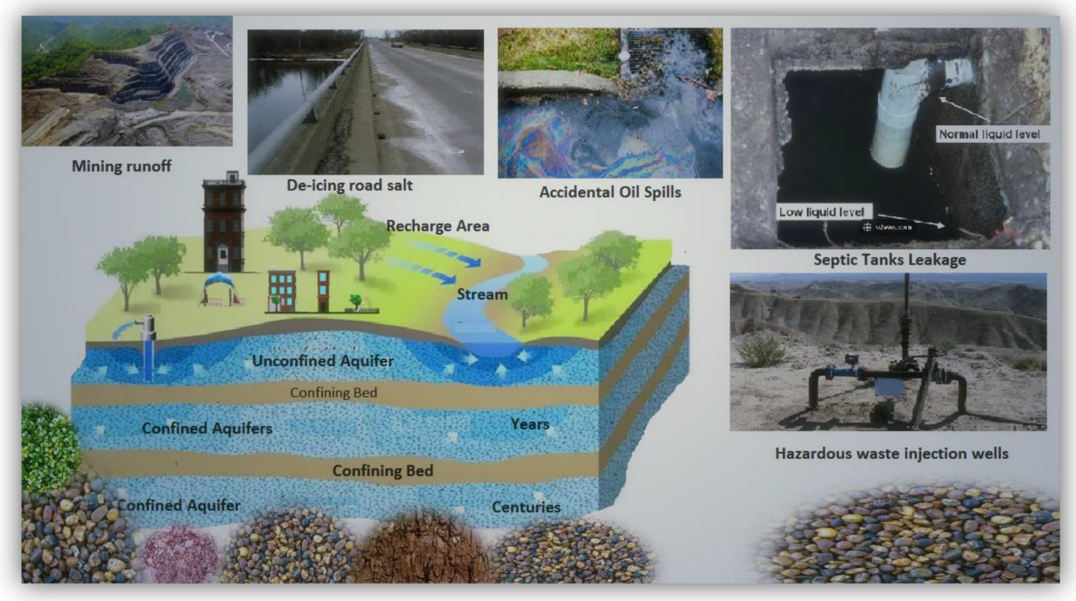

FIGURE 14.2 Different routes of surface and ground water pollution.

Due to the numerous sources of contamination, the control of toxic elements in drinking water is multifaceted, especially for execution and operations in small rural drinking water systems with limited resources and technical competence than large-scale piping systems (Herschan et al., 2020). The available information on sources and provisions to control freshwater contamination is vastly technical and focused on healthy supply arrangements. The procedures for the characterization and control of metal toxicity in small supply (drinking water) systems in rural settings are not well established.

Rural water systems in Asia urgently need a well-planned public water supply and management system to prevent future water crises and improve public health. In this chapter, an effort is made to discuss the present status of water quality in rural areas of some Asian countries with reference to physicochemical and microbiological contamination in drinking water and their sources of contamination.

14.2 Toxic and non-toxic elements in rural water

Groundwater pollution, whether urban or rural, is specified as the accumulation of unwanted materials to groundwater due to anthropogenic activities (Singh et al., 2022). This can be caused by various types of solid and liquid waste from industrial facilities. Chemicals, drugs, fertilizers, fuel, road salt, bacteria, viruses, etc. can be observed in groundwater near industrial plants and landfills. Nevertheless, groundwater pollution diverges from surface water pollution in many ways. In the case of groundwater, the contamination remains imperceptible and the revival of the resource is not easy with the existing state of the knowledge. Pollutants in groundwater are generally colorless and odorless (Dasgupta et al., 2022). Moreover, it is very difficult to find out the chronic effects of polluted groundwater on human health (Singh et al., 2018). On contamination, the revival of groundwater is difficult and expensive as it resides in underground geological stratum and residence times are long (Ravenscroft & Lytton, 2022; Zeng et al., 2022). Natural cleaning of polluted groundwater takes several years. Though the number of pollution sources is increasing quickly, generally they are categorized into three main kinds (Burri et al., 2019):

(1) chemical pollutants,
(2) biological pollutants, and
(3) radioactive pollutants.

These natural resources can turn out to be solemn causes of pollution when human actions disrupt the usual ecological equilibrium, such as the exhaustion of aquifers resulting in to the ingress of salt water, the dehydration of acid mines due to into mineral resource exploitation, and the leaching of harmful compounds due to excessive irrigation in rural areas (Donald et al., 2022). Nitrates, nitrites, and ammonia, are the common nitrogen containing inorganic contaminants generally found in agricultural intensive areas, mainly in rural areas. Nitrates mainly come from anthropogenic sources (e.g., fertilizers, manure) and domestic wastewater discharge in rural settings. The contamination because of elevated amounts of Nitrate (NO_3^-) in groundwater is broadly revealed by researchers around the globe. Anions (e.g., F^-, Cl^-), oxyanions (e.g., SO_4^{2-}), and cations (such as Ca^{2+} and Mg^{2+}) are the other inorganic contaminants commonly found in groundwater (Blarasin et al., 2020; Sako et al., 2021).

The trace elements commonly found in groundwater consist of Cd, Mn, Cr, Co, Hg, B, Pb, U, Zn, Se, and As (Butu et al., 2022). Except for a few essential micronutrients at lower levels, high-level exposure can lead to severe toxicity, e.g., exposure to chromium-VI (Cr^{6+}) may increase cancer risks (Engwa et al., 2019).

Some harmful metals are relentlessly found in the environment and moderately accumulate (bioaccumulation) as they enter the body through the food chain. Many organic pollutants (>200) have been discovered in groundwater, and the trend is increasing gradually (Jurado et al., 2022). Many of these contaminants are extensively considered carcinogenic or endocrine disruptors. Some of the pollutants are biodegradable while others remain inside the settings for a prolonged episode. Waste water from manufacturing units and households are the main sources of biodegradable organic pollutants. Pharmaceutical products, pesticides, hydrocarbons, plasticizers, personal care products, and natural estrogens are common sources of organic contaminants (Morin-Crini et al., 2022).

As organic compounds decompose very slowly or do not decompose at all, their use in agriculture can be a permanent threat to the features of drinking water in pastoral regions (Burri et al., 2019). Geological repositories of radionuclides (natural source) are the likely sources of radioactive substances in groundwater besides the waste from nuclear power plants, nuclear artillery testing, and inappropriate discarding of radioisotopes used in medicines (Rajkhowa et al., 2021). Though, the concentration levels of radioactive substances that create a threat to the health of the natives, have been rarely detected in groundwater (Bjorklund et al., 2020) but these can go into the human body if drinking water is contaminated with such substances.

The use of contaminated (especially heavy metals) groundwater in addition to the wastewater consisting of persistent toxic substances can lead to their accrual in cereals and vegetables. This type of agricultural practice leads to serious health hazards for people in rural areas (Balkhair et al., 2016). In rural areas, groundwater pollution can lead to soil pollution and the deterioration of soil characteristics (Khatri et al., 2015). The use of highly saline groundwater in agricultural fields also affects to the soil salinity in various arid regions. In rural areas, dissolved salts and other toxic substances such as noxious metals can build up at the roots and affect plant growth in agriculture. During interactions, toxic substances can also transport to the surface water from groundwater affecting the surface water characteristics in rural areas (Balkhair et al., 2016).

Equilibrium between the rate of restitution of natural assets and human requirements is always needed for sustainable economic development (Jahanger et al., 2022). Fresh water is probably the most precious resource in nature but chronic groundwater pollution can decrease freshwater accessibility and disrupt the balance of water delivery and requirement leading to socioeconomic catastrophe. Groundwater pollution is not merely an environmental issue but a societal problem, requiring teamwork among scientists working in different research domains (Le Goff et al., 2022).

Metals like copper (Cu), iron (Fe), and cobalt (Co) are able to be present as oxides and sulfides both. During various industrial processes and mining, the number of certain metals increased in water, soil, and air (Engwa et al., 2019; Punia, 2021) and affect the characteristics of agricultural products in rural regions (Chen et al., 2022; Singh, 2019). The various manufacturing materials including paints, cosmetic items, and insect and weed killers also act as an important factor in heavy metal pollution.

The heavy metals are carried to the soil and water bodies via erosion, runoff or acid rain (Engwa et al., 2019). The class of drinking water contamination further varies with the type of water source. This has resulted in huge studies evaluating the status and analytical techniques of a variety of contaminants in drinking water. The unregulated dumping of factory wastes (consisting Zn, Cd, Pb, Cr, As, Ni, Cu, Pt, Fe, and Hg) into water bodies in industrial zones, also increases the levels (Sankhla et al., 2016). Other sources that release metals into the atmosphere include volcanic eruptions, soil and rock weathering, etc. (Ali et al., 2019). Although rivers passing through colonized parts are extremely susceptible to heavy metal contamination, geological processes could also be significant contributors.

The status of water supply systems is not up to the mark in small towns and rural areas, though the quality of groundwater is good. The water distributed by the municipal corporations is of substandard class. A large number of gutters are placed 3–5 m from the installation of pipes for the drinking water supply (Arshad et al., 2017). Both are very recklessly linked by means of low-quality cement mortar and the leaks in the drain pipeline are accountable for many health issues such as diarrhea, dysentery, typhoid fever, cholera, hepatitis, thyroid dysfunction, gastric cancers, stillbirths, and premature delivery (Kirui, 2020). The only use of technology to provide secure, inexpensive, and easy availability of drinking water for everybody and the provision of safe water are observed insufficient (Hutton et al., 2016).

The direct and indirect release of domestic sewage into waterbodies, open excretion, farm run-offs in the midst of wet period having synthetic manures and insect killers, and liquid waste from agricultural production are the main causes of water pollution in rural areas (Hafizur et al., 2017). Due to the lack of common supply systems in these areas, the inhabitants are bound to collect water from deteriorated sources and use it to fulfill their domestic (including drinking) needs (Cassivi et al., 2021; Daud et al., 2017).

14.3 Essential elements for human health

The elements found in water are principally divided into vital and unnecessary categories on the basis of their biological role in humans. Some elements like Fe, Zn, Cu, Cr, Co, and Mn are required for human health at concentrations that may benefit the metabolites in the and human body (Sharma et al., 2022). Normally, these are ingested when a variety of vegetables and grains are consumed. Elements like Hg, Cd, Ni, and Pb are commonly observed in drinking water but these are not required in human physiological functions hence are non-essential. However, a concentration of these metals above the limit could be harmful to body tissues. Although the concentration of iron in natural freshwater is found to a low concentration, it often exceeds the levels recommended by the WHO. The Fe-depleting microorganisms (bacteria) help in the conversion of Fe (II) into Fe (III) through oxidation.

Water is the chief component of body fluids (including blood, saliva, urine, synovial fluid, etc). Drinking water controls all physiological tasks and offers numerous other benefits (Zhang et al., 2020). Several essential minerals and trace elements are naturally found in water in their ionic forms and these ions are easily absorbed by our gastrointestinal tract (Cetin et al., 2017).

Nearly 21 minerals, including Ca, Mg, Na, and K are known to be essential for human physiology. A balanced diet is usually recommended to maintain a good concentration of all the vital minerals; however, minerals found in water show better absorption than minerals from foodstuffs. Our body can absorb the Ca and Mg from mineral water efficiently because of their high bioavailability. Minerals in drinking water can significantly supplement dietary intake. The underground fresh water aquifers are naturally enriched with precious minerals and naturally purified by the ground bed (Teixeira et al., 2021).

Extremely low amounts (0.01–0.02%) of trace minerals are required by human beings for the growth and restoration of good health (Cannas et al., 2020; Zafeiraki et al., 2022). A number of trace minerals confer an important role in enzymatic reactions, redox reactions and in the structural stability of certain imperative biological molecules (Al-Fartusie et al., 2017). Certain trace elements manage significant biological activities that facilitate the molecular binding to their receptors and optimize the over-intake of some molecular species in cells (Awasthi et al., 2022). Several investigations have revealed to little preliminary intakes of Cd help in maintaining the steadiness of Cd in the body and persuade the synthesis and storage of small protein molecules (metallothioneins) in kidneys and the liver (Rahimzadeh et al., 2017). The WHO has also classified trace elements according to their possible nutritional functions (Fig. 14.3).

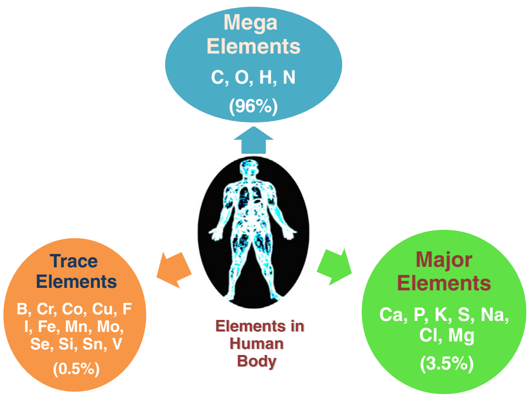

FIGURE 14.3 Abundance of elements in the human body.

14.4 Spatial patterns of freshwater availability and characteristics in rural Asia

There is a close relationship between the world maps of the human development index, poverty, and access to drinking water. Large areas of Southeast Asia experience monsoon climates in which heavy rains cause flooding and sources of drinking water are polluted. Around 80% of people in Asia live in areas where water security is at risk due to high levels of contamination in freshwater resources. A large variation in access to drinking water exists between Asian (13%) and European countries (100%). In areas like Bangladesh and Cambodia, where monsoon floods are common, the floods destroy wells and rivers and carry a lot of debris and silt. People in rural areas where sufficient freshwater is not available, depend mainly on surface water (ponds or rivers) or wells for most of their daily water needs. In some parts of Asian countries, particularly Cambodia and Bangladesh, people in isolated village communities do not have adequate tap water supply. The groundwater resources alone fulfill about 70% of rural and 40% of the drinking water needs in urban areas respectively. Millions of people in Asia (especially in South and Southeast) are facing potential issues related to the rdous levels of carcinogenic arsenic (As) as o daily basis through the drinking of contaminated water. New underground wells are being constructed continuously in these regions to fulfill the increased demand for drinking water. Weathering processes, dissolution of As-bearing minerals (pyrite, arsenopyrite, and chalcopyrite) and climate change are important factors for the mobilization of As in groundwater systems. Numerous investigations have revealed the ill effects of elevated As levels in groundwater in several locations of Asian countries like Bangladesh.

It has been estimated that more than 100 million rural residents in Myanmar, India, Vietnam, China, Pakistan, Nepal, and Cambodia drink As contaminated groundwater. The epidemiological studies conducted in these countries and elsewhere reveal the widespread disease symptoms among people drinking groundwater and the increased risk of death from bladder, liver, and lung cancer. Low-lying and topographically flat floodplains of the rivers draining the Himalayas are the areas mainly affected in South and Southeast Asia. Further, there are wide variations in the depth distribution of boreholes in these arsenic-affected areas in Asian parts. In Bangladesh and neighboring West Bengal (Indian State) the neighboring state of India, drilling for water has reached at a depth of around 350 meters compared to around 100 meters (maximum) in Cambodia, Nepal, and Vietnam. About 50% of the wells (at least one depth interval) in all five countries exceed the As level of 10 μg/L recommended by WHO (Fig. 14.4).

Naturally, high levels of (geogenic) Mn and Fe are often observed in the groundwater of some areas posing health

FIGURE 14.4 Map showing the different countries in Asian continent.

risks to the natives (Poonia et al., 2022). The high As levels in South and Southeast Asian groundwater has attracted a great deal of interest over the last 1 decade. In rural areas of these countries, the levels exceed the limit (10 μg/L) set by WHO for drinking purposes. The data values compiled for the levels of a few elements observed in the drinking water samples of rural and urban locations in some Asian countries are represented in Table 14.1. The spatial patterns of drinking water quality and availability in rural areas of selected Asian countries have been discussed country-wise in the following paragraphs (Fig. 14.5).

14.4.1 India

The lack of sufficient fresh water in some parts of rural India is a serious concern. According to reports, about one-fifth of the population in rural areas did not find the minimum amount of water required (40 L/capita per day or two buckets per day). This problem creates a very critical situation in the dry season every year, especially in rural areas, and millions of people and livestock struggle to get enough water to survive during this period. The rural population usually depends on water sources such as wells, ponds, cisterns, etc. to meet their water needs. The availability of natural resources (like lakes, streams, rivers, canals, etc.) also provides water accessibility to people of different social and economic groups. In the last 1 decade, the use of personal wells and water pumps to access groundwater has increased dramatically.

A significant percentage of wealthy and resourceful households have their submerged pumps available as their exclusive source of fresh water. This dependence of the rural population on municipal water sources has led to its problems, such as poor water quality, seasonal scarcity and lack of maintenance of water sources. To address these issues, the individual or family-level supply of tap water has been conceptualized and initiated in several countries, including India. This concept of the domestic water supply has become an essential indicator of an improvement in the standard of living. Urban areas have obviously led the way in terms of performance on this supply, but the supply of tap water has also become an important part of governance and development in the Indian village in the era of local government. Reports show that 18% of rural households receive tap water at home and more than half of all rural households still depend on public or shared water sources. The limited periods of tap water supply require residents to store water in water tanks, which can create the possibility of metallic and biological contamination of drinking water.

14.4.2 China

Over the past 2 decades, China has seen major improvements in rural water supply construction, and the regional gap in rural water supply systems has decreased significantly. The spatial model of financial progress and public investment has served significantly in this regard in addition to the other factors (Li et al., 2014).

14.4.3 Russia–Ukraine transboundary

Rivers and canals are used to supply water for domestic purposes in several countries around the world. 25% of globally available freshwater (surface and groundwater) is found in Russia only. Water companies are one of the largest industries in Russia, serving the entire population of the country. Surface and groundwater represent approximately 70% and 30% of the country's drinking water. About 90% of the water demand in rural areas is met by wells, but water management systems in rural areas have often suffered from pipe bursts and leaks due to extremely low (−20°C) atmospheric temperatures.

Water from Oligocene and Eocene aquifers is released as springs into the river valleys and canyons, which are extensively used as alternative drinking water supplies by rural and urban populations. A total of 25 springs is recorded in the city of Kharkiv and its suburbs which are being used nowadays by the local people for consumption purposes. The Udy and Lopan are the rivers in the Ukrainian part of the basin which firstly pass through rural settings, and then through the urban settings of Kharkiv having 470 inhabitants per kilometer square (2012). Both rivers receive around 700–1,000,000 m^3/day of processed wastewater (domestic and industrial) from the city of Kharkiv (Vystavna et al., 2015).

14.4.4 Afghanistan

After more than a decade of armed conflict and neglect, Afghanistan is having problems providing sanitary water to the population. The country of 32.5 million people receives water from rivers and underground supplies, which depend on rain and snow (Hayat & Baba, 2017). Clean water is not easily accessible in the country, which has led to several health problems and even the death of children especially in rural parts (80% of the total inhabitants of Afghanistan). As per the investigations, only ≈70% urban and ≈30% rural population in Afghanistan have easy availability to good quality drinking water (Campbell, 2015).

14.4.5 Kazakhstan

90% of the urban residents in Kazakhstan have easy availability to tap water, while merely 28% of rural inhabitants have easy accessibility to tap water. Water from shallow tube wells in Kazakhstan's Balkhash district is found to be polluted due to high levels of toxic elements and other pollutants. It would be harmful to residents to drink this water (Nurtazin et al., 2020).

TABLE 14.1 Concentration of some elements in the drinking water of rural and urban locations in different Asian countries (levels in ppb).

Country/location	Rural/urban	Pb	Mo	Cr	As	Cd	Ni	Hg	U	References
China, Shenzhen	Urban	0.07	0.001	0.022	0.005	0.005	0.144	0.002		Lu et al. (2015)
Pakistan, Punjab, Kot Addu	Urban	–	–	–	23	100	–	–	–	Abbas et al. (2021)
Bangladesh, Rajshahi	Urban	4.01	–	–	0.85	0.38	–	–	–	Mostafa et al. (2017)
Iran, Kerman	Urban	2.75	–	–	–	0.028	–	–	–	Abedi Sarvestani et al. (2019)
Indonesia, Bandung	Urban	217.2	–	–	–	17.23	15.7	–	–	Hasan et al. (2019)
Turkey, Yalvaç–Gelendost basin	Urban	0.9	–	6.3	6.9	–	–	–	3.5	Davraz et al. (2021)
United Arab Emirate, Abu Dhabi	Rural	4.5	–	23.4	–	2.4	4.5	–	–	Iqbal et al. (2018)
Russia/Ukraine Transboundary, Seversky Donets basin	Rural/urban	0.013	–	–	–	–	–	–	–	Vystavna et al. (2015)
Pakistan, Punjab Kot Addu	Rural	–	–	–	23	94	–	–	–	Abbas et al. (2021)

•Data not available in the reviewed literature.

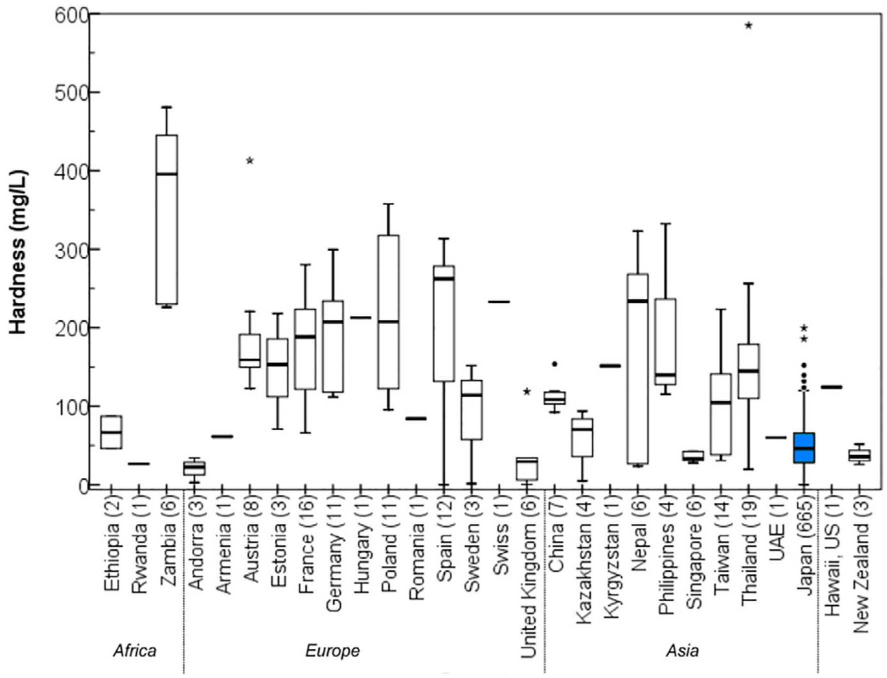

FIGURE 14.5 Distribution of hardness in supply water (tap water) in Africa, Europe, and Asia (Hori et al., 2021).

14.4.6 South Korea

The Han, Nakdong, Geum, Yeongsan, and Seomjin Rivers are the five large rivers in South Korea. Due to the higher flow regime coefficient compared to various other countries, the flowing land up the estuary very quickly (in 1–3 days), just following a huge rainstorm occurrence during the overflow period. For this reason, a number of reservoirs are constructed to stock up this overflow and supply water throughout the dry period. The rapid industrialization of South Korea in the 1960s led to a sharp deterioration in the water quality in the majority of rivers. Several steps have been followed by the Governments in South Korea to improve the environmental infrastructures and water quality (Yi & Yi, 2020).

14.4.7 Japan

The availability of quality drinking water is universal in Japan and mostly (97%) people utilize piped water supplied by public departments. Merely 3% population has personal facilities (wells) predominantly in rural parts (MHLW, 2006). Like several other countries, the tap water quality standards are specified in the Water Supply Law (1957) of Japan and quality is regularly monitored for the levels of metals, pesticides, organic pollutants, microbes, etc. The levels of water quality parameters rarely exceed quality standards in Japan (Japan Water Works Association, 2017, 2019).

14.4.8 Thailand

Most groundwater supply systems in rural Thailand are less contaminated with regard to metal toxicity. The levels of certain metals including Znare reported below the water quality standards in drinking water supply systems, while levels of Fe and Mn exceed the desired levels recommended by the health departments. The quality of the groundwater supply falls into the low heavy metal contamination class (HPI < 100), indicating the groundwater supply is not critically polluted in reference to heavy metals in rural areas. However, pH values are reported below the Thai permitted limit as well as the WHO standards. Therefore, rural areas need adequate pre-treatment to solve the problem of low pH for domestic and drinking use. However, data on some toxic elements (e.g., As, Cr, Cd, Hg, Pb, and Ni) is insufficiently reported in the literature. Microbiological quality and toxic heavy metals should be analyzed in water supply systems to prevent health problems in rural Thailand (Chiamsathit et al., 2020).

14.5

14.5.1 Source of toxic elements in drinking water

The initial water quality depends on the source. Rainwater and snow are the two important sources of drinking water in addition to freshwater aquifers and surface water bodies

(Batdelger et al., 2022; Mackie et al., 2022). Nearly 50% of the drinking water sources like lakes, reservoirs, streams, and rivers in rural areas are usually found to be of inferior quality and require proper treatment (Tong et al., 2022). Though groundwater quality is better in these areas but it can still be polluted by runoffs from agricultural fields and surface or underground disposal of liquid wastes, as well as the leachate from solid waste landfills in rural areas (Burri et al., 2019; Mukhopadhyay et al., 2022). The quality of springs and rainwater varies in characteristics and quality but can be treated and improved to make it potable (Alim et al., 2020; Dutta et al., 2022). Almost all water supply systems have a water source (such as a well, spring, canal, or lake), a reservoir, and a piping system for distribution (Valente et al., 2022). A water treatment method may also be required to eliminate detrimental microbes and chemicals (Srivastava et al., 2022).

Water systems made for large supply generally depend on surface water resources while small systems mostly exploit groundwater (Bowen et al., 2022; Moshfika et al., 2022). Groundwater is generally extracted by the borewells drilled into the aquifers. Aquifers are geological formations in which water is collected, often deep in the ground (Hibbs, 2022). A few aquifers are even situated higher than the surface of the adjacent land, which can lead to gushing springs or artesian (natural) wells. These artesian wells are commonly drilled for various water requirements. Just the once aquifer is pierced, water start flowing into the soil due to the hydrological pressure of the aquifer.

The toxic elements are primarily introduced into water bodies by wastes generated from smelters, refineries (oil), and industrial units (producing chemicals, petrochemicals, and pesticides), sludge of untreated sewage, metal pipes, traffic, and by-products of the coal combustion (Ostrakhovitch, 2022). Depending on the source, drinking water pollution can be divided into three categories (Lwimbo, 2021; Tracy et al., 2020) (Fig. 14.6):

(1) Chemicals from natural origin.
(2) Pollution of the watershed.
(3) Chemical compounds used in the treatment of water.

The elevated levels of toxic substances in spring water may be found in small rural drinking water networks (Bera et al., 2022; Khabo-Mmekoa et al., 2022). Some toxic metals including As, Fe, Mn, Se, and U are dissolved naturally from the earth's crust thereby going into the aquatic environment (Blake et al., 2022; Darma et al., 2022). Evidently, in areas of granitic rocks, the levels of As and U in the groundwater may be high. Many other factors such as the geology of the surroundings patterns of land use and climate also influence the levels of natural toxic elements in water systems (Lee et al., 2022). The levels of Al, Fe, and Mn can increase after volcanic ash fall (natural event), and As can mobilize from sediments by acid rain (Adeloju et al., 2021;

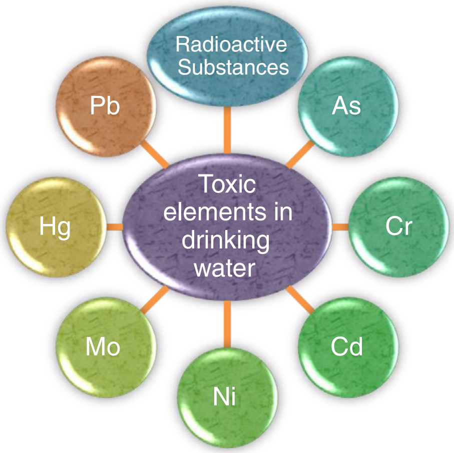

FIGURE 14.6 Naturally occurring toxic elements in drinking water (BIS:10500).

Gevera et al., 2021). Although groundwater contamination is steadier than surface water, levels can vary significantly among individual wells within an area (Brewton et al., 2022). The levels of pollutants in low wells may not be much steady as compared in deep wells because they fluctuate with rainfall.

Pollution levels can also rise in rural water systems due to mining activities; metallurgical processes, expansion in oil and gas, manufacturing of pesticides, herbicides, and electronics, and processing of leather and textiles (Garai et al., 2021; Shakeel et al., 2022). Waste from these activities can go into water bodies and groundwater through leaky reservoirs and perforated pipes, unintentional spills, unmanaged discharges of sewage and stormwater, poorly lined sewage treatment ponds, and precipitation and aerial deposition (Bahadori, 2020). Though human settlements with higher population densities are considered a significant source of water pollution in urban areas but toxic elements can still enter the freshwater aquifers in rural areas through poor sewage and waste management (Chen et al., 2022; Seifollahi-Aghmiuni et al., 2022). Discharges into surface waters can be detected more quickly but it can take many years for contamination to pass through the soil and end up in groundwater. Water treatment and supply systems can be the source of elements such as Cu, Pb, Fe, and Zn into the water through the partial dissolution of materials (general corrosion) used in the piping system. Over time, protective coatings weaken and piping systems start corroding and the metals are released into the water (Zhang et al., 2021). Worn or damaged portions of the water supply network are more prone to accelerated corrosion. Advanced methods should be preferred in order to avoid water contamination due to treatment processes (Garg et al., 2022) (Fig. 14.7).

Another often overlooked factor is the installation of water systems and the quality of construction (Geldreich, 2020). Improper installation, design, and construction

FIGURE 14.7 Sources of ground water pollution at rural locations in Asia.

practices can unintentionally add contaminants to the water supply. This also increases the chances of continued corrosion and leads to scratching of surfaces. The use of gravels, pumps, and pipes with a high metal content is particularly problematic. Insufficient system flushing and long periods of stagnation after installation can leave remains in the system, hinder the development of a defensive layer on the pipes, and cause pitting corrosion.

14.5.2 Some toxic elements present in drinking water

14.5.2.1 Chromium (Cr)

Chromium naturally exists in soil, rocks, volcanic dust, animals, and plants. Chromium with a +3 oxidation state (Cr-III) is the most common form found in natural water (Singh & Sharma, 2020). Health problems caused by excessive chromium intake comprise breathing issues (asthma), irritation in the eyes, perforation in the tympanic membrane of the ear, lung cancer, harm to kidneys, liver problems, fluid retention in tissues, stomach cramps, skin, and nasal disorders.

14.5.2.2 Lead (Pb)

The pipes, taps and plumbing consisting of Pb used in drinking water supply systems serve as the key source of Pb in drinking water. In addition to these sources, the other common sources of lead poisoning include lead-based paints and dust contaminated with Pb. The health problems caused by lead in drinking water are cardiovascular effects, increased blood pressure, and incidence of hypertension, anemia, and weakness.

14.5.2.3 Mercury (Hg)

Rain and snow can transport mercury from the air to lakes, rivers, and reservoirs. Mercury can enter underground water supplies from industrial and hazardous waste dumps. The direct release of industrial and mining effluents into the

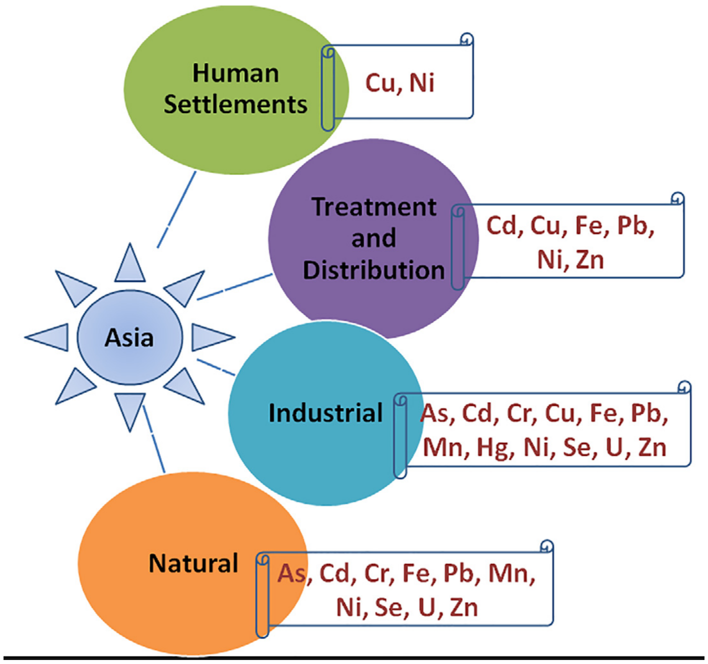

FIGURE 14.8 Primary sources of some toxic elements in water systems (WHO, 2007; 2017).

water bodies and naturally occurring minerals of Hg also contribute to the Hg pollution in water bodies. Mercury in drinking water can seriously affect human systems (nervous, digestive, and immune systems), lungs and kidneys. High levels of the water supply can lead to neurological and behavioral disorders.

14.5.2.4 Arsenic (As)

Arsenic can enter into the supply systems from minerals in the soil or through industrial and agricultural pollution. The elevated concentration of As in water regularly used for drinking purposes can develop carcinoma, skin problems, high blood pressure, and issues related to the heart and nerves (Fig. 14.8).

14.5.3 Sources of non-toxic elements in drinking water

14.5.3.1 Zinc (Zn)

Zinc enters into water systems through man-made means, such as an offshoot of steel production, coal-based power stations, and waste incineration. Stomach cramps, skin irritation, vomiting, nausea, and anemia are common health issues that can occur due to high Zn intake (Singh et al., 2018).

14.5.3.2 Copper (Cu)

Corrosion of household plumbing, faucets, and water mixtures are the usual sources of copper in drinking water distribution systems. High Cu intake can cause nausea, diarrhea, abdominal pain, and damage to the liver and kidneys.

14.5.3.3 Iron (Fe)

Iron remains present in surface and groundwater bodies and can release from natural deposits. It can also get into the natural resources due to the mixing of factory waste, refinement of iron from its minerals, along with rusting of ferrous parts and equipment. An elevated concentration of Fe in water can cause nausea and stomach pain in humans.

14.5.3.4 Cobalt (Co)

Cobalt (Co) is generally found in +2 and +3 oxidation states in water. A big amount of cobalt deposits are found in Russia. Though, higher levels of Co in freshwater have been found linked with industrial and mining areas but animal proteins and surface rub-offs also contribute a significant amount of cobalt in fresh. Human health is caused by Co in drinking water pulmonary effects, such as asthma and pneumonia, blood, liver, kidney, and heart.

14.5.4 Sources of essential elements in drinking water

A number of essential elements remain naturally there in different water bodies in variable amounts. The sources of a few essential elements have been discussed in the following section.

14.5.4.1 Calcium (Ca)

Calcium occurs naturally in water due to the dissolution of calcium-containing rocks including carbonate sedimentary, metamorphic calcium sulfate dihydrate, fluorspar, and phosphate (Deshpande et al., 2012; Wadira, 2020). Calcium is also found in concrete and bricks. Plants mostly have calcium oxalate and approximately 1% (of dry matter) Ca is stored in them.

14.5.4.2 Sodium (Na)

The chemicals used in street defrosting, water treatment, household water softeners, and wastewater add significant amounts of Na to water bodies (Mackie et al., 2022). Sodium and chloride occur naturally in water due to erosion or the ingress of salt water (when salt water from the ocean seeps into groundwater reserves) (Arega, 2020). Sodium can reach both groundwater and surface water resources as a result of residential, commercial and industrial activities. Water from private wells filled by lateral infiltration through the ground often contains high levels. Much of this exists in the sulfate or nitrate form and is more difficult to detect by taste than chloride (Bidhuri et al., 2020). The high solubility of sodium salts is the reason for the everlasting presence of Na+ ions in water. Groundwater generally consists of higher levels of minerals and salts as compared to surface water, particularly in regions having sodium mineral deposits or inflows of sea or estuary water (Kaushal et al., 2021). Municipal supplies can have sodium levels of 30–120 mg/L. The occurrence of sodium in surface waters of rural and urban areas of Asian countries varies greatly. Sodium levels detected in surface waters generally remain lower than those in groundwater systems.

14.5.4.3 Potassium (K)

High levels of K are rarely found in drinking water which could affect human health. It is widely found in all-natural water bodies (Larsson et al., 2022). If $KMnO_4$ is utilized as an oxidizing agent in the treatment of water, could elevate the levels further.

14.5.4.4 Iron (Fe)

Iron occurs naturally in rocks and soil, and dissolves easily in surface and underground water bodies. It is therefore often found in the spring waters of rural areas (Teresa, 2021). Though iron is an important resource on the planet but it can be a burden for the water supply systems. It remains present in drinking water at a level >10 mg/L and makes $\approx 5\%$ of the earth's crust. Rainwater infiltrating through the soil pores as well as the underlying geological rocks solvate the iron, allowing it to infiltrate the groundwater. In water it exists in ferrous (soluble) and ferric (insoluble) forms. The iron in its Fe (+2) state completely dissolve in water and do not impart any color to it (Khozyem et al., 2019).

14.5.4.5 Silicon (Si)

Silicon occupies the second position in the category of most abundant element contributing $\approx 28\%$ of the earth's crust. Large amounts of silicon are found in various minerals and are abundant in the oceans and almost all other water resources like silica (Petkowski et al., 2020). The water in the interstices of marine sediments contains more silicon than the sea surface (Stranghoener et al., 2020). The concentration of silicon commonly found in rivers is 4 ppm (Vasanthi et al., 2012). Silicon is generally not ionized when dissolved but exists as orthosilicic acid (H_4SiO_4). Alkaline silicones are added to detergents, adhesives, and bleaches in textile industries.

14.5.4.6 Copper (Cu)

It occurs in the environment as a mineral in rocks and soils and is commonly found in small amounts in natural bodies of water. Copper tubing is widely used in plumbing systems in various nations (Harvey et al., 2016). However, when corrosion occurs in copper pipes, copper can enter drinking water in quantities that can affect its quality and safety (Lytle et al., 2016). Certain plumbing parts or fittings, such as faucets or valves, may also contain copper, which can also leach into drinking water.

14.5.4.7 Boron (B)

Boron is a natural element found in rocks, soil, and water (Brdar-Jokanovic, 2020). Elemental boron does not dissolve in water but orthoboric acid and sodium tetraborate are somewhat soluble (Ince et al., 2022). Boron enters drinking water from both natural and artificial sources (Khaliq et al., 2018). It can enter the environment through the burning of nonrenewable fuel sources, and the release of domestic and industrial effluents. In water, boron is mainly found as boric acid and borate (Chaudhary et al., 2021; Sonone et al., 2020).

14.5.4.8 Fluorine (F)

Fluorine is naturally released from rocks into the water bodies (up to 10 ppm). Almost all water sources contain some amount of fluoride (minimally detectable to over 10 ppm) (Ling et al., 2022; Mukherjee et al., 2018). The fluoride content in rivers and lakes (surface waters) varies widely due to count the act of rainwater with washed-out soils (Paul et al., 2021). Levels of fluoride may also vary in groundwater depending on the geochemistry of the region. Fluoride in seawater (96.5% of earth's water) typically ranges from

1.2 ppm to 1.4 ppm. Water sources with high fluoride concentrations affect up to 60% of the population in Pakistan, Thailand, China, and Sri Lanka.

14.5.4.9 Iodine (I)

The average levels of iodine in seawater remain around 60 ppb but vary from one place to other. Rivers typically contain around 5 ppb of iodine, and some concentration can even be found in mineral springs. Iodine naturally enters surface waters through rainfall and water evaporation, but it is also introduced through anthropogenic activities. Natural sources of iodine include weathering of iodine-bearing rocks and volcanic activities (Sharma et al., 2019). The wastewater may contain 1–16 ppb of iodine and high concentrations in water bodies may be present near chemical waste landfills.

14.5.4.10 Cobalt (Co)

Cyanocobalamin (vitamin B_{12}) is an organic cobalt complex found in surface waters, sediments and sewage sludge. Many plants and microorganisms use vitamin B_{12} as their main source of cobalt (Mahey et al., 2020). Cobalt can enter the surface water through windblown dust, runoff and rainwater leaching through soils and rocks holding it. Cobalt is found in the minerals such as cobaltite, skutterudite, and erythritol. Coal and oil combustion, coal or oil, cobalt processing, and the production of cobalt-containing chemicals also contribute to the cobalt release.

14.5.4.11 Selenium (Se)

Selenium remains naturally present in soils and deposits and its levels in water bodies are found very low, but depends on the characteristics of local rocks and soils (Du et al., 2018). The agricultural runoffs and leaching of natural Se compounds from dry and uncultivated land, may also contribute to the increased levels of Se. Mining operations often contaminate surface and groundwater with selenium but the contribution of selenium to water due to the natural weathering of rocks and erosion of soils is very small (Etteieb et al., 2020; Tabelin et al., 2018). The selenium content of ground and surface waters ranges from 0.06 μg/L to 400 μg/L but levels can reach up to 6000 μg/L in the groundwater. Concentrations may vary at high and low pH due to conversion to compounds with higher water solubility. Selenium levels in public water supplies around the world are generally well below 10 μg/L, except for a few rare cases (50–160 μg/L) reported in China.

14.5.4.12 Chromium (Cr)

Trivalent (Cr-III) and hexavalent (Cr-VI) forms of chromium are generally found in water bodies (Chondo, 2021). Electrolytic deposition, textile and leather processing and fabric manufacturing units discharge reasonably big amount of chromium into surface water bodies (Madhav et al., 2018). Discharging from earth and rocks are the main source of its input to aquatic environments (Uddin et al., 2021). Additionally, Cr-VI enters drinking water sources through releases of paints, pigments, wood preservatives, chrome plating waste, and through leaching from hazardous waste landfills. About 96% of the global Cr wealth are naturally located in Kazakhstan and Southern Africa. Manmade sources are the main sources of Cr (70% of chromium in the environment). It exists in various forms, but +2, +3, and +6 are the common valence states due to their stability in the atmosphere.

14.5.4.13 Molybdenum (Mo)

Molybdenum is found in the outermost layer of the earth at levels <2 mg/kg (Smedley et al., 2017) and exists in the formal oxidation states +2 to +6, though +4, +5, and +6 are the main states normally found in the environment. It occurs naturally in different geological formations but not in a free state. It is a natural component of water and soil. Surface water sources generally have concentrations up to 0.005 ppm (Hojjati-Najafabadi et al., 2022; Kody, 2019). Trace amounts (1–10 mg/kg) are found in the majority of rocks, soils, and open marine waters (10 μg/L) (Frascoli et al., 2018; Okonji et al., 2021). Higher concentrations are usually found to be associated with spills or certain historical waste disposal practices. Molybdenum is generally not included in the list for regular testing.

14.5.4.14 Tin (Sn)

The natural quantity of tin in the soil as well as the water bodies is found fairly low but anthropogenic processes can increase the tin content about 110 times compared to release from geological processes (Ostrakhovitch, 2022). Tin is usually useful in corrosion prevention but if in any case of corrosion occurs in such equipment, it significantly contributes to the high levels of Tin in the water environments (Gulati et al., 2022). The utilization of Tin in organotin compounds (known for fungicidal, insecticidal, acaricidal, and bactericidal effects), is also a big source of high tin levels in wthe ater. In addition, they are used as thermal stabilizers in PVC and PCB (Wijnhoven et al., 2010). Superconducting magnets, drum blocks, and brakes in motors have Tin. From all these sources, tin and tin compounds can enter the water if safety measures are not taken care of sufficiently.

14.6 Factors affecting water chemistry and human health in rural Asia

About 25% of all diseases such as diarrhea, malaria, and respiratory infections are the result of climatic variations and ecological degradation, such as watercourse pollution by agricultural waste consisting of pesticides and other harmful fertilizers. The water characteristics in relation to climatic variations have not been well explored. Water-borne infections such as cholera and vector-borne infections such as malaria and dengue fever prevail with changes in rain, temperature, and humidity. Non-governmental as well as government agencies are operational on water deterioration and associated issues in different countries but currently, there is no framework or exhaustive investigations have been done to show the explicit situation of water wealth management, farming, water quality, and community wellbeing (Escobedo Garcia et al., 2022).

The improper disposal of wastewater is a significant source of water pollution in Asian countries (Izah et al., 2016). Chemical as well as microbial contaminants both be able to influence marine life as well as human health. The multiplicity of antibiotic-resistant microbes in water systems can also increase by water contamination. The incidence of pollution in the water supply causes waterborne diseases and poses substantial threats to life and finance in both developed and developing countries.

Floods carry biological as well as chemical pollutants that can eventually contaminate groundwater in both rural and urban areas. Floods often cause soil erosion and if such soils are contaminated with organic and inorganic pollutants may threaten groundwater resources and can be absorbed by crops and other plants. Chemical manures and infested soils both potentially contribute to the levels of polycyclic aromatic hydrocarbons (PAHs) in water. Vector and water-borne illnesses like cholera, diarrhea, dysentery, typhus dengue, malaria, and yellow fever can increase after a flood event (Lee et al., 2020; Wright et al., 2019). Flood-connected events also boost the danger of respiratory problems. The intensity of the floods and drought has a harmful impact on community health both during and immediately after the event. The incidences and strength of floods, dry spell, and high atmospheric temperature can increase in a country due to climate change at the regional level.

Agriculture can have a negative effect on water quality, particularly in rural regions whether it is a developed or under developed country. Agricultural fields are frequently irrigated by wastewater contaminated with household and manufacturing effluents consisting of heavy metals that can be taken up by vegetables and other commercial crops and end up as part of the food chain (Gashaye, 2020; Khalid et al., 2018). Urban agriculture plays an important function in the dispersal of a fight with insect killers and malaria. Exposure to chemicals can be minimized through the use of natural fertilizers and the principles of sustainable agriculture in general. Fertilizers and animal excretion contain pathogens, animal drugs and nutriments, as well as heavy metals, which are reached and extend through the surroundings, eventually threatening both the environment and individual fitness (Ahamad et al., 2018).

14.7 Conclusions and suggestions to restore the drinking water characteristics in countryside areas

People in rural areas of Asian countries have less availability of purified drinking water because of the low income, awareness, engineering solutions, internal community management, water pollution from agrochemicals, industries (mostly small scale), and waste disposal. Water resources in agricultural communities often have high nitrates, which penetrate groundwater from fertilizers and manure. However, in 85% of the nitrate violations, there is no specific plan of treatment systems to remove the chemical. The most problematic chemical parameters are fluoride, arsenic, chromium, iron, and nitrates. Iron also turns out to be a major problem because many homes have excess iron in their water. The various sources of fresh water in Asian countries include municipal water supply (tap water), handpumps, boreholes, fed wells, jet wells, dug wells, drilled wells, cisterns, rivers, springs, etc. Contamination of water sources is a foremost issue of scarce water resources in Asia. This seriously degrades water quality and has a negative impact on public health, especially in a distant rural population that rarely have treated municipal water. Overuse, increased demand, pollution, mismanagement, improper waste disposal, lack of infrastructure, and changes in weather patterns due to global warming are major factors affecting freshwater availability in rural Asia. Rural communities need to be educated on the importance of environmental conservation. The awareness and knowledge of good agricultural practices, proper waste management, impacts of deforestation, and hazards of improper waste disposal could improve the situation in these areas. Though, environmental awareness in rural parts of developing nations has augmented significantly in the previous few years. The financial and demographic expansion of rural areas leads to numerous environmental nuisances including water pollution, soil deterioration, resource exhaustion, loss of biodiversity, and risks to public health. Such nuisance leads to the outbreak of a series of epidemics such as cholera, typhus, etc. Practices like secure conduct of freshwater, innovative ways of effluents disposal, protected discarding of human feces (together with children's diapers), solid waste organization, household food, and personal and village hygiene may drastically change the regional water quality. Rural areas face greater environmental degradation in terms of water as they have easier access to water sources such as rivers, springs, and lakes. They usually wash their clothes near rivers. There is a need to boost sustainable availability to improve water supplies and promote better cleanliness and hygiene practices in rural Asia. The development of infrasturure for piped water supply and proper sewage as well as the solid waste disposal alongwith the regular water quality monitoring would improve the living standards and health in rural Asia.

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Chapter 15

Water resources of rural India: Challenges and management strategies for sustainable development

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15.1 Introduction

Water is one of the most important factors in the development and sustenance of all communities. As a consequence of increased pressure on this renewable natural resource, there is a pressing need to manage water effectively and efficiently due to the fact that there are so few resources available. The fact that the amount of water available in a given area and time is limited, the need for a globally viable water management regime has arisen in order to ensure its sustainability for future generations (Agarwal et al., 2000; Singh, 2004). There are also many economic benefits associated with the use of water. As a matter of fact, it is necessary for a wide range of agricultural practices, as well as the majority of industrial manufacturing operations (Kay et al., 1997; Merrett, 2004). Furthermore, water offers a variety of ecological and environmental services (Frederick, 1993; Seckler et al., 1998) that are beneficial to the environment. As a result of the decrease in land available to people per capita, it has also been observed that the amount of water available to people per capita is also decreasing. It is estimated that more than 5300 m^3 of water was present in 1951, but by 1999 it had been reduced to 1905 m^3 and is likely to be reduced to 1500 m^3 or less by 2025 (CWC, 2008; CWC, 2013; Kumar et al., 2005). Water availability with a stress level of less than 1700 m^3 per capita has been described as being at a critical level. There is a severe constraint on socioeconomic development and environmental quality in the region below this level, as a result of the scarcity of water below this level (Kumar et al., 1999). A number of rural regions across the country are already experiencing severe water shortages, as a result of wide variations in the spatial and temporal distribution of water resources. "Global prosperity and stability are at risk because of chronic water scarcity, hydrological uncertainty, floods, and droughts," according to the World Bank. Drought and water scarcity are both contributing to conflict and fragility. The role of these factors in aggravating conflict and fragility is becoming more widely acknowledged. This also applies to India. During the summers, like most tropical countries, the country experiences high temperatures and little rainfall. In India, and worldwide, agriculture still consumes a majority of water resources, so storing and treating water throughout the other seasons is necessary to prepare for the summers. As far as water management and administration are concerned, the biggest challenge facing the authorities in India is the number of investments required to set up initiatives in rural areas across the country (Kumar, 2020). Availability and utilization of electricity is the second hurdle that needs to be overcome. Water management in India occurs mostly in rural communities, organized in villages, which are also the smallest viable social units in the rural milieu (Singh, 2004). The most important question concerning about water sector in rural India is "in rural Indian communities, what are the traditional practices for meeting water needs?" Water resource management (WRM) is defined by the World Bank as "the process of planning, developing, and managing water resources, as well as their quality and quantity, across all uses." Water management is based on institutions, infrastructure, incentives, and information systems. In other words, water management involves considering all

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existing and projected water demands and allocating available water resources as fairly as possible in order to meet as many demands as possible (Bansil, 2004; Palanisami et al., 2015). The implementation of an effective water management strategy will ensure a sufficient supply of water of appropriate quality to meet all of our water needs, including drinking, sanitation, agriculture, ancillary food production, energy production, inland water transport, etc., while also maintaining and protecting water ecosystems and protecting aesthetic and spiritual qualities of water bodies (Bansil, 2004). Natural calamities such as floods and droughts, or contamination of the natural resource, are also considered when developing water management strategies (Cosgrove & Loucks, 2015). The management of water resources also involves the complexities of their availability and their use across households, economies, and ecosystems (Parvathi, 2011; Thomas & Gibbons, 2018). Unfortunately, as with most resource management planning, the ideal distribution of water resources seems a long way off.

15.2 An overview of India's water resources

One of the most important assets of a country is its water resources. India receives about 4000 km^3 of precipitation each year. As a result of the high variation in rainfall in India, many rural areas of India, which receive the highest rainfall, suffer from a shortage of water during the non-rainy season almost every year (Kumar et al., 2005). A total of 1953 km^3 of water flows through Indian rivers each year. A total of 432 km^3 of replenishable groundwater is estimated to be available each year. Approximately 690 km of surface water and 396 km of groundwater are utilizable each year in India. Our water resources are under pressure due to an increase in population and improving living standards, which are reducing the availability of water per capita. Table 15.1 displays the state of the water resources right now in India. Freshwater comes primarily from rainfall, which is somewhat acidic due to atmospheric carbon dioxide dissolving (Adhikary et al., 2021). Organic and mineral materials, soil particles, microorganisms, etc. will be gathered by surface run-off. Infiltration of surface runoff into the subsoil forms groundwater. Because of varying land formations, groundwater levels rise above surface levels and produce springs. Streams, rivers, and lakes are the sources of surface water (Kumar et al., 2005). In terms of water system design and cost, the source of water plays a major role. There are varying degrees of treatment required for water from different sources due to its quality. Local conditions greatly influence the selection of the most appropriate source of water supply. At any of the above stages of the water cycle, a source of water supply can be identified if it provides sufficient quantities most of the time. As a result, rainwater, groundwater, and surface water can be used to supply water to rural communities (Setegn & Donoso, 2015).

TABLE 15.1 The availability of water resources in India.

S. no.	Particulars	Quantity (billion cubic meter)
1	Annual precipitation (including snowfall)	4000
2	Average annual availability	1869
3	Per capita water availability (2001) in cubic meter	1820
4	Estimated utilizable water resources	1123
(i) Surface water resources		690 Km^3
(ii) Ground water resources		433 Km^3

From: Website of Ministry of Water Resources, GOI www.wrmin.nic.in.

15.3 Emerging challenges in the context of water resource management

In order to maintain agricultural production, water management is one of the most important aspects that need to be taken into account. By the year 2050, the International Organization for Migration and UNDP estimate that 22% of the area and 17% of the population will face absolute water scarcity globally (500 m^3 per capita per year), while 70% of the area and 16% of the population will experience economic scarcity and health concerns due to less than 1000 m^3 per capita per year of water availability globally (Chaudhuri et al., 2021). Water is the most important constraint for agriculture due to the declining amount of water available for irrigation, as well as the use of water of low quality (Bharadwaj, 1990; Kumar et al., 2021). We are currently suffering from a number of issues when it comes to the management of water, including low productivity in terms of the amount of water used per unit. As a result of the alarming increase in groundwater extraction, a lot of groundwater is being depleted. In spite of the fact that some groundwater resources have reached their maximum potential in the northern, western, and southern states, there are still some untapped potential in the eastern and north–eastern regions (Guntu & Agarwal, 2022). Water availability at the national level has decreased over the years as a result of a decline in the availability of water per capita. It has been noticed that water is becoming increasingly unsuitable and inadequate for basic human needs as a result of deteriorating water quality, pollution problems, and seasonal shortages. Water safety and access are key challenges. In rural areas, women are responsible for fetching water from distant sources, yet they do not have a voice in the planning of water resources (Parvathi, 2011). We have therefore failed to

TABLE 15.2 Identifying the key challenges and characteristics of the water sector for sustainable development.

Challenges	Characteristics
Challenges faced by the institutions	a) Infrastructural failures and poor maintenance of the water system. b) Farmers, citizens, industries, and the state have an imbalance of power. c) Water reforms that focus primarily on organization rather than governing user-regulator interactions. d) Water resources development requires public-private partnerships (private sector participation).
Problems related to water stress and pollution (environmental concerns)	a) Water availability per capita is declining. b) Human needs and agricultural needs are not met by adequate water availability. c) There is no access to safe drinking water. d) Pollution and water quality problems are deteriorating. e) Water shortages during certain seasons. f) Droughts and floods are becoming more frequent.
Problems associated with groundwater overexploitation and pollution	a) Water tables are declining. b) Coastal areas are subject to sea water intrusion. c) The quality of groundwater has deteriorated (arsenic and iron concentrations). d) A lack of clear definition of property rights. e) Power subsidies that trigger the extraction of the resource and the related equity issues.
Conflicts over water are growing	a) Disputes over river water sharing between states. b) A conflict between domestic, agricultural, and industrial users. c) Conflicts within and between urban, rural, and peri-urban areas.
Participation of beneficiaries in water management programs is lacking and there is a lack of openness	a) Water management information is not accessible to the public in an adequate manner. b) The rule is not accountable, participatory, or transparent. c) Lack of participation of beneficiaries in water resources management authority.

From: Water Resources Development in India: Critical Issues and Strategic Options (Parvathi, 2011).

ensure that everyone has access to safe drinking water. There are many issues that need to be considered when it comes to groundwater governance, including high extraction rates, fluctuating water tables, contamination of groundwater, a reduction in agricultural production, as well as issues of equity. A large amount of water is uncontrolled and unjustly distributed among users, such as agricultural, industrial, domestic, and hydropower users. There have already been a growing number of conflicts caused by severe water shortages across the country. In India, interstate rivers drain more than 90% of the country's land. Water allocation rules that are unclear and ambiguous impose high economic and environmental costs on states. In the current state of the country's water sector, a number of crucial issues are facing the sector, such as the growing conflict over water between different users, areas, and states (interstate disputes over the sharing of river water between states). Various key challenges in the context of WRM has been identified and enlisted in Table 15.2.

15.4 The management and strategic planning of water resources in rural areas of India

A number of ambitious projects have been undertaken by the World Bank, the Government of India (GoI), and various state governments to streamline water management in rural areas. Over the past twenty years, the World Bank has implemented nine rural water supply and sanitation (RWSS) projects in Maharashtra, Karnataka, Uttar Pradesh, Uttarakhand, Kerala, Punjab, and Andhra Pradesh. The projects, which are valued at more than USD 1.4 billion, are expected to benefit 24 million people in rural areas across more than 15,000 villages. Guidelines of the GOI's National Rural Drinking Water Program (NRDWP) emphasize the importance of involving local authorities and communities in planning, implementing, and managing drinking water supplies, as well as monitoring and evaluating them. Drinking water security for rural households is also ensured in the Ministry of Drinking Water Supply and Sanitation's long-term strategic plan (2011–2022). It is planned to provide piped water to 90% of the country's households by 2022 and tap water to at least 80%.

However, MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act) is perhaps the most significant of all these initiatives in terms of its significance. It has been reported that more than 75% of the MGNREGA funds are being used for conservation efforts of water, which is a complement to the Jal Shakti Abhiyan (JSA) launched in 2019 with the aim of harvesting rainwater and rejuvenating rivers which will ensure safe drinking water supply. In a developing country like India, wastewater management does not have the importance it deserves, owing to high construction costs, high electricity consumption, and a lack of advanced technical support. However, other strategies like constructed wetlands, waste stabilization ponds, and up-flow anaerobic sludge blankets, as well as soil aquifer treatment are highly recommended for an efficient wastewater management system.

In spite of this, it is important to keep in mind that not every initiative can be taken by the government. It is also possible for private citizens and companies like Rite Water Solutions (RWS) to participate in this project as part of a shared burden. With the help of the water ATM system, Solar Water Purification System, and Solar Energy Based Water Distribution Schemes developed by Rite Water Solutions, we have been able to overcome the hurdles of heavy initial investment, as well as the substantial amount of electricity consumed to provide clean water to the rural population through initiatives like the Water ATM System, Solar Water Purification System, and Solar Energy Based Water Distribution Schemes. In order to achieve water security for all in rural India, RWS aims to implement effective water management strategies across the country in order to ensure water security for everyone. Various management strategies in the context of water resources have been enlisted in Table 15.3.

15.5 Practices for the management of water resources

15.5.1 Structural conservation measures

India's rainfed areas have a significant amount of runoff water as part of their water balance. The precipitation in some areas of the nation is concentrated over a period of 90–100 days, depending on the topography features, the rain patterns, and other variables that may contribute to it. It may also contain a few high-intensity and stormy episodes that contribute to significant runoff volumes. It is possible to save, store, and recycle the volume of runoff water for additional irrigation during a protracted dry spell.

15.5.1.1 Farm ponds

There are several ways to create these water bodies, including building embankments across waterways, digging pits, or doing both of them at once. Generally, in areas with flat terrain, the construction of dug-out ponds is recommended; in areas with undulating topography, the construction of farm ponds of the impounding type is advised. It is important to keep in mind that runoff potential determines the size of agricultural ponds (Sastry et al., 1981). It is also important to determine the maximum depth of a pond and its side slopes in accordance with the soil conditions at the site to ensure both the stability of the side walls and the retention of water in the pond over the long term (Bhumbla, 1984; Katyal, 1997). In the case of ponds with smaller catchments, spillways could be of a vegetative nature; however, when it comes to ponds with large catchments, well-designed mechanical structures must be provided. Agricultural ponds in rainfed areas are being used less widely due to the percolation losses that are associated with the use of these ponds (Bhumbla, 1984; Katyal, 1997). Different lining materials, such as bentonite, soil and cement, soil and dung mixed with the straw slurry, and plastic liners, have been used to varying degrees of success, depending on the situation at hand (Msangi & Cline, 2016).

15.5.1.2 Low earthen dams

This type of dam is often used in places where there are many streams of water available for use. A water reservoir is built by using engineering concepts across the entire waterway system in order to build a water storage facility.

15.5.1.3 Nala bunds and percolation tanks

The purpose of these buildings is to slow down runoff, amplify water percolation, and achieve a high level of soil moisture in watershed areas by building them across nalas.

15.5.2 In-situ conservation

During in situ conservation, water is preserved in its natural state where it is applied in accordance with appropriate moisture conservation measures. There are several techniques that can be used to grow crops in the off-season, such as deep ploughing, mulching, dead furrows, keyline cultivation, compartmental bunding, cover crop strips, and inter-plot water harvesting (Pathak et al., 1989). As a result of off-season tillage, weed infestations are reduced, and rainwater can more readily seep into the soil profile, which facilitates water infiltration. It is, however, discouraged in aridisols to cultivate in the offseason because it would speed up wind erosion. A deep ploughing (>22 cm) once every two to three years has been shown to increase the penetration of rainwater into the soil and to increase yields of crops grown with rainwater, especially in soils with a hardpan. In order to promote soil water conservation and lessen the activity of insects and pests after the harvest of post-rainy season crops, deep tillage should be performed immediately after harvest (Parihar & Sandhu, 1987). The purpose of mulching is to prevent moisture from escaping into the atmosphere from the soil. A vertical mulching method can be used to improve the rate of infiltration in low-permeable soils, in which sorghum stalks are planted in trenches that are 40 cm deep, 15 cm wide, and 10 cm above the ground, to improve the rate of infiltration. During the season, "dead furrows" are sown at intervals of 3–6 m in order to enhance water retention. In areas with a low level of rainfall, the inter-row water collection system is a suitable method for collecting water from light-textured soils. It may be possible to significantly enhance the yield of crops such as pearl millet by implementing this technique in conjunction with the

TABLE 15.3 Options for water management strategies with key characteristics for sustainable development.

Strategies	Characteristics
The focus should shift from "water resource development" to "water resource management"	a) A holistic approach to managing water by location and use is integrated water resource management (IWRM). b) Distribute water equitably across geographies and users in sufficient quantities to support diverse uses of water. c) Restructuring and strengthening existing institutions to enhance resource sustainability and service delivery. d) Large water resources projects must consider all environmental, ecological, and human concerns. e) The government should develop water management laws, policies, capacities, and organizations. f) Involving service providers in the overall water resources management authority will ensure sustainable local governance.
Partnership between public and private sectors	a) Due to financial constraints and managerial limitations of governments, the private sector should be encouraged to participate in water resources development. b) An explanation of the rights and responsibilities of both service providers (public and private). c) A partnership between the public and private sectors influences the mix of public and private funding for the provision of services.
Increased resource efficiency and demand management; tank rejuvenation	a) In order to transfer water from a season/region of abundance to one of scarcity, water is stored in reservoirs. b) Utilizing water resources efficiently and minimizing the need for supply-side solutions. c) Promoting conservation and minimizing waste while fostering a sense of scarcity. d) A modernization of the systems for allocating and monitoring surface and groundwater resources is needed. e) Implementing water entitlements, water pricing, accountable institutions, and effective regulations to manage water resources efficiently. f) Investing in environmental quality and shifting government focus from traditional areas (constructing and operating water supply infrastructure). g) Water conservation through tank rehabilitation and restoration. h) Providing safe drinking water for all and ensuring everyone has access to it.
Human resource development and empowering users	a) Groups of users and gram panchayats should be empowered. b) The establishment of a formal water entitlement system and clarifying that water is publicly owned and water entitlements are usufructuary, which means that they are not rights to own water but rights to use it. c) Water service schemes should be planned, implemented, operated, and managed by the local government and community. d) Improve the quality and diversity of professionals engaged in interdisciplinary teamwork in the water sector.
A governance framework for groundwater	a) A holistic approach must take into account multiple levels, multiple actors and multiple instruments. b) Depending on the nature of the problem, state participation, people participation, or even market participation may be required. c) Energizing pumps and administering their distribution and setting tariffs for their use. d) Groundwater withdrawals will be monitored and regulated by the Central Groundwater Authority.

From: Water Resources Development in India: Critical issues and strategic options (Parvathi, 2011).

recycling of captured water for additional irrigation (Parihar & Sandhu, 1987).

15.5.3 Agronomic practices

15.5.3.1 Tillage practices

The purpose of tillage is to mechanically aerate the soil in order to promote root growth and plant growth in the soil. When it comes to rainfed and dryland farming, the objective of tillage is to provide an environment conducive to seed germination and root growth, to control weed infestation, to prevent soil erosion, to retain moisture in the soil, and to minimize runoff (Abrol, 1988; Sehgal & Sharma, 1994; Singh, 1988). As a rule of thumb, in rainfed and dryland environments, the following tillage techniques are commonly used: minimal or optimal, reduced, conservation, mulch, and zero tillage. As a result of minimum, optimal, and reduced tillage systems, several objectives are achieved: (1) the minimum energy input and labor needed for crop production are reduced; (2) the seedbed is provided with the best seed quality rather than a uniform seed bed is provided; (3) soil compaction is minimized; and (4) soil moisture is conserved and erosion is reduced (Sehgal & Sharma, 1994; Sehgal et al., 1990). In both systems, crop residues often cover the soil continuously throughout the growing season. It is important to note that conservation tillage minimizes runoff and evaporative losses while altering the energy balance of the soil and reducing the variations in soil temperature caused by tidal variations. No-till or zero-tillage methods involve planting seeds without preparing the seedbed before the seeds are planted. As a result of no-tillage techniques, energy is saved, soil moisture is preserved, and crops can be planted earlier than they would otherwise be after rainy seasons. As a consequence, it also increases the possibility of weed infection of the crop, particularly in the later stages of its growth.

15.5.3.2 Water availability period in relationship to crops and cropping systems

It is commonly acknowledged that agricultural production in rainfed areas is plagued with a number of problems, such as (1) an insufficient and unpredictable water supply, which leads to moisture stress, (2) farmers' typically limited resource bases and therefore a low capacity to bear risk, and (3) low and unstable crop production. There is a variation in the availability of water in the sub-mountain areas of Punjab and Himachal Pradesh, based on the inceptisols and the soil zone corresponding to them, from 260 days to 280 days. Water availability in western Rajasthan and portions of Haryana (Aridisols zone) usually lasts between 75 days and 90 days, depending on the season. In areas with 350–600 mm of rainfall and 20 weeks of the actual growing season, it is only possible to have single cropping (100% crop intensity) in the growing season of Kharif (red and shallow black soils) and Rabi (deep black soils) where 350–600 mm of rainfall is received (Aggarwal & Khanna, 1983). The intercropping of crops is possible in areas with a growing season of 20–30 weeks. It is guaranteed that a double crop will be produced if the effective growing season lasts more than 30 weeks and if there is a precipitation total of over 750 mm/yr.

15.5.3.3 Use of mulches

The purpose of a mulch is to lower the amount of water that evaporates from the surface of the soil by applying a material to the soil's surface. There are several benefits to mulching, including boosting infiltration, regulating soil temperature, reducing the amount of evaporation, preventing weed infestations, and improving runoff management of precipitation into the soil. It has been shown that mulched soils are highly beneficial in the establishment of seedlings as there is a significant difference in moisture content between them and bare soils just below the surface of the soil. In areas where rain falls, a variety of materials can be used as mulch. Mulches made from agricultural waste materials are popular, efficient, and cost-effective when used in areas where rain falls. In rainfed areas, there have been many different kinds of mulches used with great success, including stalks from maize and pearl millet, groundnut hulls and shells, rice husk, wheat straw, soybean straw, twigs from wild shrubs, pine needles, and coir pith dust. As part of Indian agriculture, soil mulch is also considered to be of great importance. The use of soil mulch can benefit both kharif and rabi crops. When it comes to rabi crops, its primary purpose is to reduce evaporation, but in kharif crops, it assists in reducing weeds and improving the infiltration of moisture (Parihar & Sandhu, 1987). In black soils, it is extremely important to apply soil mulch in order to reduce evaporation through shrinkage cracks and the resulting loss of moisture.

15.5.3.4 Planting geometry

In order to provide overland flow resistance to crops, the shape of the crops can be effectively changed. If the plant population is at its ideal level, then the land and soil water will be able to be efficiently used by the plants. There is a possibility that high plant populations can cause significant moisture stress in rainfed areas, causing crop failures as a result of moisture stress. If it is necessary to modify or improve the practices outlined above, it will depend on the conditions of the site and the geography of the area. As a result of adopting the "watershed management" technique, the best outcomes are attainable in terms of the conservation of natural resources, their efficient utilization, increased biomass yield, and sustainability of the system (Annual Progress Report, 1993–94).

15.5.4 Significance and management of groundwater resources

The freshwater that is present in the pores of soil and rocks is called subsurface water or groundwater due to its presence in the pores of soil and rocks (Saha & Ray, 2019). There is also water movement in the aquifers under the water table that are also experiencing water movement. In relation to the 790 billion cubic meters of water, which is expected to enter the soil, an estimated 430 billion cubic meters will produce soil moisture, which is essential for the growth and development of plants. It is estimated that 360 billion cubic meters of water percolate into the porous layer of the soil as a result of subsurface water enrichment. The amount of water that can be collected on a commercial basis is only about 255 cubic billion meters. To ensure a country's overall development, sustainable groundwater management is therefore of paramount importance. Groundwater is one of the most important sources of water for agriculture and domestic use. As a unique resource, it is not only accessible in large quantities, but it also protects against droughts, and it is intimately connected to surface water sources and the hydrological cycle, as well (Saha & Ray, 2019). There is no doubt that groundwater is more desirable than other sources of water because of its steady supply, consistent quality and temperature, low turbidity and pollution, little evaporation losses, and inexpensive development costs. As a result of population growth and economic growth, the world's groundwater reserves have been under more strain than ever before, and in many countries, groundwater pumping, which has been improperly managed, and/or pollution which has been caused by inadequate water management, have already caused significant damage. As a result of these trends, especially in developing countries, there can be serious socioeconomic consequences, especially for the poor. It has been observed recently that groundwater resources have been depleted and degraded as a result of rapid population growth, urbanization, industrialization, and competition for economic development in the recent past (Datta, 2019; Kumar, 2003). In terms of quantity and quality, this important resource is managed in a way that is determined by its accessibility and usability. As a result of an imbalance between the supply and demand of the services offered by the company, management techniques are facing different ethical dilemmas. Those in charge of planning and deciding on the development and management of groundwater resources will have to deal with the inextricable links between water policy and ethical considerations in order to develop and manage groundwater resources in an effective, efficient, and sustainable manner in the future (Singh et al., 2019). Due to the fact that groundwater is a hidden resource, it is often developed without a thorough understanding of its occurrence in time and place, as it is a hidden resource. This is why it is imperative that scientific groundwater management is carried out for the long-term viability of this vital resource (Kumar & Ballabh, 2000; Madhukar et al., 2014).

15.5.4.1 Deep aquifer development

There is a lack of effective mining and development of deep aquifers in many parts of the country, resulting in a large portion of the world's accessible groundwater resources not being fully utilized. Several states, such as Haryana, Uttar Pradesh, and Punjab have been underutilizing deep aquifers at such a level that they have created almost stagnant conditions at depths and, as a result, the quality of their ground water has deteriorated rapidly (Madhukar et al., 2014; Shah, 2012). It is evident that the deeper aquifers of the alluvial soils are not fully developed in the top stages, and so the unused groundwater in small aquifers will eventually fall into the salty aquifer close to the basin's edge. In order to ensure that groundwater can be used on a long-term basis, it is essential to maintain and develop deep aquifers.

15.5.4.2 Groundwater development in underdeveloped areas

There is a general tendency for policymakers to focus on sites with great potential for groundwater development, while ignoring other areas that have untapped potential for groundwater development. There is still a lot of work to be done in the eastern and north-eastern areas of India to develop their groundwater resources. Despite the fact that there is a scarcity of water in the region, it is not surprising that small farmers find it challenging to increase their agricultural production (Kumar et al., 1999). There is a lot of potential for groundwater development in these areas, which often flood during the rainy season because of the heavy rainfall.

15.5.4.3 Floodplain aquifer development

There are a lot of groundwater sources in flood plains, so they are excellent sources of water. It is necessary to ensure that floodplain aquifers are managed efficiently in order to support the development and increased demand for water. In the Yamuna floodplain area of Delhi, an example of scientific WRM can be found in the rise of groundwater levels as a result of WRM. During the monsoon, groundwater augmentation from river flows is carried out by shallow aquifers in flood basins that have been overdeveloped. These shallow aquifers provide the necessary subsurface space for the augmented flow of groundwater. The use of induced management is considered to be an effective strategy for bridging the supply-demand imbalance in areas near rivers that have active flood plains. Due to this fact, it is essential that the floodplain aquifer's growth is accompanied by effective groundwater development and management.

15.5.4.4 Groundwater development in waterlogged areas

Floating areas in canals can be developed into groundwater resources by lowering the water table by at least 6 m, thereby offering chances for groundwater development. Canal water can be combined with poor-quality water in an amount appropriate for irrigation with canal water of a quality that is appropriate for irrigation (Singh & Singh, 2002). In this way, there may be more water available to be used for irrigation, and the area's lower water table will assist with rainwater recharge, which will lead to an improvement in the quality of the soil and water in the area.

15.5.4.5 Development of groundwater in canal commands

In order to maintain long-term groundwater management, one of the most effective methods is to use surface water in one place and recharge it with groundwater development in adjacent areas to canals (Khare et al., 2007). It would be a great way to improve the use of the existing water resources, but it would also provide a subsurface drainage system for flood-prone areas, in addition to making better use of the existing water resources (Rogers, 1994; Singh & Singh, 2002).

15.6 Assessment and planning of groundwater resources

The current method of assessing groundwater resources in India does not take into account the effect of static storage, which is crucial for drought mitigation and is one of the most important functions of the groundwater system (Kumar et al., 2005; Kumar, 2000). In order to create drought-hydrogeology, it is necessary to combine groundwater modeling with drought analysis. Depending on the nature of the state, there may be elements that need to be included in the planning process, such as drought analysis, deficit irrigation, or dynamic storage calculations. Soft models of the state variables may also need to be developed (Chatterjee & Purohit, 2009). Currently, there is no method in place for assessing the groundwater resources in India that allows for a proper outflow into the sea to prevent saltwater intrusion into the groundwater supply. It is necessary to develop model-based methods for calculating the needed outflows or resources, based on a given quantity of allowed seawater intrusion, for a given quantity of permitted seawater intrusion. In India, groundwater is a significant part of the agriculture sector. For the purpose of solving the planning challenges associated with agricultural groundwater development, it is necessary to make two modifications to the general groundwater planning methodology. It is first of all the crop regions that have to be considered, not the pumping rate, as the determining factor. The second requirement is that the defined constraints have to be able to be met over an infinitely long period of time (Jha & Sinha, 2009).

There are many enterprises that continue to release their polluted or untreated effluents into the groundwater system illegally, despite all the regulations and oversight in place. Modern numerical techniques have enabled us to detect these anomalies due to the advancement of modern numerical techniques. Currently, the most common way to estimate recharge in India is to relate it to past changes in the water table as well as other source/sink factors, and then average the coefficient of recharge (i.e., the fraction of rainfall that appears as recharge at the water table). It is expected that the fraction that has been achieved in the region will be the region's stationary attribute. In spite of the fact that this tactic has been successful over the years, considering how the environment is changing, it may no longer be appropriate in the future (Chatterjee & Ray, 2016).

As there would be no historical data to use as a basis for calculating the recharge under the expected climatic scenarios, it would be necessary to use an unsaturated flow model to calculate the recharge under each scenario. The prediction methods described in this paper will also be useful for determining the impact of land-use change, forestation/deforestation on recharge in the future. In India, unconfined aquifers are the basis for estimating groundwater resources using the Indian technique of groundwater estimation. To provide a reasonable estimate of the amount of water that can be extracted from deeper confined aquifers where they outcrop as unconfined aquifers, it is imperative to determine the recharge zones of these confined aquifers. For the identification of the recharging zones, it is necessary to develop appropriate geophysical and hydrogeological approaches (Shankar et al., 2011).

Research on these aspects may enable a more reliable estimation of groundwater resources as groundwater estimation committee norms may be more reliable if lateral outflows are taken into account, which appear as base flow in hydraulically connected drains, and if recharge estimates are correlated with saturated zone water balance studies (Chatterjee & Ray, 2016). Additionally, there have been a number of regions of the nation over the past few years where groundwater mining has become a significant issue. For these issues to be addressed effectively, it is necessary to develop innovative indigenous methods.

15.7 Participatory water management

Today, water scarcity is one of the most pressing issues facing the country (Kumar et al., 1999; Sidhu et al., 2021). There is no doubt that poor resource management is a major contributor to this problem. On one hand, we overexploit our rivers, lakes, groundwater, and other water sources, while on the other hand, we let vast quantities of water wash out into the sea and not be utilized. In order to manage the country's water scarcity, participatory water management is necessary as a means of managing the country's water scarcity. To solve this issue, the government, civic society, and local communities should all work together to find solutions in order to maintain, protect, and supplement the water resources that are available.

In regions such as Maharashtra and Gujarat, participatory water management has been used to convert dry, barren farmlands into fields that produce a variety of crops each year by converting this dry land into a variety of crops (Kumar, 1995a, b). A comprehensive approach to the management of water resources is the only way to ensure their sustainable development that covers both supply-side management and demand-side management. In order to reduce groundwater levels below the recommended level, demand-side management focuses on reducing withdrawals and improving the efficiency of water use by restricting withdrawals. An important component of supply-side management is the management of aquifer systems and the recharging of groundwater resources. As a result, community involvement is required as part of demand-side management. There is a need for the community to work together to ensure that water is collected sustainably, that crop patterns are appropriate for the region, drip/sprinkler irrigation is encouraged, as well as water budgeting (Sivanappan, 1998). The government must encourage and promote participatory management of the nation's water resources in order to ensure the long-term and sustainable development of these resources. A participatory management approach is used to manage groundwater as a resource under participatory management. Local populations control the extraction, use, and replenishment of water when this method of groundwater management is used, and they take the initiative to replenish and recharge the resource when this method is used (Kumar & Ballabh, 2000).

15.8 Concluding remarks

At the moment, India faces a number of severe challenges when it comes to managing its water resources. It is clear that we have a significant gap in our understanding of physical problems and the management solutions to those problems. There is a lack of management solutions that are both technically and economically viable, as well as socially and politically acceptable. Additionally, most government policies and programs are focused on developing rather than managing water resources. Water availability and quality, demand for water in various sectors, and the type, scope, and causes of water problems make developing sustainable water management plans difficult. In addition, the problem has been attributed to a lack of coordination between agencies in terms of data collection, processing, and retrieval, and to a lack of integration of social, economic, and environmental factors. There is also a need to address technology. There is a shortage and underutilization of technologies relating to water conservation and management. In water management, there have been no technological advancements aimed at developing solutions that are technologically feasible, commercially viable, ecologically and environmentally friendly, and socially acceptable. In the country, most water planning and development is done along administrative boundaries rather than using river basins for hydrological purposes. Water conflict has arisen within many states because most river basins are shared by multiple states, and water demands for domestic, industrial, and agricultural purposes have increased. In order to understand the variability of water resources across India, a basin-by-basin analysis is necessary. Because of fluctuations in rainfall, replenishment occurs unevenly over time. Therefore, managing water, including storing it for recharge, is even more important than simply having a large quantity of water. To manage water resources more effectively, a more localized approach is urgently needed. Thus, rural areas of India should be able to manage, allocate, and value their water resources more sustainably.

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Chapter 16

A comprehensive analysis of fluoride contamination in groundwater of rural area with special focus on India

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16.1 Introduction

Fluorine is a highly reactive element in the periodic system that belongs to the halogen group. It is abundantly available in the earth's outermost layer (Ali et al., 2016). Fluorine exists in water as negatively charged F^- ions. More than 95% of the total fluorine level in drinking water is accounted for by F^- ions. The level of F in water is determined by several factors, including fluorinated mineral solubility, aquifer anion exchange capacity, rock water interaction, retention time, and climate (Ranjan & Ranjan, 2015). Water's alkaline nature speeds up the enhancement of F^- concentration in the groundwater (Narsimha et al., 2018). Groundwater with a greater fluoride content is found in igneous and metamorphic rocks. According to estimates, fluoride danger affects 65% of India's rural population (UNICEF, 1999). Fish and tea-devouring people are more exposed to fluoride (Yadav et al., 2019). Daily ingestion of 1 mg/L of F^- is essential for the healthy growth of teeth (Yousefi et al., 2018). Fluorosis and tooth decay are two possible negative effects of fluoride doses above 1.5 mg/L. (Jannat et al., 2022; Keramati et al., 2019). Due to the fact that air temperature has a significant impact on how much water is drunk, and subsequently, how much fluoride is ingested, the USPHS (1962) created a range of acceptable fluoride concentrations in drinking water for a different location based on the climatic conditions. As a result, the highest permissible level in Indian conditions is 1.4 mg/L instead of 1.5 mg/L.

Chemical weathering, evapotranspiration, dissolution of fluoride-containing minerals, and exchange of ions are some typical processes that cause the mobilization of fluoride from rocks and sediments (Li et al., 2020, 2022). The exchange of ions and the dissolution of carbon dioxide (CO_2) from the soil, air, and carbon-containing materials cause lower calcium (Ca^{2+}) content and a higher bicarbonate ($HCO_3{}^-$) content which amplifies the dissolution of fluoride-containing minerals in the water (Brahaman et al., 2013).

$$CaF_2 + 2NaHCO_3 \rightarrow CaCO_3 + 2Na^+ + 2F^- + H_2O + CO_2$$

$$CaF_2 + Na_2CO_3 \rightarrow CaCO_3 + 2Na^+ + 2F^-$$

The pH of groundwater becomes high due to a high concentration of bicarbonates (HCO^{3-}).

$$HCO^{3-} + H_2O \rightarrow H_2CO_3 + OH^-$$

Some fluoride-bearing sediment like biotite, muscovite, and amphiboles displace hydroxide (OH^-) ions with fluoride (F^-) ions. For example, the reaction with muscovite minerals is shown below.

$$KAl_2[AlSi_3O_{10}]F_2 + 2OH^- \rightarrow KAl_2[AlSi_3O_{10}][OH^-)] + 2F^-$$

This process contributes to the increment of hydrogen ions (H^+) under the ground. These hydrogen ions steadily affect the weathering of various minerals and in return, release the positively charged species.

$$2NaAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2Na^+$$

$$CaF_2 + H_2O \leftrightarrow Ca^{2+} + 2F^-$$

Fluoride leaches out from rocks by the action of water and solubilizes in the groundwater. The solubility of fluoride depends on the type of rock as some rocks are sparingly soluble (fluorite, cryolite) while some solubilize rapidly

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(mica). A high pH value favors the fluoride ions desorption from the surface of rocks or sediments and becomes accessible to water. Therefore, exposure of fluoride-bearing rock to water provides appropriate conditions for releasing fluoride ions into the water. Water with high pH, sodium ions, and bicarbonate concentration in water was also reported to contain high fluoride (Malago et al., 2017; Mukherjee et al., 2018). In the regions of the developing world, coagulation and adsorption processes are still the most frequently used fluoride removal methods. Many nations, including India and Tanzania, have used the Nalgonda technique and adsorption by bone char, or a combination of the two, at both the domestic and community levels (Sarkar et al., 2022). There are many other techniques also which are followed in the rural area and have been compiled in this chapter.

The objective of this chapter is to compile the sources, fluoride levels, health hazards, defluorination techniques, and water management strategies in the rural area of India.

16.2 Source of fluoride contamination in groundwater

Fluoride contributes to the environment through natural and anthropogenic sources in a rural area.

16.2.1 Natural sources

Fluoride occurrence in the water is because of its high reactivity. The natural sources of fluoride in water might be geological: fluoride-containing rocks (gneissic, granitic, and volcanic rocks) and sediments. Mafic minerals like fluorite or fluorspar (CaF_2), hornblende, apatite ($Ca_5(PO_4)_3F$), cryolite and topaz. All these fluoride-bearing minerals do not dissolve in water. Therefore, it dissolves in groundwater only if favorable conditions are available for dissolution (Malago et al., 2017; Shyamal et al., 2020). Weathering and leaching of minerals from rocks is enhanced by the moving actions of water. These minerals percolate into the soil resulting in excess fluoride in the groundwater (Jain et al., 2014). Hydrothermal and volcanoes are also natural fluoride sources (Vithanage & Bhattacharya, 2015).

16.2.2 Anthropogenic sources

Excessive use of phosphatic fertilizers, pesticides, and fumigants in agricultural fields are the leading anthropogenic cause of fluoride in the water of the rural area. A fluoride concentration of almost 0.34 mg/L is supplied through fertilizers. The emission of particulate fluoride ions, i.e., aluminum fluoride (AlF_3), calcium fluoride (CaF_2), and sodium hexafluoroaluminate ($NaAlF_6$) from glass, iron, steel, and aluminum industries is attributed to high fluoride in the soil. Combusting coal in coal-based thermals and impeachment of fly ash results in damp and dusty particulate fluoride deposition. The release of chlorofluorocarbons (CFCs) from appliances like air conditioners and refrigerators also contributes to fluoride. The clay used to make bricks and ash released from brick kilns industries are reported to contain a high fluoride concentration (Mukherjee et al., 2018; Sankhla et al., 2018; Singh et al., 2018).

16.3 Distribution of fluoride in India

With a population of 1378.6 million, India is the world's seventh-largest and second-most populated country. India has 16% of the world's population, but just 4% of the world's water resources. Because surface water in India is scarce, groundwater supplies 90% of the country's water demands. This overuse of groundwater leads to geological contaminants such as fluoride (Ayoob et al., 2006). Low calcium and high bicarbonate ions are common in India (Daniel et al., 2012), and prolonged consumption of such groundwater causes health concerns. A high concentration of F^- in the groundwater of various parts of the world is liable for boundless fluorosis. In India, 18 states have been identified as having F^- concentrations in water more than the tolerable limit (Table 16.1).

There are reports that the concentration of fluoride in the granite aquifer in the Wailapally Basin of Andhra Pradesh is very high because of fluorapatite minerals and the widespread use of phosphate fertilizers in the southeast region. Fluoride levels in water increase after the monsoon due to the high evapotranspiration in the pre-monsoon season. The monsoon season causes the precipitation of fluoride-rich salt. The geological conditions and climate of Telangana and Andhra Pradesh are the same, thus the fluoride pollution (Adimalla et al., 2019). The Nalgonda region in Andhra Pradesh is known for its most intensive research on fluoride (Beg et al., 2009). Around 18 districts of Gujarat are affected by fluorosis. The northeastern part of Gujarat is covered with alluvial sediments, while the western and central regions with fluvial deposits. More than 60% of the area is covered with a Deccan trap. The occurrence of rainfall causes drainage-free dissemination of water, and the water system in endured items leaches out minerals, resulting in F^- enrichment in drinking water (Shaji et al., 2007). The high F^- level in Haryana might be credited to the penetration of modern squanders and substance manures from human sources, the breakdown of rocks, and the testimony of volcanic particles (Samantara et al., 2017). Leaching of fluoride and aridity or semi-aridity is an essential justification for the high concentration of F^- in the groundwater of Maharashtra. The central and western regions of the Orissa also suffer from groundwater F^- pollution (Sahu et al., 2021). The Indian peninsula's southernmost region is home to the people of Tamil Nadu. The state's geology is made up of rocks from the Archean and Proterozoic periods. The drinking water adjacent to the Cooum river bears a

TABLE 16.1 Distribution of F^- in drinking water of India.

S. no.	States	Location	Conc. of F^- (mg/L)	Source	Possible cause	References
1	Rajasthan	–	0.1–19.52	Groundwater	Fluoride bearing minerals, i.e., sand, clay, silt, basalt, shale, conglomerate, quartzite, limestone, granite, gneiss, schist, phyllites, dolomites, amphibolites, arenites, anorthosite and anthropogenic activities	
		Dausa	0.48–3.64			Tiwari et al. (2020)
		Eastern Barmer district	–			Coyte et al. (2019)
		Jodhpur district				
		Jaipur, Ajmer, Tonk, Dausa				
		Kota, Bundi				
2	Jammu and Kashmir	–	0.00–1.50			CGWB (2020)
3	Punjab	–	0.05–8.00			CGWB (2020)
		Bhatinda	0.32–4.05			Kumar and Singh (2015)
			0.0–4,0			Krishan et al. (2017)
		Malwa region	0.99–10.6			Sharma et al. (2016)
		Eastern and Western Malwa	0.6–5.07			Ahada and Suthar (2018)
4	Haryana	–	0.05–12.0			CGWB (2020)
5	Uttar Pradesh	–	0.00–5.90			
		Pratapgarh	0.41–3.99			Tiwari et al. (2016)
		Raebareli	0.1–8.3			Shukla and Saxena (2020)
		Agra	0.14–4.88			Ali et al. (2016a)
		Unnao	0.06–1.83			Ansari and Umar (2019)
6	Gujarat	–	0.0–10.1			CGWB (2020)
		Patan	0.39–4.75			
		Mandwi taluka, Surat	0.17–4.17			Prajapati et al. (2017)
		Ambaji, Banskantha	0.31–2.3			Pradhan et al. (2018)
7	Madhya Pradesh	–	0.00–4.00			CGWB (2020)
8	Bihar	–	0.00–4.00			Ranjan et al. (2019)
		Bhagalpur	1.93–2.98			Gouri and Choudhary (2017)
		Amas, Gaya district	0.2–5.0			Krishan and Mishra (2020)
9	Jharkhand	–	0.00–2.35			CGWB (2020)
		Gharbar village	0.01–18.55			Thapa et al. (2019)
		Ranchi city	0.0–2.19			Tirkey et al. (2017)
		Bokaro district	0.24–1.89			Singh et al. (2018a)
10	West Bengal	–	0.72–6.10			CGWB (2020)
		Birbum district	0.23–19.0			Batabyal. (2017)
		Simlapal, Bankura district	0.1–12.2			Mondal and kumar (2017)
11	Orissa	–	0.02–3.94			CGWB (2020)
		–	1.0–4.0			Sahu et al. (2021)
12	Maharashtra	–	0.00–3.46			CGWB (2020)
13	Andhra Pradesh	–	0.04–4.61			CGWB (2020)
		Guntur	1.3–12.9			Rao et al. (2020)
		Coastal region	0.6–1.8			Rao et al. (2015)
14	Karnataka	–	0.02–6.90			CGWB (2020)
		Indi taluk (Vijayapura district)	0.26–3.53			Ugran et al. (2016)
		Yadgir	0.21–4.8			Kumara et al. (2020)
15	Tamil Nadu	–	0.10–2.56			CGWB (2020)
		Tuticorin	0.45–3.30			Chidambaram et al. (2018)
		Dharmapuri	0.15–6.14			Jagadeshan et al. (2015)
16	Kerala	Chittur (Palakkad)	0.05–6.30			Shaji et al. (2007)

(*continued on next page*)

TABLE 16.1 Distribution of F^- in drinking water of India—cont'd

S. no.	States	Location	Conc. of F^-(mg/L)	Source	Possible cause	References
17	Assam	–	1.03–4.70			CGWB (2020)
18	Arunachal Pradesh		0.04–4.61			
19	Tripura		0.03–2.30			
20	Telangana	–	0.11–4.16			CGWB (2020)
		Pre-monsoon	0.4–2.2			Narsimha and Rajitha (2018)
		Post-monsoon	0.8–4.2			
21	Chhattisgarh	–	1.0–3.19			CGWB (2020)
22	Uttarakhand	–	0.00–4.42			CGWB (2020)

very high amount of fluoride. Low precipitation combined with a high evaporation rate in a semi-arid climate causes groundwater to become salinized, causing calcite to precipitate and fluoride to dissolve (Chidambaramet al., 2014). The Fluoride enrichment in Punjab is due to the use of phosphatic fertilizer in agricultural fields. Rajasthan is the only state where high F^- levels influence every district. 26 districts are highly contaminated by fluoride.

The arid climate and lack of fresh water in the Paddandadka basin in the Bellary region of Karnataka resulted in exacerbated fluoride pollution. The western part of West Bengal is highly influenced by fluoride (Mondal et al., 2016; Mukherjee et al., 2018). Assam and Tripura are moderately affected by F^-. Fluoride has long been a problem in the Ganges and Brahmaputra rivers floodplains (Alcaine et al., 2020).

Rajasthan is India's driest state. The state's eastern, southern, and middle portions are located within the Plateau of Peninsular, while the northern and western portions are under north India. 11 million population in Rajasthan are impacted by a high level of fluoride in groundwater, and about 26 districts are at danger of fluorosis (Ali et al., 2016a) (Table 16.2). There is a lack of surface water due to deficient rainfall, Rajasthan supports 15 rivers only two of which are perennials, i.e., Chambal and Mahi. Due to a lack of sufficient surface water, groundwater is regularly used for drinking and other common uses.

The state is categorized into three hydrogeological units: unconsolidated sediments, semi-consolidated sediments, and consolidated rocks (Rai, 2020). The Bhilwara supergroup, Delhi supergroup, Aravalli supergroup, Deccan trap, Marwar supergroup, Fatehgarh, and Jaisalmer formation make up the state's geology. The Delhi supergroup is composed of quartzite, mica schist, and gneiss and is strongly folded with metamorphosed rocks. Basalt and rhyolite form the Marwar supergroup, which is coated in sandstone and limestone. Additionally found here are slate, phyllite, dolomite, schist, and carbonate rocks. Numerous different types of minerals, including feldspar, apatite, mica, fluorite, clay, and vermiculite are found in the state. The breakdown of granitic rocks, which contain several fluoride-bearing minerals, is the primary source of fluoride pollution in groundwater.

Weathering by the action of the chemical under parched conditions with comparatively immense basicity favors the high F^- in water, which has caused tooth and bone fluorosis in the state (Vikas, 2009).

After Rajasthan, Haryana is a highly F^- contaminated state. In India, Haryana is a state with high fluoride concentrations ranging from <0.05–12.0 mg/L (Table 16.3). The geology of Haryana is divided into Quaternary, proterozoic, pre-tertiary, and tertiary. 98% of the region of the state is covered with alluvium comprised by Quaternary. Siwalik in the tertiary group includes boulders, sand, and clay. Aravalli hills involve a significant part of rocks of the pre-Cambrian age, northern and southern districts are exposed to it. The three physiographic units reported are Indo-Gangetic, peninsula, and extra-peninsula. Alluvium deposits of the Quaternary age underlie a significant part of Haryana. The thickness of these deposits decreases towards Gurugram, Bhiwani, Mahendergarh, and Faridabad. More than 1.5 mg/L fluoride is detected in areas where agricultural-based activities dominate due to the use of phosphatic fertilizers (Gahlot et al., 2020).

16.4 Health risk assessment

Fluoride plays an essential role in our life. Daily ingestion of 1 mg/L of fluoride is beneficial for healthy body functioning, but its excess has a detrimental effect. The occurrence of F^- in water does not produce any color, smell, or flavor, and it acts as an imperceptible poison in the water. Fluoride is a potent calcium-pursuing element, and at higher concentrations, it affects the calcified structure like bones (skeletal fluorosis) and teeth (dental fluorosis) in humans and animals (Jain et al., 2014; Singh et al., 2018). It also affects the body's soft tissues (non-skeletal fluorosis) (Yadav et al., 2019). The United States Environmental Protection Agency (US EPA) proposes the health risk assessment model, the most

TABLE 16.2 Distribution of F^- in drinking water of Rajasthan.

S. no.	Districts	Provinces	Conc. of fluoride (mg/L)	Source	Possible cause	References
1	Ajmer	–	0.07–5.14	Ground water	Fluoride bearing minerals, i.e., Alluvium, blown sand, sandstone, bentonitic clay, basalt, limestone, clay, lignite, shale, dolomite, conglomerate, quartzite, schist, gneiss, marble, shale, slate, phyllite, meta volcanics, migmatites, granite gneiss and anthropogenic activities.	CGWB (2020)
		Kishangarh	0.30–10.80			Panwar et al. (2015)
2	Alwar	–	0.11–2.05			CGWB (2019–20)
			0.1–13.3			Agrawal and Sharma (2015)
3	Banswara	–	0.27–5.00			CGWB (2020)
4	Baran	Baran tehsil	0.67–4.32			Kumar and Rakshit (2014)
		Mangrol	0.82–5.8			
		Shahabad	0.51–9.89			
		Saheriya basti	0.36–4.10			
5	Barmer	–	0.01–4.50			CGWB (2020)
			0.6–20.1			Singh (2017)
6	Bharatpur	–	0.32–5.50			CGWB (2020)
7	Bhilwara	–	0.00–4.99			CGWB (2020)
			0.2–5.8			Hussain and Arif (2013)
8	Bikaner	–	0.35–9.24			CGWB (2020)
		Kolayat	0.2–4.12			Kumar et al. (2015)
9	Churu		0.02–2.95			
10	Dausa	–	0.40–3.10			
			0.48–3.64			Tiwari et al. (2020)
11	Dholpur	–	0.21–2.50			CGWB (2020)
12	Dungarpur	–	0.37–3.15			CGWB (2020)
13	Ganganagar	–	0.22–7.80			
14	Hanumangarh	–	0.10–5.40			
15	Jaipur	–	0.12–19.52			
		Sanganer	0.2–3.5			Anurika et al. (2015)
		Bassi	0.03–12.5			Saxena et al. (2018)
16	Jaisalmer	–	0.00–5.50			CGWB (2020)
17	Jalore	–	0.01–3.70			CGWB (2020)
18	Jhunjhunu	–	0.09–2.85			
			0.1–6.7			Malsaria and Saxena (2017)
19	Jodhpur	–	0.13–18.00			CGWB (2020)
			0.6–10.2			Mathur et al. (2010)
20	Karauli	–	0.31–3.10			CGWB (2020)
21	Nagaur	–	0.01–16.80			
			0.4–8.6			Arif et al. (2015)
22	Pali	–	0.74–8.20			CGWB (2020)
			1.45–15.70			Tanwar et al. (2018)
23	Pratapgarh	–	0.05–4.75			CGWB (2020)
24	Rajasmand	–	0.08–5.00			
25	Sawai Madhopur	–	0.36–3.50			
26	Sirohi	–	0.04–2.35			
			0.5–13.0			Chouhan (2016)
27	Udaipur	–	0.12–3.20			CGWB (2020)

TABLE 16.3 Distribution of F^- in drinking water of Haryana.

S. no.	Districts	Locality	Conc. of fluoride (mg/L)	Source	Possible cause	References
1	Bhiwani	–	0.14–5.71	Ground water	Fluoride bearing minerals, i.e., sand, silt, siltclay, clay, calcrete, limestone, gypsum, pegmatite, quartz veins and granites	CGWB (2020)
		Tosham	0.0–1.9			Kumari et al. (2020)
2	Fatehabad		0.31–2.23			
3	Hisar		0.19–3.80			
			0.5–2.98			Sunil and Sanjay (2017)
4	Jhajjar		<0.14–9.90			CGWB (2020)
			0.3–9.3			Gupta and Misra (2018)
5	Jind		0.08–12.00			CGWB (2020)
		Safidon	0.11–2.93			Sultan et al. (2012)
		Julana				
6	Kaithal	–	<0.05–2.75			CGWB (2020)
7	Mahendragarh	Sihma	0.9–6.0			
		Kanina	0.4–2.5			
		Ateli	0.9–16.0			
8	Panipat		0.20–6.50			
			0.5–5.95			Kaur and Rishi (2018)
9	Rewari		0.24–2.60			Singh et al. (2018b)
10	Rohtak		0.19–10.00			CGWB (2020)
11	Sirsa		0.19–6.50			
12	Sonipat		0.09–2.90			

convenient arithmetic procedure to understand the impacts on people (Adimalla, 2019a, 2020). The health risk assessment is generally explained in articulations of non-cancer-causing hazards based on assessing the hazard level for fluoride exposure (Chen et al., 2017a). Pathways in intake and skin exposure to harmful components are generally essential to evaluate health hazards. However, the effect of the skin exposure pathway is negligible in the case of fluoride (Chen et al., 2017b). Subsequently, ingesting water is considered the primary way of exposure by which an enormous amount of fluoride goes into the human body. Chronic intake can be computed using the following equation (Adimalla & Qian, 2020):

$$C_I = \frac{C_F \times I_R \times E_D \times F_E}{B_W \times A_T}$$

where, C_I = chronic daily intake of groundwater (mg/kg/day);

C_F = concentration of fluoride in groundwater (mg/L);
I_R = ingestion rate of groundwater (L/day);
E_D = duration of exposure (years);
F_E = frequency of exposure (days/year);
B_W = average weight of the body (kg); and
A_T = average exposure time in a year (days).

hazard quotient (HQ) can be calculated using the following equation:

$$HQ_{\text{fluoride}} = C_I/R_D$$

HQ_{fluoride} = hazard quotient,
R_D = reference dose of fluoride.

16.5 Water defluoridation techniques in rural area

As higher fluorinated drinking water can affect the health of humans and animals, various methods have been proposed and used to purify water from fluoride, especially in rural areas where there are no other drinking water sources (Kazi et al., 2018).

16.5.1 Alum

Alum's ability to defluoridate water is well known and has been practiced in rural areas for a long time. People of Rajasthan are using it very frequently due to the high fluoride contamination of groundwater. Despite being commonly employed in water treatment, the chemistry of fluoride removal by alum is quite complex. Alkalinity, pH, coexisting anions, and other solution properties all affect how effectively a fixed amount of alum removes fluoride

(Ayoob et al., 2008). Fluoride levels beyond 10 mg/L in water necessitate larger alum dosages, which can leave treated water with unwanted levels of sulfate and aluminum. Alum coagulation results in high aluminum residuals of 0.37 mg/L at a pH of 9.8. However, lowering the pH considerably reduces the amount of aluminum that is left.

16.5.2 Nalgonda technique

Condensation and subsequent precipitation remove excess fluoride in drinking water. The Nalgonda technique is a well-known coagulation and precipitation process. It was originally utilized in the Andhra Pradesh district of Nalgonda, where it was developed by the CSIR-National Environmental Engineering Research Institute, Pune, to defluoridate drinking water at the community level (Waghmare & Arfin, 2015). It comprises several components, such as mixing aluminum salt and lime, flocculation, sedimentation, filtration, and bleaching powder disinfection. The precipitate settles more quickly with sodium aluminate or lime, and bleaching powder guarantees disinfection. Lime is preferred because it is more affordable than aluminates and has a dose of only 1/20th to 1/25th of filter alum. For disinfection, raw water is treated by adding 3 mg/L of bleaching powder. Coagulation with alum is used in the procedure in an alkaline aqueous environment. pH range for best Fluoride removal efficiency is obtained in the range of 5.5–7.5. The benefits of this method are readily available chemical, economical, palatable, and straightforward in design and handling, and removal of additional water contaminants such as turbidity, bacteria, color, and odor. However, if total dissolved solids (TDS) is greater than 1500 mg/L, desalination will be required. It requires precipitation to soften when hardness is between 200 mg/L and 600 mg/L, and also produces sludge (Singh et al., 2018), which is the drawback of this method.

16.5.3 Solar distillation

Water is converted into steam by the physical process of distillation, and the steam is subsequently condensed back into liquid water. India has a sufficient amount of sunlight for this process, so this method is a preferable method for defluoridation in the rural area of India. Contaminated water is kept in a clear container and then exposed to direct sunshine. A corrugated iron roof is often used to boost this technique's efficiency by placing the container on it. The leftover brackish water contains dissolved salts. The procedure is straightforward, clean, and effective, but the wastewater produced must be evacuated to prevent vessel encrustation and be disposed of carefully due to its high salinity. Solar distillation is the most practical method for avoiding high power expenses in rural areas since it uses the sun's abundant radiation. This purification method is simple, reliable, and effective for rural areas (Antwi et al., 2011).

16.5.4 Soil and clay

Soils and clays have a high potential in water defluoridation. The availability of these in natural abundance and their high absorption capacity makes them the most friendly technique in rural areas for removing fluoride from water. The known adsorption capabilities, availability, and desirable physicochemical qualities of soil determine its suitability as an adsorbent for defluoridating water. Soils are among the most extensively researched matrices for water defluoridation. Research is being done on the prospect of using clay- and soil-based defluoridation techniques in many fluoride-endemic areas, notably in developing countries. According to Bower and Hatcher (1967), the first in-depth investigation on the removal of fluoride from water using minerals and soils, excess fluoride in water might be reduced to various levels by employing various types of soils and minerals (Bower & Hatcher, 1967).

16.6 Rural water management

Implementing community health risk assessments and management programs, monitoring high water fluoride levels, looking for safer water sources, creating water defluoridation strategies, conducting behavior change and F awareness campaigns, and creating water policies and legislation for F mitigation are some of the management strategies which should be applied in the rural area. Besides these, people in a rural area should be trained in local, cost-effective and less laborious defluoridation techniques. The pregnant mother should e advised to take Vitamin C and calcium during pregnancy and lactation thorough dietary sources so that the fetus does not develop any fluoride-related issues (Susheela, 2002).

During the 11th Five Year Plan, the Indian government launched the National Programme for Prevention and Control of Fluorosis (NPPCF), a fresh health program that was started in 2008–09 and gradually expanded. During the 11th plan, the initiative was implemented in 100 districts throughout 17 states, and during the 12th plan, 95 further districts were gradually covered. The program has been brought under the National Health Mission's NCD flexi-pool in the 12th plan. The program consists of training at various levels, health education and publicity, assistance to the states for strengthening manpower in endemic districts, the purchase of lab equipment, including an ion meter, treatment, including reconstructive surgery, and rehabilitation to benefit the residents of the affected districts.

16.7 Conclusion

Fluoride in groundwater above the permissible limit of 1.5 mg/L has become endemic in more than 25 countries, 17 states of India, 26 districts of Rajasthan, and 11 districts of Haryana. More than half of the population residing in the rural area of India is suffering from fluoride problems. The physiological state of rocks, such as decomposition, dissociation, and dissolution of rocks over a long period, contributes to F^- contamination. High concentrations of F^- are often developed in groundwater with long residence times in aquifers. In rural areas, artificially excessive F^- occurs due to fertilizer, sewage sludge, and pesticides. Excess fluoride causes dental, skeletal, and non-skeletal health impacts. Recently, there has been a paradigm shift in how Indians view community-based water supply treatment systems, with many now favoring domestic defluoridation units (DDUs), particularly those that use activated alumina. However, the majority of people in fluoride-prone rural areas cannot afford these DDUs. Reverse osmosis, electrocoagulation, electrodialysis, and nanofiltration are additional methods that ensure high-quality water, but they are "high technology and high cost" alternatives for the majority of developing nations where fluoride contamination is a problem. Local water defluoridation techniques like the use of alum, solar distillation, Nalgonda technique, soil and clay are the best solution to purify the water. Governments and non-governmental organizations (NGOs) should take the initiative to spread awareness about fluoride contamination and train people in local purification techniques. Farmers should also be encouraged to use organic fertilizers as chemical fertilizers are the main anthropogenic source of fluoride in water in a rural area. Besides this, other rural water management strategies should also be followed to minimize the effect of fluoride in drinking water.

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Chapter 17

Prevalence of Uranium in groundwater of rural and urban regions of India

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17.1 Introduction

Groundwater resources are under tremendous stress in the Indian subcontinent as a result of urbanization and the green revolution (Pant et al., 2019). In many regions of the world, drinkable groundwater quality has now emerged as a major issue in addition to water scarcity. India, a nation with a significant agricultural economy, requires a lot of water for irrigation. India is becoming more and more dependent on groundwater as a result of the country's limited water resources. Groundwater supplies around 90% of the rural population and nearly 50% of the urban populace (Kaur et al., 2019; Tanwer et al., 2022b). According to earlier research, between 50% and 80% of irrigation is carried out utilizing groundwater (Tanwer et al., 2022a). In several areas of the nation, particularly in the northwest Indian states of Punjab, Haryana, and Rajasthan, intense abstraction has resulted in substantial groundwater table decreases (Dalin et al., 2017; Rodell et al., 2009). Heavy metal pollution in groundwater and water quality degradation are critical issues, especially in arid and semi-arid regions having limited water resources (Coyte et al., 2018). There is a real threat to the usage of groundwater resources sustainably as a source of clean drinking water in the near future because of the depletion and pollution of groundwater that is already occurring in many parts of the world, including India (Tanwer et al., 2023a, 2023b). While some cations found in natural water samples, such as copper, iron, selenium, and zinc, may be advantageous to living beings, others, such as lead, mercury, arsenic, and uranium, as well as rare elements and elements of platinum group (PGE), are harmful to human beings (Balaram et al., 2022a). Numerous studies have connected drinking water uranium (U) exposure to lung cancer, chronic renal disease, and other health issues (Zamora et al., 1998). Due to the implementation of remediation techniques to prevent uranium contamination in water sources, millions of people in India and other nations will benefit from access to clean drinking water. In addition to uranium contamination, fluoride, and arsenic contamination are two issues with India's water quality (Jha & Tripathi, 2021).

Uranium pollution in the aquatic environment is becoming a global concern (Balaram et al., 2022a). Various studies in India and throughout the world reported that uranium contamination exceeds the permissible limit of 30 ppb recommended by the World Health Organization (WHO) (Daniel et al., 2022; Das et al., 2020; Duggal et al., 2021a, 2021b; Gandhi et al., 2022; Haakonde et al., 2020; Jones et al., 2020; Kumar et al., 2021; Nizam et al., 2022; Pandit et al., 2022; Pant et al., 2019; Patni et al., 2020; Prakash et al., 2020; Somboon et al., 2019; Tanwer et al., 2022a, 2023c). Because of industrialization, agricultural activities, and overuse of groundwater supplies, uranium contamination has been progressively rising in recent years as the world economy has grown. The intricacy of uranium in the environment makes it crucial to comprehend the possible effects on both human health and the ecosystem.

Uranium is a potentially hazardous element found in rocks such as granites and other mineral formations and soils. The typical concentration of natural uranium in the earth's crust is around 3 ppm and 3 ppb in seawater. It consists of three isotopes: ^{238}U, ^{235}U, and ^{234}U. These isotopes decay by emitting alpha, beta and gamma rays. Natural uranium is mostly ^{238}U, which accounts for 99.284%, along with 0.711% ^{235}U and 0.0055% ^{234}U. Although ^{238}U

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is the most prevalent isotope, ^{234}U and ^{235}U are equally important due to their greater specific activity (Tanwer et al., 2022b; Waseem et al., 2015). To estimate the dosage that the typical person will absorb through this pathway, it is crucial to analyze the uranium content of drinking water. Though Uranium occurs in various oxidation states but the most prevalent and water-soluble state of uranium is hexavalent i.e. uranyl ion (UO_2^{2+}). Uranium is found in the tetravalent oxidation state in anoxic water, which has a low oxidation-reduction potential (ORP) value and is more likely to precipitate and become stationary (Daniel et al., 2022). Furthermore, uranium solubility in underground water is affected by a variety of elements such as aquifer rocks, CO_2 partial pressure, dissolved oxygen, complex agents such as phosphates and bicarbonates, and so on (Chahal et al., 2019). The pH, temperature, amount of dissolved ions, contact duration, and flow rate of water all influence its solubility in groundwater (Sahoo et al., 2021). The concentration of uranium in groundwater vary seasonally due to various factors reported in the previous investigation (Sharma et al., 2021; Tanwer et al., 2022a). The potential risk of uranium exposure to the general population is determined by several factors, including the amount of uranium in the drinkable water, the rate of intake, the longevity of ingestion, and the person's overall health (Tanwer et al., 2023c). It is toxic in both chemical and radiological forms, harming the liver and the kidneys in the human body (Bhardwaj et al., 2020). The three most prevalent naturally occurring, harmful groundwater contaminants are uranium, arsenic, and chromium. In addition to being a poisonous heavy metal, it also has a radioactive nature that, when taken in large quantities, can induce various adverse health effects, such as renal failure, decreased bone development, and DNA damage (Brugge & Buchner, 2011). However, while being radioactive, uranium's chemical properties are more hazardous to human health. When consumed at higher doses through drinking water, uranium's chemical toxicity represents a more significant threat to health than its radiotoxicity (Zamora et al., 1998). Drinking water accounts for around 85% of total uranium absorbed, whereas food accounts for roughly 15% (Mittal et al., 2017). Uranium concentration in different matrics of environment can vary up to a great extent as shown in Table 17.1.

Prior research on uranium contamination in India's groundwater resources has been focused on a small number of states or restricted geographical regions. However, in this chapter, an effort is made to present a detailed overview of various aspects of uranium contamination in groundwater, including distribution, potential sources, and health impacts, and also provides a summary of the remediation technologies that are currently in use to remove uranium from water for both domestic and municipality water supply.

TABLE 17.1 The concentration of uranium in a different component of the environment.

S. no.	Uranium in different matrix	Concentration (mg/kg)
1	High-quality ores	20×10^3
2	Low-quality ores	1×10^3
3	Granitic rocks	4
4	Volcanic rocks	20–200
5	Sedimentary rocks	2
6	Crustal composition of earth	2.8
7	Sea water	0.003
8	Mean groundwater	>0.001–0.008

17.2 Prevalence of uranium

Both developing as well as developed nations primarily rely on ground and surface water to supply their demands for drinking water, irrigation, and other essentials. It is among the most priceless and necessary resources that are available to living beings. Uranium contamination of water has been verified in several research investigations and has been observed in different amounts in India and all around the world.

17.3 Contamination of uranium in various places in India

Groundwater contaminated with uranium covers a large portion of the drinking water in several arid and semi-arid parts of the northwestern states. People living in rural areas, many of which lack municipal supply facilities and are heavily dependent on groundwater sources, may be at serious risk for health problems. Surface and groundwater samples have average uranium concentrations of 0.8 ppb (may be ranged: 0.2–22 ppb) and 2.1 ppb (may be ranged: 0.2–4918 ppb), respectively, in a recent assessment map of the uranium content in drinking water sources across India (Sahoo et al., 2021). According to that article, uranium concentrations in the groundwater were reported to be between 0.02 ppb and 685 ppb, 2.4 ppb and 1443 ppb, and 217 ppb and 4500 ppb in Panjab, Karnataka, and Madhya Pradesh, respectively. According to another investigation in North India, uranium levels in one-fourth of the 324 wells examined in the states of Rajasthan and Gujarat exceeded the WHO limit (Coyte et al., 2018). Researchers from various groups have found extremely high uranium concentrations in groundwater samples (0.5–579 ppb) in the Punjab, Rajasthan, Haryana, and Himachal Pradesh (Duggal et al., 2017; Mittal et al., 2017; Rani et al., 2013). A new study from the Central Groundwater Board of the Indian government makes it clear that 151 districts in India have groundwater that is uranium-contaminated, i.e., uranium concentration is higher than 30 ppb as prescribed by WHO (CGWB, 2020). A comprehensive study of uranium distribution from Haryana by Tanwer et al. (2022a) reported that the average levels of uranium in groundwater were found to be lower in Fatehabad, Jind, Rohtak, Mahendargarh, Gurgaon and Sohna, and Rewari than the WHO-recommended limit, but it was higher in Hisar, Sonipat, Panipat, Sirsa, Jhajjar, and Bhiwani districts (Tanwer et al., 2022b). A recent study from Haryana reported that 11% of samples were found contaminated with uranium higher than the prescribed limit of WHO (Tanwer et al., 2022a). The detailed distribution of uranium in groundwater is given in Table 17.2. Considering that the rocks of Haryana and Punjab are composed of acid volcanic rocks with high uranium contents and granites, the high uranium concentrations therein appear to be geogenic. The probability of elevated uranium in these areas may result from the regional geology, which is further influenced by the Aravali hills in southwest Haryana. Other water quality issues, such as excessive dissolved solids, salinity, fluoride, and nitrate, rendered a large portion of the high-uranium groundwater unfit for human consumption. The two largest coal-fired power plants in Punjab's Malwa district produce fly ash with significant quantities of uranium. Additionally, excessive groundwater use may have exacerbated the issue in some areas. According to Patnaik et al. (2016), there has been a considerable mobilization of uranium from the Himalayan Siwaliks to the Malwa region, which is situated in the northwest of Punjab. This mobilization is thought to be the cause of uranium toxicity in Punjab. Additionally, according to Srivastava et al. (2017), the increased uranium contamination in the Malwa of Punjab state, which is also known for having a greater-than-average prevalence of cancer, is likely caused by geogenic mobilization. Specifically, in the Siwan, Gopalganj, Patna, Saran, Nalanda, and Nawada districts of Bihar, uranium concentrations are significantly increased along an NW–SE zone that goes along and to the eastern half of the Gandak River and the southern section of the Ganga River towards Jharkhand. Other affected states include Uttar Pradesh, Telangana, and Karnataka (Babu et al., 2008; Prakash et al., 2020; Raghavendra et al., 2014). In reality, some states have reported rising uranium levels in drinking water, indicating that uranium contamination of groundwater is on the rise nationwide (CGWB, 2020).

17.4 Uranium contamination throughout the world

In several limited geographical regions around the world, groundwater has been found to have higher than average levels of naturally occurring uranium. Extremely high uranium concentrations have been discovered in water samples taken from residential communities' private wells in a variety of different countries across the world (Germany, Greece, United States, Finland, Australia, Canada, etc.). Most of these countries use borewells to provide drinking water in sparsely populated rural areas where it is frequently difficult to establish local water delivery networks because of considerable distances. For instance, over 200,000 people in Finland or roughly 4% of the total population, regularly obtain their drinking water from privately drilled wells (Vesterbacka et al., 2005). The research on widespread hydrological traits and human behaviors in Southeast Asian countries, such as China, India, Bangladesh, and Pakistan, with background conditions like granite-rich geological formation, extensive use of phosphate fertilizers in agricultural practice, disposal and discharging of industrial waste into river systems, neutral to alkaline pH, and deficient iron concentrations indicating toxic environment, there are high uranium concentrations in several regions (Ali et al., 2019). The estimated average dosage, determining hazard quotient, and the prevalence of cancer in Pakistan are only a few instances of the human health risk assessment indicators demonstrating the severity of the health concerns connected to drinking groundwater that contains more uranium than the acceptable limit. Additionally, there is significant uranium poisoning in India's Punjab and Rajasthan regions, which are connected geologically to the middle and eastern Sindh and Punjab districts of Pakistan (Table 17.3). Such circumstances are common, and major populations are facing possible health issues as a result of high levels of uranium contaminants in drinking water supplies even in highly developed nations like the United States (Redvers et al., 2021). Uranium pollution affects several locations, comprising the high plains areas and central valley aquifers, that provide approximately 6 million people with drinking water (Nolan & Weber, 2015). In some regions in northern New Mexico, for instance, more than 50% of the wells have uranium levels in groundwater over the United States Environmental Protection Agency's (USEPA) recommended limit of 20 ppb (Table 17.4), with a maximum value of 1200 ppb (Hakonson-Hayes et al., 2002). More than 500 inactive uranium mines are located on tribal grounds in states like Arizona, New Mexico, and Utah, which complicates the matter further (Harmon et al., 2018). A typical American takes between 0.9 μg and 1.5 μg of uranium per day through drinking water, according to an estimate. Even at this amount of uranium consumption, some areas of the United States that relied on poisoned groundwater may greatly exceed it (Redvers et al., 2021). However, extraordinarily high concentrations (such as 1250 ppb and 1920 ppb) were discovered in surface waters in selected regions of Kazakhstan and Kyrgyzstan, which are a result of uranium dissolving from the source rocks (Uralbekov et al., 2011). 160 of the 4140 wells in South Korea—most of which were in the plutonic bedrock regions exceed the WHO standard of 30 ppb. 24 rural wells are under use as a drinking water source out of the total. According to the statistics, groundwater contained uranium

TABLE 17.2 Distribution of uranium in groundwater of India.

Location/states	Sources	Ranges (mean) (ppb)	References
Haryana	Groundwater	0.1–290	Tanwer et al. (2022b)
Bhiwani and Charkhi Dadri/Haryana	Groundwater	1–300	CGWB (2020)
Nadia/West Bengal	Groundwater	0.21–20.9	Das et al. (2020)
Bankura/West Bengal	Groundwater	0.5–5.0	Dwivedi et al. (2010b)
Malda/West Bengal	Groundwater	34.26	Balaram et al. (2022)
Garhwal/Uttarakhand	Groundwater	0.02–63.27	Ramola et al. (1988)
Tehri Garhwal/Uttarakhand	Groundwater	1.08–35.83	Prasad et al. (2020)
Pitthoragarh/Uttarakhand	Surface water	0.10–9.96	Patni et al. (2020)
Bageshwar/Uttarakhand	Groundwater	0.1–28.4	Kumari et al. (2021)
Dehradun Haridwar/Uttarakhand	Groundwater	0.03–19.19	Rohit et al. (2018)
Gorakhpur/Uttar Pradesh	Groundwater	0.21–21.60	Balaram et al. (2022)
Gunnaur/Uttar Pradesh	Groundwater	0.01–51.5	Pandey et al. (2021)
Fatehpur/Uttar Pradesh	Groundwater	4–40	Prakash et al. (2020)
Tehsil/Uttar Pradesh	Groundwater	0.11–39.76	Shashi et al. (2020)
Bijnor/Uttar Pradesh	Groundwater	14.52–82.74	Mehra et al. (2019
Uttar Pradesh	Groundwater	BDL—189	CGWB (2020)
Tiruvannamalai/Tamil Nadu	Groundwater	0.2–25.8	Ganesh et al. (2021)
Central parts of Tamil Nadu	Groundwater	0.4–70.9	Adithya et al. (2020)
Kanniyakumari/Tamil Nadu	Groundwater	0.2–14.9	Raja et al. (2021)
Salem district/Tamil Nadu	Groundwater	0.01–385	Muthamilselvan et al. (2020)
Kudankulam/Tamil Nadu	Groundwater	0.2–6.6	Selvi et al. (2016)
Raigad/Maharashtra	Groundwater	0.2–2.6	Koliyar et al. (2021)
Aurangabad/Maharashtra	Groundwater	0.012–16.67	Kale et al. (2018)
Beed/Maharashtra	Groundwater	0.03–32.85	Kale et al. (2020)
Ganganagar, Churu/Rajasthan	Groundwater	2.5–171	Duggal and Sharma (2017)
Dauga and Jaipur/Rajasthan	Groundwater	5–145	Pant et al. (2019)
Jodhpur, Jaipur, and Ajmer/Rajasthan	Groundwater	1.1–30	Coyte et al. (2018)
Jhunjhunu, Bikaner, and Nagaur/Rajasthan	Groundwater	0.89–166	Mittal et al. (2017)
Ernakulum and Idukky/Kerala	Groundwater	0.132–2.542	Prabhu et al. (2008)
South Coast/Kerala	Groundwater	0.82–7.32	Jose et al. (2011)
Trivandrum and Allappy/Kerala	Groundwater	0.31–4.92	Ben Byju et al. (2012)
Across Kerela	Groundwater	0.1–1.45	CGWB (2020)
Bengaluru/Karnataka	Groundwater	0.13–2027.5	Mathews et al. (2015)
Yadgiri/Karnataka	Groundwater	BDL—320	Manoj et al. (2017)
Kolar/Karnataka	Groundwater	0.3–1442.9	Babu et al. (2008)
Bangalore/Karnataka	Groundwater	0.2–770.1	Nagaiah et al. (2013)
Bemetara/Chhattisgarh	Groundwater	1.15–96.08	Sahu et al. (2020)
Bijapur/Chhattisgarh	Groundwater	0.2–10.4	Kashyap et al. (2020)
Rajnandgaon/Chhattisgarh	Groundwater	0.5–99.0	Diwan et al. (2019)
Balod/Chhattisgarh	Groundwater	0.56–78.93	Kumar et al. (2018)
Jammu/Jammu and Kashmir	Groundwater	0.18–20.81	Ajay et al. (2016)
Jammu and Kashmir	Groundwater	BDL—23.7	CGWB (2020)

(*continued on next page*)

TABLE 17.2 Distribution of uranium in groundwater of India—cont'd

Location/states	Sources	Ranges (mean) (ppb)	References
Nalbari/Assam	Groundwater	0.3–10.3	Saikia et al. (2021)
All 38 districts/Bihar	Groundwater	0.92–80.5	Richards et al. (2020)
Patna/Bihar	Groundwater	0.10–14.45	Kumar et al. (2018)
Bihar	Groundwater	2–57	CGWB (2020)
Himachal Pradesh	Groundwater	0.26–33.14	Rani et al. (2013)
Kulu/Himachal Pradesh	Groundwater	0.3–2.5	Rohit et al. (2018)
Hamirpur/Himachal Pradesh	Groundwater	0.15–18.92	Bhardwaj et al. (2020)
Chamba/Himachal Pradesh	Groundwater	0.50–90.46	Kumari et al. (2021)
Punjab	Groundwater	0.44–45.59	Rani et al. (2013)
Amritsar/Punjab	Groundwater	3.2–35.6	Singh et al. (2003)
Amritsar and Bathinda/Punjab	Groundwater	0.9–63	Singh et al. (2009)
Mansa, Faridkot, Ferozpur, and Bathinda/Punjab	Groundwater	0.5–645.22	Saini and Singh (2016)
Malwa/Punjab	Groundwater	5.41–43.49	Mehra et al. (2007)
Ahmedabad, Sabarkatha, Patan, and Rajkot/Gujarat	Groundwater	BDL—30	Coyte et al. (2018)
Dohad, Ahmedabad, Vadodara, and Patan/Gujarat	Groundwater	31.9–56.7	Balaram et al. (2022)
Nalgonda/Andhra Pradesh	Groundwater	0.2–118.4	Adimalla et al. (2020)
Andhra Pradesh	Groundwater	0.2–2387	CGWB (2020)
Tummalapalle uranium mining area, Kadapa/Andhra Pradesh	Groundwater	0.0–2.0	Kumar et al. (2020)
Delhi	Groundwater	2–89.4	CGWB (2020)

TABLE 17.3 Distribution of uranium in groundwater all over the world.

Location/states	Sources	Ranges (ppb)	References
Quebec/Canada	Groundwater	1–845	Zamora et al. (2009)
Ontario/Canada	Groundwater	05–4.21	Moss et al. (1985)
Idaho state/United States	Groundwater	10.17–43.84	Tkavadze et al. (2016)
United States	Groundwater	<5–560	Jones et al. (2020)
Rio de Janeiro/Brazil	Groundwater	<1–930	Godoy et al. (2019)
Japan	Surface water	0.13–590 pg/mL	Somboon et al. (2019)
Switzerland	Groundwater	0.05–100	Stalder et al. (2012)
Vicano–Cimino Volcanic/Itley	Groundwater	0.05–62	Cinti et al. (2015)
Russia	Groundwater	0.01–61.0	Farkhutdinov et al. (2021)
Southern Mongolia	Groundwater	34.7–200	Ariunbileg et al. (2016)
Burundi	Groundwater	<700	Post et al. (2017)
Zambia	Groundwater	111.31	Haakonde et al. (2020)
Incheon/South Korea	Groundwater	0.02–1640	Cho and Choo (2019)
Sindh and Punjab/Pakistan	Groundwater	0.1–556.0	Ali et al. (2019)
Argentina	Surface water	0.01–50	UNSCEAR (2016)

TABLE 17.4 Recommended limits of uranium in groundwater throughout the world.

Country/organizations	Limit (ppb)	References
Japan	2	MHLW Japan (2015)
Slovenia	6.8	EFSA (2009)
Germany	10	Banning and Benfer (2017)
Russia	15	SANPIN (2021)
Sweden	15	Balaram et al. (2022a)
Australia	17	NRMMC (2011)
Canada	20	Government of Canada (2018)
New Zealand	20	New Zealand (2008)
WHO	30	WHO (2011)
Brazil	30	Sahoo et al. (2020)
BIS	30	Tanwer et al. (2022a)
Switzerland	30	FIV (2014)
United States	30	US EPA (2009)
Bulgaria	60	EFSA (2009)
AERB, India	60	AERB (2004)
Finland	100	UNSCEAR (2016)
Slovakia	346	EFSA (2009)
Czech Republic	964	EFSA (2009)

due to processes of desorption and re-dissolution from host rocks. Uranyl carbonates were thought to be the main uranium phase (Shine et al., 2016). Although it is challenging to pinpoint a direct connection because the groundwater flow passes underground. The uranium contamination source may not certainly emerge in the host rock. It may come from other sources through groundwater passages. The high content of uranium in groundwater in Switzerland is observed primarily in the alpine regions which may be attributed to the geological composition of the bedrock. Interestingly, there were no significant correlations between the other trace elements in the Swiss groundwater samples, and uranium (Stalder et al., 2012). Redox parameters seem to play a significant role in controlling the levels of uranium in the groundwater of Central Italy. Although relatively insoluble species predominate in anoxic warm waters, uranium species dissolve more readily in cold waters due to oxidizing conditions (Cinti et al., 2015). The underground water in African nations like Ghana, Burundi, and Zambia is severely contaminated with uranium (Table 17.3), either due to the solubilization of host rock having uranium or contamination with untreated mining waste (Haakonde et al., 2020). Contrary to expectations, uranium contamination of groundwater may be more widespread elsewhere in the world. Groundwater tests from a mountainous region near Rio de Janeiro City, Brazil, revealed unusually high uranium concentrations of up to 930 ppb. This is 30 times greater than the WHO standard, which is quite concerning for a large number of visitors and water-related businesses like brewers and mineral water producers (Godoy et al., 2019).

17.5 Prescribed limits in India and the world

Different countries, as well as international regulatory organizations like the WHO, make every effort to provide pure and safe potable water for their populaces in accordance with state recommendations and legislation. Uranium (VI) has been identified by the WHO as a carcinogenic agent, and it is advised that the concentration of uranium in drinking water be kept to a minimum of 30 ppb. Table 17.4 lists the regulatory thresholds that are adhered to by many nations, including India. These controlled uranium levels are required for drinking water in order to safeguard the general public over the long term from potential negative health impacts. To determine if the water supply complies with the established standards, random samples from the community supply system are to be examined. Recently Bureau of Indian Standards (BIS) has set a provisional limit on uranium in drinking water (Tanwer et al., 2022a). However, uranium in drinking water has a radiologically based limit of 60 ppb, according to the Atomic Energy Regulatory Board (AERB, 2004). Because there is so much uncertainty around the toxicological and health data, the current prescribed value of 30 ppb of WHO is still listed as provisional. In Japan, the recommended guideline concentration is 2 ppb, but in Russia, it is 15 ppb (Table 17.4). In order to lessen the risk of exposure for residents who drink groundwater, the borewells and other drinking water sources of water with high uranium concentrations, as well as the surrounding areas, must be periodically checked. The quantities of uranium were found to be well under the WHO limits in the majority of the 908 packaged mineral water and around 163 samples from community supply systems from Germany and other regions of Europe that Birke et al. (2009) examined for uranium content. However, some samples of tap water, bottled water, and stream water particularly in the central and southern regions of Germany and some parts of Europe exceeded the safe levels.

17.6 Uranium occurrence and possible sources in groundwater

Numerous minerals include the naturally occurring component uranium, which is mildly radioactive. Although some uranium compounds are used as catalysts and coloring pigments, nuclear power plants predominantly use uranium as a fuel (Berlin & Ruddell, 1986). It is primarily accumulated in acidic volcanic rocks and is integrated into auxiliary minerals including uraninite, zircon, and monazite (Sasaki et al., 2017). Sedimentary, metamorphic or igneous rocks, soils, and liquids, including surface and groundwater, can all contain trace amounts of uranium. Uranium is easily oxidized to generate a variety of typical uranium oxides, as well as oxyhydroxide minerals like pitchblende and schoepite. Black shales are relatively rich in uranium along with certain metals and metalloids that are sulfide-forming, oxidation, and reduction reactive, and can reach up to 400 ppm. This is evident that sedimentary rocks have a relatively low uranium level compared to other shales or the usual composition of the earth's crust. Along with human-mediated activities like nuclear weapons, power plants, mining, phosphate fertilizers, etc., geology is the principal source of uranium in groundwater. Weathering of uranium-containing rocks and minerals causes uranium to end up in soils and streams. After being dissolved in water and assimilated into the soil, it is absorbed by plants and consumed by humans, grazing animals, or other organisms. Uranium is more prevalent and practically pervasive in granitic materials due to its existence in various chemical forms, including U^{+4} and U^{+6}. These forms have a large atomic radius (0.97 A), high chemical reaction, higher solubility of U^{+6} in the aqueous phase, and relative insolubility of U^{+4} compounds. The groundwater in a fracture has a significant quantity of dissolved oxygen, forming an oxidizing environment, which oxidizes uranium to hexavalent states, which is highly mobile and readily dissolves into water and travels to the aquifer. Uranium is converted to its U^{+4} form under reducing circumstances, which results in a low content of uranium in water due to its stability as it is weakly soluble in the mineral uraninite. Therefore, due to more reducing circumstances and lower uranium solubility, deeper groundwater would have lower uranium concentrations (Balaram et al., 2022).

17.7 Characteristics of uranium

Pure uranium is a silver–white, malleable, ductile heavy metal that melts at a temperature of 1132.3°C and boils at about 3818°C. Its density is 19.05 g/cm (Nandal & Rastogi, 2018). Because of its easily oxidizing nature, elemental uranium is rarely seen in the environment (Beddow et al., 2006). Consequently, once it comes into contact with air at room temperature, it spontaneously ignites and creates uranium oxides with six different oxidation states. Because U^{+3} quickly oxidizes into U^{+6} under most redox conditions, U^{+5} readily converts to U^{+4} and U^{+6}. U^{+4} and U^{+6} are the most common oxidation states in nature (Markich, 2002). Although more than 234 different species of minerals make up uranium, it only accounts for 5% of all known minerals (Barthelmy, 2008). The two most common forms of uranium oxide are uraninite (UO_2) and triuranium octoxide (U_3O_8), which have poor solubility in water but are very stable under various environmental conditions. U_2O_5 and UO_3 are the primary forms of U_3O_8 in nature (Wersin et al., 1994). Many substances with colors that trend toward yellowish or greenish are frequently made using uranium. Due to this chemical feature, uranium has historically been used to tint and create shadows in early photography and to create orange-reddish to lemon-yellowish hues for glassware and ceramic items. With an atomic number of 92, uranium has known as the heaviest naturally occurring element. Uranium has three isotopes, i.e., uranium-238, uranium-235, and uranium-234. When these isotopes disintegrate, alpha and gamma radiation are produced. Continental-type rocks have the highest uranium concentrations among geological materials. In addition to being the heaviest element found in nature in measurable proportions and nuclear fuel in power plants, due to its chemical and radiological impact on the environment and human health, uranium is significant.

17.8 Sources of uranium in the environment

Even though uranium's main source is geological; anthropogenic processes can also contribute to its mobilization including mining of uranium, coal mediated plant, phosphate fertilizers in agriculture, oil, and gas mining operations, nuclear power plant, too much nitrate, and a declining groundwater table. A summary of the different significant sources of uranium in groundwater is presented in Fig. 17.1. As previously indicated that local geology significantly impacts the background levels of uranium in surface and subterranean waters. A detrimental impact on the local soil, flora, wildlife, and humans can result from drilling operations, cutting, blasting, transporting, stockpiling, processing, and leaching, all a component of mining and extraction activities.

17.9 Natural sources

17.9.1 Geological sources

Geogenic sources are a significant uranium addition in groundwater and are dependent on several factors, including water-rock interactions that extract uranium from various rocks, oxidizing circumstances, interactions between the extracted uranium and other ions and compounds in the groundwater, such as carbonate, that even more increase its miscibility (Rathore, 2018). Groundwater with abnormally high uranium content is primarily found in granite regions. For instance, higher uranium content in the gneiss and granite rocks in the northern section of the Karnataka state's Kolar district may be to sole source for higher uranium concentrations there (Babu et al., 2008). The plentiful monazite placer deposits in Tamil Nadu, India, have significant background radiation levels. Gamma radiation rates of up to 3880 nSv/h have been detected in groundwater samples from these sites (Raja et al., 2021).

17.9.2 Cosmic sources

This amount of uranium is insignificant concerning the level of uranium in the crust of the earth. Numerous radiations

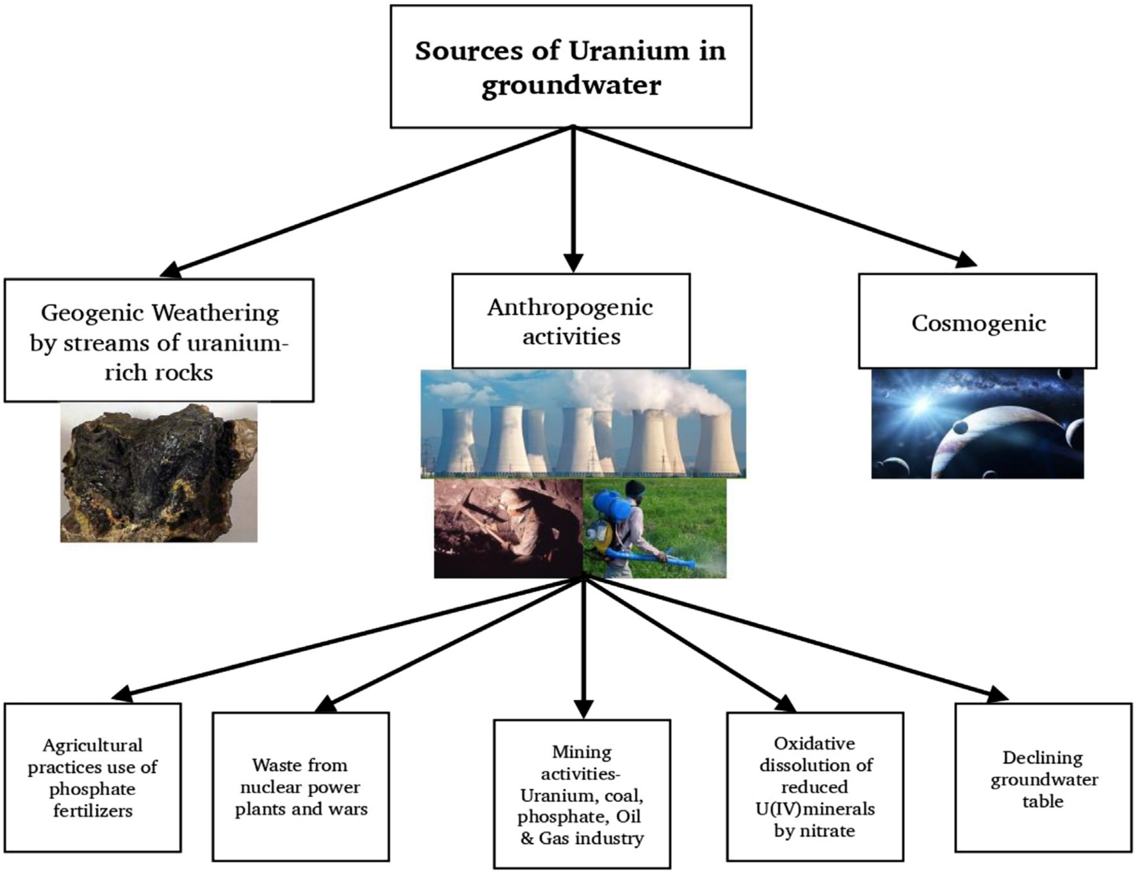

FIGURE 17.1 Various uranium sources in groundwater.

from space have been reaching the surface of the earth ever since it has existed (cosmic rays) (Tanwer et al., 2021). Cosmic rays produce uranium and other radionuclides. Several make it to the earth's surface, where they mix with water and dirt. The hydrosphere, earth's crust, and atmosphere all contain naturally occurring radionuclides that move around the environment. ^{3}H, ^{32}P, ^{14}C, ^{40}K, ^{222}Rn, ^{238}U,^{226}Ra, ^{235}U, and ^{232}Th are some of the radionuclides in this group. Some of them are known as cosmogenic isotopes because these are produced under the influence of cosmic radiation (Tanwer et al., 2023d, 2023e). Recent research suggests that some uranium may be produced when neutron stars and the merging of meteorites. This process may also contribute some uranium to the continental crust. People in the United States are exposed to radiation from space on average 5% of the total annual exposure (USEPA, 2021). The sun and other stars in our galaxy continuously generate cosmic radiation, which frequently strikes the earth.

17.9.3 Anthropogenic sources

Increased uranium concentrations in adjacent water bodies will be caused by industrial, agricultural, and military operations. A higher uranium concentration could result from overusing groundwater. Let's look at each of these aspects separately.

17.10 Mining of uranium

Kazakhstan accounted for 42% of all uranium mined globally in 2019, followed by Canada (13%) and Australia (12%). The 11th-largest producer of uranium worldwide is India. Water contamination from mining and milling activities is a possibility in uranium mining sites. Additionally, uranium pollution of the nearby groundwater resource, surface water, soil, and air can result from improper dumping of uraniferous mill tailings and trash in a uranium mining region. Dewatering of the mining region is necessary for both open and underground mines and their operating regions, which contaminate the surrounding water. Additionally, uranium will enter the nearby water bodies by runoff from surface waters and seeping through waste rock piles. For instance, mine water is routinely discharged into the neighborhood in various U.S. regions without appropriately removing uranium; this could lead to uranium exposure from the food grown in such sites with polluted soils (Redvers et al., 2021). Consequently, chronic diseases are more common in nearby towns. Another incident involves discovering extraordinarily high uranium levels in drinking water supplies near uranium mines in the Siavonga district of Zambia's southern province (river, 135.30 ppb; dams, 115.62 ppb; boreholes, 111.31 ppb; and shallow wells, 110.03 ppb) (Haakonde et al., 2020). These results imply that people drinking water close to mining areas may be more prone to potentially non-cancerous health effects.

17.11 Nuclear waste

A relatively small amount of uranium may be released during the manufacture, processing, and disposal of nuclear fuel, which could affect the environment or expose workers to hazards. The military stockpiles of three NATO countries—the United States, France, and Great Britain—include depleted uranium weapons (Ough et al., 2006). Depleted uranium (DU) is used in certain bullets and tank armor because of its high density and ability to puncture adversary armored vehicles. These arsenals were also utilized in more modern battles like the Bosnian and Kosovo wars. According to data from Gieré et al. (2012), cypress leaves collected adjacent to a French plant that processed uranium had uranium-rich particles on their surface.

17.12 Mining of coal

Around <200 feet below the ground, is a typical depth at which uranium-bearing coals are found. Wufuer et al. (2018) have emphasized the uranium exposure brought on by coal extraction activities in the Xinjiang region due to the waste dispersion containing high uranium level, in recent Chinese publications. For instance, the range of uranium contents in coal samples from the regions of the Illinois Basin of the United States is between a little under 1 ppm and 4 ppm and between 10 ppm and 30 ppm which is reasonably high. Uranium concentrations in the hair and urine of individuals who resided in this coal mining region and were exposed to it for prolonged periods varied from 22.2 ppb to 634.5 ppb with an average of 156 ppb and 8.44–761.6 ppb with an average of 202.6 ppb, respectively. The radioactivity property of normal fly ash is comparable enough to the concrete and other constructing materials like granitic rocks or brick, despite the fact that fly ash is frequently employed as an additive constructing material with less radioactive potential.

17.13 Mining of phosphate rock

Water quality will be impacted by phosphate rock processing and extraction since contaminated water is discharged into streams that include radioactive elements and toxic metals like uranium. Phosphate rocks generally contain about 75 mg/kg of uranium, which could lead to a substantial amount of uranium in the mine water flow. The enormous amounts of dust that are released also contribute to the problem of harmful air in the nearby region and the mining area. Radon gas emanation and fluoride at high concentrations are both major issues that harm human health (Reta et al., 2018).

17.14 Oil industries

The usage of radiation-producing machines using unsealed and sealed radiation sources has the potential to be hazardous to the surrounding environment and living beings is widespread in the oil and gas sector. Additionally, during production, maintenance, and decommissioning operations, considerable amounts of NORMs (naturally occurring radioactive materials) emanating from the reservoir rock are excavated (IAEA, 2003). Numerous rock and soil types naturally contain radioactive elements, including uranium. It dissolves in water that percolates through them. Those sources are brought to the surface by the production of oil and gas. It contains heavy metals and considerable concentrations of radium, another radioactive element known to cause cancer. Blasting and drilling produce crushed rock and dirt known as drilled cuttings that have high levels of uranium and thorium. This can have adverse impacts on human health by increasing the risk of cancer in oil and gas employees, their families, and the residents of adjacent areas.

17.15 Agricultural activities

For over 60% of India's population, agriculture provides their primary means of subsistence in around 60% of the nation's area. The extensive use of fertilizers is one of the main sources of uranium in groundwater, a considerable amount of uranium is entering agricultural soils. Yamazaki and Geraldo (2003) analyzed the levels of uranium in different foreign fertilizers as well as the most popular phosphate fertilizers used on Brazilian agricultural land. The uranium concentration of phosphate fertilizer in Brazil ranges from 5.17 ppm to 54.3 ppm, while it ranges from 3.2 ppm to 221 ppm in other nations. Furthermore, most commercial fertilizers decrease soil pH and encourage uranium to leach into groundwater. Depending on ambient CO_2 pressure and soil pH, the development of soluble uranium species may lead to transport from soil to water bodies. As a result, regular use of fertilizers containing uranium can significantly raise the amount of uranium in fertilized agricultural soils (Bjørklund et al., 2020). Moreover, as uranium moves through soils and groundwater, plant roots can now absorb it (Rahman & Hasegawa, 2011). Crops receive lots of nitrogen because nitrate fertilizers deliver enough nitrogen to the soil. In the case of excessive nitrate and low pH, reduced uranium (IV) minerals may be oxidatively dissolved. Uranium may form chemical complexes with calcium and carbonate ions in groundwater after nitrate oxidizes, facilitating its movement through the soil and into the subsurface. The USEPA's maximum permissible limits have been exceeded. The Central Valley (CV) and High Plains (HP), the two largest aquifers in the United States, provided 78% of the groundwater geochemical data associated with nitrate contamination in groundwater (Nolan & Weber, 2015).

17.16 Overuse of groundwater

Human over-consumption of groundwater resources, particularly the overuse of groundwater for household, commercial, and agricultural activities, raises the issue of declining underwater levels, which creates an oxidizing environment that encourages the formation of water-miscible complex uranium and carbonate (Coyte et al., 2018). Uranium and arsenic can be mobilized from the soil and contaminate the water bodies as the water level drops.

17.17 Environmental factors make it dissolve in groundwater

Aquifer rocks, contact time, partial pressure of CO_2, oxygen content, and complex compounds like phosphates and bicarbonates all influence the concentration of uranium in groundwater (Sahoo et al., 2021). The characteristics of water, including pH, temperature, the kind and quantity of dissolved salts, contact time, and flow rate, all impact how soluble it is in groundwater (Chahal et al., 2019). Along with redox conditions, other parameters such as pH and amounts of associated dissolved ions also affect how mobile uranium is in water. Uranium-enriched aquifer rocks undergo a process like weathering, sorption, and desorption mechanism with contact with clay, organic matter, oxides of iron, etc. causing it to dissolve in water from aquifer rocks (Giammar & Hering, 2001). U^{+6} is more prevalent in its hexavalent form in groundwater at low levels of pH. The hexavalent version, however, can build water-soluble carbonate compounds with uranium at high pH levels that are typically transferred to natural waters by creating carbonate and hydroxide compounds (Himri et al., 2000). Thus, the production of carbonate complexes and oxidizing conditions are two major chemical factors affecting groundwater uranium levels. The positive correlation between uranium and alkalinity shows the likelihood of anionic uranyl-carbonate complexes, which preserve uranium in a soluble state. $Ca_2 UO_2(CO_3)_3(aq)$ and $Ca(UO_2)(CO_3)_3{}^2$, which are produced by calcium, have an impact on uranium speciation and can hasten uranium mobilization. Despite the increased prevalence of both of these species in waters, there is a lack of clarity regarding the toxicity of these waters for human consumption (Prat et al., 2009). Uranyl salts like uranium hexafluoride, nitrate, fluoride, and tetra-chloride are other soluble compounds that can cause the most serious systemic effects in people. These minerals have varying degrees of water solubility. In granitic terrains and regions near ore resources, the concentration of uranium in groundwater can be very high. Such terranes' weathered soils and rocks contain uranium in greater quantities than the nearby aquifers (Thivya et al., 2016). The relationships between uranium and various components in groundwater, such as $HCO_3{}^-$, $SO_4{}^{2-}$, F, and Sr are extremely favorable (Cho & Choo, 2019). The variability of uranium concentrations in groundwater samples is caused by different processes, such as weathering, solubilization, evaporation, etc. of uranium-bearing rocks, all of which have varying rates. Uranium can form compounds with OH^- and $CO_3{}^{2-}$ in the solution at neutral pH levels when it is leached into natural water (Langmuir, 1978). Although $HCO_3{}^-$, $SO_4{}^{2-}$, Cl^-, $NO_3{}^-$, NO_2, F, and $HPO_4{}^{2-}$ are the primary inorganic anions often found in water samples, it is anticipated that the $CO_3{}^{2-}$ anion will be the most potent ligand for $UO_2{}^{2+}$ in slight basic conditions (Prat et al., 2009).

17.18 Health impacts

Several processes lead to the release of uranium into the environment, including leaching from different types of rocks, mineral deposits, ore, and soils, discharge from mining operations, releases from the nuclear industry, usage of coal in thermal power plants, and phosphate fertilizers that include uranium. Uranium has been recognized as a nephrotoxin, similar to cadmium, lead, and mercury (Goodman, 1985). Along with arsenic and chromium, uranium is one of the top three toxic, naturally present groundwater pollutants. It is a hazardous heavy metal that is radioactive and can damage DNA when consumed excessively. Renal dysfunction and delayed bone growth are further detrimental health impacts (Brugge et al., 2005).

17.19 Impacts on human-beings

Uranium has serious ill effects on human beings, but the severity of its impacts depends on routes of entry, exposure duration, and route of excretion. However, rather than its radioactive characteristics, uranium poses a greater chemical threat to human health. According to research by Zamora et al. (2009), chemical toxicity would pose a bigger threat to health than radiotoxicity at higher uranium ingestion quantities through drinking water. It can be challenging to link greater uranium concentrations to health issues among the community's uranium consumers. For instance, despite significant concentrations of uranium contamination in drinking water flowing from dug wells in Southern Finland, the exposed population reported no overt health symptoms, further complicating the scenario (Prat et al., 2009). Uranium may enter a vital organ by breathing uranium dust or aerosol, drinking water, ingesting, or coming into contact with their skin, which may have harmful health effects (Fig. 17.2).

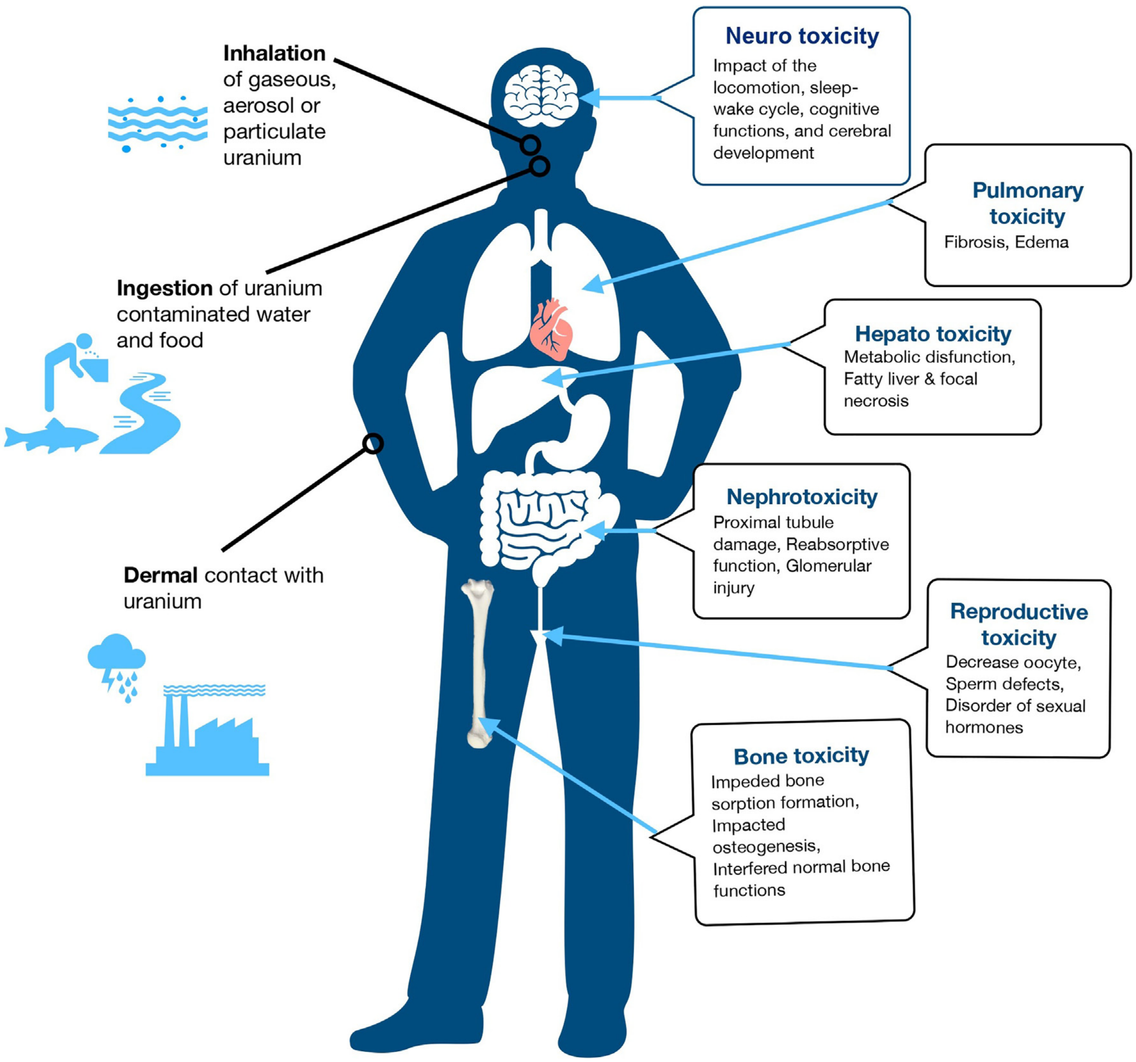

FIGURE 17.2 Picture depicting different modes of exposure and health impacts on human beings. *(From: Balaram et al., 2022)*

Since uranium naturally exists in soil, surface, groundwater, and air, veggies and drinking water are the main exposure routes for people who are not exposed at work. When potable water is acquired from groundwater sources, without treatment, that have been impacted by geology or from water sources that have been contaminated by anthropogenic activity, the risk of exposure to uranium may increase. The uranium mining workers in particular are negatively impacted. High occupational uranium exposure can occasionally cause chemo-toxicity to the kidneys, lungs, and liver which can cause serious health issues, including kidney failure. Furthermore, exposure to uranium has an impact on the respiratory and reproductive systems (ASTDR, 2013). Along with exposure to uranium, coal miners are also exposed to radon gas, another radioactive substance. Maximum uranium concentrations in privately drilled wells can exceed 200 times the WHO limit in some regions (Godoy et al., 2019). The uranium contamination issue can be quite bad if the mining activities are upstream from the community. Furthermore, uranium emits particles, and several by-products of its decay, such as radon, are created as the uranium decay cycle advances from ^{238}U to ^{206}Pb. Although alpha particles, which have two protons and two neutrons, are heavy and cannot pierce human skin, internal radiation exposure can still occur when particulate debris containing alpha emitters is breathed or consumed. For instance, around 20% of lung cancer occurrences in Canada are caused by radon gas (Dewar et al., 2013).

17.20 Brief about techniques available to detect

The detection limits for some ions, such as uranium, have recently been reduced to the level of parts per quadrillion,

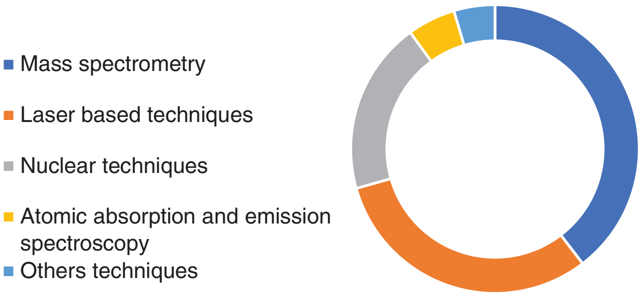

FIGURE 17.3 Different techniques used to measure uranium throughout the world.

enabling the analysis of many elements and isotopes of smaller samples with improved accuracy and precision (Balaram, 2021). The majority of analytical methods used today are effective at identifying uranium in water at ppb and sub-ppb levels. Different techniques and their relative percentage are utilized to measure uranium all over the world as shown in Fig. 17.3. Table 17.5 includes some of the most often-used instruments for determining the amounts of uranium and its isotopes in water samples.

17.21 Remediation strategies/techniques

The adverse health effects caused by uranium exposure through drinking water must be regularly addressed in areas where uranium levels are higher than the recommended limit. In remedial procedures, uranium speciation, other contaminants, and the overall water quality all play a crucial role. Remediation techniques for uranium in natural water can be considered based on its physical, chemical, and biological characteristics. This section discusses several methods and the fundamental ideas involved in removing uranium from drinking water and groundwater. Physical and chemi-sorption, which is recognized as a basic, efficient, and affordable method, was the main focus of the majority of uranium cleanup research until recently. The physical methods are based on process coagulation, evaporation, adsorption, and membrane technologies like RO. The current investigation in physical methods is underway for the development of more effective and upscalable methods for removing uranium from water. When reverse osmosis is used at the community level, it is very expensive. The use of sorbent materials like resin, activated silica, titanium adsorbent, activated carbon, and others has received extensive research (Li & Zhang, 2012). Chemical treatment techniques include ion exchange, co-precipitation, defluoridation, precipitation, and adsorption. Adsorption is a physicochemical mechanism, and the forces and interactions between the adsorbent and adsorbate determine whether it is physical or chemical. When water is polluted by low amounts of uranium, substantial regions can benefit from bioremediation techniques such as biochar, phytoremediation, and microbial-remediation. Large amounts of soil polluted with low concentrations of uranium may benefit from phytoremediation techniques. Researchers examined the effectiveness of sunflower, Indian mustard, and other plant roots in removing uranium from soils and water (Yao et al., 2010). Point-of-use water filter systems are the best alternative to minimize the quantity of uranium if domestic drinking water testing reveals that it contains more than is recommended. In particular, the utilization of novel nanocomposites, based on graphene and hybrid metallic oxide nanomaterials showed encouraging evidence to achieve an effective removal of uranium from water (Tolkou et al., 2020). Abd El-Magied et al. (2021) generated a graphite adsorbent with a lot of potential for cleaning up uranium-contaminated water systems. Dinis and Fiuza (2021) recently examined the progress of groundwater remediation technology. The most significant recent advancements in this regard are listed below.

17.22 Remediation using nano-particles

Tetravalent form uranium cannot dissolve in water because it produces uraninite, which is also insoluble. Uranium's migration into groundwater can be prevented by reducing it from the uranium (VI) form to the uranium (IV), which is an efficient way to safeguard our drinking water sources. In research, the adsorption of uranium from synthetic uranyl solutions and uranium-contaminated mine water onto zero-valent iron nanoparticles in the presence and absence of oxygen was investigated (Balaram et al., 2022a). Because of their extraordinary mobility and high surface-to-volume ratios, various zero-valent iron nanoparticles have been thoroughly investigated as chemical reducing agents and adsorbent nanomaterials for environmental applications. An enrichment procedure that is both secure and efficient can be carried out by employing the same method. The same method might enrich and remove uranium from low-level resources like groundwater, wastewater from uranium tailings, and possibly even the ocean (Hua et al., 2021). Nanostructured graphene-based adsorbents were utilized in a recent study of methods for removing uranium from water sources (Tolkou and others, 2020). Wang et al. (2021) published a report on an in-situ electrolytic deposition of uranium from an aqueous medium. The electrode used is made of functionalized reduced graphene oxide foam which also serves as a catalyst for hydrogen evolution and a substrate for uranium deposition. Developing a recyclable filter out of graphene oxide (GO) foam that acts as a magnet for uranium and effectively removes the radioactive element from drinking water established that GO foam can be used effectively to filter uranium out of water. The process begins with an electric charge transmitted through the foam, which

TABLE 17.5 Techniques and their detection used to detect Uranium in water.

Instruments/analytical techniques	Limit of detection (ppb)	References
High-resolution inductively coupled plasma mass spectrometry	0.031 pg/mL	Satyanarayanan et al. (2018)
Inductively coupled plasma-time of flight—mass spectrometry	0.7 pg/mL	Krejčová et al. (2012)
Laser-induced kinetic phosphorescence analysis	0.001	Brina and Miller (1992)
Instrumental neutron activation analysis	0.04	Zikovsky (2004)
UA-3 laser fluorimetry	0.05	Robbins (1978)
Digital readout laser fluorimeter, RRCAT	0.05	RRCAT, Indore (https://www.rrcat.gov.in/)
Anodic stripping voltammetry (ASV)	0.1	Sahu et al. (2014)
Fluorimetry	0.1	Sahu et al. (2014)
Spectrophotometry	0.1	Paunescu (1986)
Indore miniaturized digital read-out laser fluorimeter	0.1	Quantalase
Laser fluorimetry	0.2	Bhangare et al. (2013)
LED fluorimetry	0.2	Quantalase
Raman spectroscopy	0.2	Ruan et al. (2007)
Electrothermal atomic absorption spectroscopy (after matrix separation)	0.6	Santos et al. (2010)
Inductively coupled plasma mass spectrometry	0.6	Balaram and Gnaneshwar Rao (2003)
High-performance liquid chromatography-spectrophotometry	1.0–2.0	Kerr et al. (1988)
Inductively coupled plasma optical emission spectrometry	2	Chandrasekaran et al. (2011)
Gold nanoparticle/paper-based lateral flow device	8.66	Quesada-González et al. (2018)
Paper-based biosensor	9	Quesada-González et al. (2018)
Colorimetric sensors	12	Lee et al. (2008)
Flame atomic absorption spectrometry	120	Santos et al. (2010)

stimulates the adjacent water to split and release hydrogen, raising the pH in the area. This generates a chemical transition that pushes the uranium ions to the foam's surface. With GO foam, which can be recycled and reused, significant uranium concentrations may be recovered. These advancements open up new opportunities for using 3D-FrGOF electrodes as a cutting-edge water treatment technique. These developments are also helpful for mining waste and extracting uranium from nuclear waste.

17.23 Defluoridation techniques

Different methods for removing fluoride were rigorously analyzed by Mobeen and Kumar (2017), and Renuka and Pushpanji (2013). When using the defluoridation procedure, fluoride is removed together with uranium that may have been present as a co-precipitant (uranium is a particularly good co-precipitant of calcium/magnesium fluoride). Following uranium co-precipitation into calcium fluoride, a technique for determining ultra-trace amounts of uranium has been reported (Johnston & Wright, 1981; Perry et al., 1981). Additionally, it has been claimed that fluoride and uranium can be eliminated from water sources using RO membranes. RO is among the newest membrane-based methods for eliminating contaminants from water. Sahoo et al. (2021) conducted research on a hybrid membrane system for removing uranium from drinking water.

17.24 Adsorption using Mg-Fe-based hydrotalcite compound

By employing inorganic anion exchange and other techniques, double-layered hydrotalcite and hydrotalcite-like compounds can adsorb various elements (Kumasaka et al., 2013). Kato et al. (2016) demonstrated the effectiveness of removing uranium from drinking water samples using a hydrotalcite-like compound based on magnesium and iron. A water sample from wells of Kabul, which had an average uranium contamination level of 190.4 ppb could be remedied up to 1.2 ppb by 1% weight of Mg-Fe-based hydrotalcite in 60 sec at a very cheap cost, demonstrating the efficiency of Mg-Fe-based hydrotalcite to remove uranium contamination from drinking water.

17.25 Bioremediation using biochar and microbes

A wide range of pollutants, including uranium, can be effectively removed from aqueous systems using biochars of diverse origins. Compared to commonly employed low-cost methods, including boiling, sand filtration, solar disinfection, and chlorination, this underestimated low-cost method for treating drinking water may provide several advantages (Gwenzi et al., 2017; Mohan & Pittman, 2007). Biochar, a material rich in carbon, is produced when biological waste, such as hay, dried grass, wood, and coconut debris, is ignited at a relatively low temperature (about 700°C). Its high porosity and charged surface lead it to become a powerful adsorbent (Liu et al., 2020). The ability of biochar to remove inorganic contaminants, such as uranium, depends on the surface area available, the pore density, the functional groups on the surface, and the size of the pollutants/ions to be removed. The sorption characteristics of U^{+6} onto eucalyptus charcoal have been studied as a function of several factors, such as the baseline ion concentration of the target element, contact time, pH, and overall ionic strength of the medium (Mishra et al., 2017). It is discovered that the pH range of 5–6 is where maximum sorption of roughly 95% occurs. U (VI) adsorption on charcoal achieved equilibrium at pH 5.5 in less than 20 min. The chemical interaction between the U^{+6} and the surface functional groups of the adsorbent, such as carboxylic, hydroxyls, and carbonyls, has been demonstrated to be the reason for the adsorption process. Low-temperature generated biochars are more adapted to absorb inorganic contaminants because they have less surface area, are less porous, and have more functional groups that contain oxygen. Electrostatic interactions primarily control the sorption properties (Enaime et al., 2020). The essential advantage is that biochars eliminate physical, chemical, and biological contaminants, whereas other methods mainly eliminate infections. Biochar's physicochemical attributes indicated that it would function well as an adsorbent to remove uranium from groundwater. The adsorption mechanism is directly related to the pH of the aqueous solution (Kumar et al., 2011). For the regeneration of abandoned mine lands, the use of woody biochar is shown to be especially beneficial (Rodriguez-Franco & Page-Dumroese, 2021). Morrison et al. (2021) have recently studied microbial phosphatase activity in conjunction with the adding of an organic phosphorous source. This remediation approach enables an extended release of inorganic phosphorous into uranium-polluted areas, precipitating meta-autunite minerals and providing a workable way to reduce uranium levels below those permitted in drinking water. Numerous studies on the capacity of various biochars to remove uranium and lead from soils and water are currently being conducted (Guilhen et al., 2021; Mishra et al., 2017).

17.26 Future perspective of contemporary and innovative methods for bioremediation

Bioremediation techniques in pollution abatement have been an expanding field of study for several years due to their omnipotence and eco-friendliness. Many studies have used bioremediation to reduce pollutants like uranium. In terms of sustainability and effectiveness, there are various obstacles to implementing lab-based outcomes at a large-scale or commercial level. Some of the potential future research projects include preventing over-deposition and further soil pollution because it is necessary to investigate the best way to store or use the transformed uranium produced during bioremediation. More research needs to be done on the toxicity of uranium in plants and how consuming these plants affects people and animals. The research reports specifically lack the threshold hazard values in plant uptakes. The bioleaching process can be profitable if the impact of particle size is thoroughly studied. It was noticed that the uranium leaching process takes an unusually long time. Consequently, additional research into the factors that determine the required time and the kinetics of the leaching is essential for using this on a large scale. Investigating the large-scale effects of uranium biosorption and desorption is crucial because it provides a relatively successful method for large-scale remediation. Additionally, for improved efficacy of the bio-based processes, microbial activity toward uranium bioreduction under various environmental circumstances needs to be studied. In the case of phytoremediation, it has been revealed that mineral translocations in plants are conceivable, and research in this area could pave the way for large-scale phytoremediation of uranium. Additionally, it is necessary to research how fertilizers and pesticides affect phytoremedies.

17.27 Conclusion

India and the rest of the globe are cautious about uranium contamination in groundwater supplies. This chapter details all about uranium distribution, techniques available to detect it, health effects, and remedial measures used throughout the world. The main sources come from both manmade and natural sources. Overuse of fertilizers containing uranium and over-extraction of groundwater resources are to blame for contamination in several states. However, it should be remembered that all of the literature cited above, suggested the prevailing issue. The groups who experience resource limitations regarding access to safe drinking water are the most impacted when available water supplies become contaminated. Additionally, nitrate, fluorides, Arsenic, and other pollutants were identified in excess in water with high uranium concentrations, according to research. The main causes of high uranium content in groundwater in many parts of the nation and abroad are subsurface geological composition having granitic rock, substantial use of phosphate fertilizers in agricultural practices, and direct discharge and dumping of industrial waste into river systems. The interelement correlations further demonstrate that the factors controlling the presence of considerable amounts of uranium in groundwater are rock fracture, redox conditions, and leaching of host rocks. The quality of the drinking water supplies must be checked regularly for monitoring of harmful elements, such as uranium, and any sources that reveal excessive amounts of the radioactive element must be immediately taken into consideration and cleaned up before being used for drinking. Additionally, comprehensive investigations must be carried out to achieve a deeper understanding of the origin, mobilization mechanism, and health effects of uranium in groundwater on the general public and those exposed to it at work. Some encouraging advancements have been made in the field of eliminating toxic uranium from water supplies in communities. These techniques can also be used to recover enriched uranium from nuclear waste and mine tailings, which are utilized to produce energy. Additionally, several remediation techniques that are effective and affordable and that are used globally are highlighted.

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Section 4

Future scenario and case studies related to rural water management

Chapter 18

Challenges and mitigation techniques for clean rural water supply in Himachal Pradesh, India

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18.1 Introduction

Air, soil, and water pollution is a common constant problem for the environment and ecosystems. Reports have shown that many emerging countries are exposed to harmful chemicals where the concentration of pollutants exceeds the safety limit. People are still not aware of the methods of reusing and recycling which leads to an increase in the waste volume which directly adds to pollution (Panchal et al., 2020). Plants and animals are immensely important for our environment as they form the basis for food, raw materials, and everything else. Human practices like deforestation are making these species vulnerable and extinct. Not only animals but there are also thousands of people who are dependent on forests and coastal regions for their survival. The continuous and expanded extraction of raw materials like ores, coal, minerals, and other fossils has led to the scarcity of these resources. On top of that, the increasing prices and costs of locating and then extracting them make the consequences even worse. Blind overuse of resources has led to the shutting down of many industries in countries like China and the United States. The burning of fossil fuels and energy resources releases harmful greenhouse gases which are responsible for climate changes (temperature change, distorted rainfall patterns, etc.). Greenhouse gases are released via industry activities also which raises the temperature and the melting of glaciers takes place leading to a devastating rise in the sea levels (Mishra et al., 2021). The United States Environmental Protection Agency (USEPA) published a list of organic and inorganic chemicals identified in wastewater that pose substantial health risks in 1978. The most dangerous elements listed in the study are antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc (Gautam et al., 2021).

Due to massive development in industrialization and urbanization over the last few decades, a global environmental challenge has emerged. Aqueous effluents containing relatively high amounts of heavy metals are discharged by industries, such as mining, steel electroplating, and so on (Ghosh et al., 2014, 2015, 2016, 2017a, 2019). The environment suffers as a result of the untreated effluents from these production operations. The majority of industrial wastewater contains heavy metals that are toxic to humans and the environment. Beach litter is both a source and an obvious sign of ongoing chemical contamination of marine biota. Chemical contaminants, which are present at ultra-trace levels but are often highly toxic, can be difficult to understand and measure. As the most problematic links in food chains biomagnify, predator sampling provides a global picture of ocean pollution (Elliott et al., 2015). Also, drug pollution in sewage is another issue in recent days. The applicability of numerical modeling was shown by Issakhov et al. (2021), and this indicates the tool's potential for large-scale risk assessment of pollution.

The effect of water pollution by different contaminants on biodiversity or life, the available techniques for wastewater treatment plants, and future scopes have been discussed in this article focusing on sustainability.

Also, the scenario of water issues in Himachal Pradesh and future scopes have been discussed.

18.2 Sources and effects of different contaminants on biodiversity

The significant sources of heavy metals are anthropogenic activities and natural sources, such as wind-borne dust particles, natural rock, aerosols, and volcanic eruptions.

Worldwide, human activities are significantly reducing biological diversity. The issue is so serious that cumulative human impacts may have increased current

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extinction rates to 1000–10,000 times the rate of natural extinction. Overfishing, overharvesting, pollution, alien species, land reclamation, dredging, and climate change all pose threats to marine life in the oceans. Anthropogenic activities and natural sources are the two main categories of water pollution sources. The Environmental Protection Agency (EPA) states that 0.1 mg/L is the maximum amount of chromium that should be present in drinkable water (Aloulou et al., 2020). At hazardous waste sites, chromium is the most common inorganic pollutant in groundwater. Electroplating, alloys making, corrosion control, chromite ore processing, leather tanning, wood preservation, pigment and dyes, textile, and metal industries generate wastewater containing relatively large amounts of chromium (Carmona et al., 2005; Peng et al., 2018; Wang et al., 2021).

Different body parts are affected by various acute and chronic harmful effects of heavy metals. Examples of the difficulties caused by the toxic effects of heavy metals include gastrointestinal and nervous system illnesses, kidney dysfunction, skin lesions, vascular damage, immune system malfunction, congenital impairments, and cancer. Exposure to two or more metals concurrently may have additive effects. Another important element of chronic exposure is that a number of metals have been identified as human carcinogens. Aberrant genome and gene expression changes are a fundamental process, even though the precise mechanism is unclear. DNA synthesis and repair can be triggered by carcinogenic metals like cadmium, arsenic, and chromium. Heavy metal toxicity and carcinogenicity are dose-dependent.

The Minamata Convention of Mercury was followed as a result of the mercury levels in marine mammals (Elliott et al., 2015). The Stockholm Convention of 2001 forbade or severely limited the use of the deadliest chlorinated compounds. But given that thousands of new chemicals are released every year, some will unavoidably evade regulation. Compared to fish or marine animals, seabirds have less fluctuating organochlorine concentrations. A biologist can sample a marine area that would cost millions of dollars to examine on a research vessel in an afternoon at a seabird colony.

Numerous studies offer a global perspective on the contaminants found in seabirds (Elliott et al., 2013). Since the 1970s, some wealthy nations have continued their efforts at continuous sampling. Particularly the lipid-rich avian egg offers a straightforward matrix for testing the lipophilic compounds of greatest concern. Early in the 1980s, deep-sea environments began to be exposed to chlorinated organic pollutants (POPs) such dichlorodiphenyltrichloroethane (DDT) in coastal habitats. Over the past ten years, more pollutants have begun to endanger marine biota. In seabirds, lipophilic chemicals that are stored in body lipids and slowly ejected are the principal source of pollution accumulation. Chromium-enriched wastewater poses substantial environmental contamination and health risks to plants, animals, and people if it is dumped without any treatment. The most frequent natural source of chromium pollution in water bodies is leaching from rocks and topsoil. Chromium contamination of groundwater can occur as a result of incorrect disposal of solid waste from chromate-processing enterprises in landfills, with chromium residence times of many years. Nowadays, the Government of India has introduced and progressively enforced stricter regulations concerning the discharges of metals, especially for industrial operations (Aksu, 2007).

Copper is necessary for human life and health, yet it is also potentially harmful, as are all heavy metals (Ghosh et al., 2012). It is not biodegradable and bioaccumulates throughout the food chain (Sobhanardakani et al., 2018). Metal cleaning and plating baths, pulp, paper board mills, wood pulp manufacture, the fertilizer sector, and other industrial effluents all contain copper (Padhan et al., 2021; Pourang & Rezaei, 2021). It has been discovered that excessive copper concentrations in water are harmful to marine life. High copper uptakes have been linked to liver, kidney, and brain damage, as well as mortality. Copper in the soil hurts the microbial population. As a result, copper removal from wastewater is critical, because its toxicity for humans is between 100 mg and 500 mg per day. Copper concentrations in drinking water should not exceed 2.0 mg/L, according to the World Health Organization.

Anthropogenic and natural geochemical processes can both poison the environment with lead. This metal is widely employed in a variety of essential industrial applications, including the production of storage batteries, printing pigments, fuels, photographic materials, explosives, coatings, and the automotive, aviation, and steel sectors (Ghosh and Das, 2014; Ghosh et al., 2017b, c; Ghosh et al., 2018; Karthikeyan et al., 2007). Heavy metals are a key source of worry due to their widespread use in poor nations and their inability to degrade. Lead, a highly toxic and cumulative pollutant, has the potential to harm the neurological system, kidneys, and reproductive system, especially in youngsters.

A dye is a colored material with a specific affinity for the substrate to which it is applied. Pigments are commonly used to color products in industries such as textiles, paper, plastics, and leather. These companies' effluents frequently contain large amounts of dye waste. Synthetic dye molecules with different molecular structures, such as acidic, basic, azo, diazo, reactive, anthraquinone, dispersion, and metal complex, are widely utilized as coloring agents in the food, cosmetic, and textile industries. According to reports, over 100,000 dyes are commercially accessible, with an output of over 7105 tons per year (Kamal El-Dean et al., 2019). The global dye production rate is 7×105 metric tons per year, with 5–10% discharged as effluent. The wastewater produced by the dyeing and textile industries has a high biological oxygen requirement and a lot of colors, other hazardous compounds, and suspended particulates. Dyes are generally poisonous and carcinogenic or made from other recognized carcinogens. Aside from their toxicological effects, dyes' color is one of the earliest signs of pollution in wastewater. Water's aesthetic value and clarity are commonly affected by dye since even a trace amount makes the dye visible. When these dyestuffs are discharged into rivers and lakes, the dissolved oxygen concentration is lowered, resulting in anoxic conditions, which damage aerobic creatures. Because of its photolytic and chemical stability, a dye is exceedingly persistent. Dye slows metabolism, growth, and fertility and harms the heart, liver, kidney, and spleen, and causes lesions on the skin, lungs, eyes, and bones. As a result, the indiscriminate release of colors may risk bioaccumulation in the food chain. Synthetic dye poisoning of water bodies has become a global environmental hazard. These companies' effluents are highly colored, and these pollutants' disposal in receiving waters harms the ecosystem (Fu & Viraraghavan, 2001, 2002). It is widely acknowledged that their presence in the aquatic ecosystem is responsible for various environmental problems and can damage a variety of life forms. The marine ecosystem has sparked widespread concern because of its purported genotoxic, mutagenic, teratogenic, and carcinogenic consequences. It affects the liver, spleen, kidney, heart, skin, eyes, lungs, and bones and reduces food intake capacity, growth, and fertility rates. It also damages the liver, spleen, kidney, and heart and causes lesions on the skin, eyes, lungs, and bones (Maheshwari et al., 2021; Mashkoor & Nasar, 2021; Moorthy et al., 2021; Sharma et al., 2022).

Plastic waste is one of the solid wastes that can linger in the environment for a long period, causing harm to many terrestrial and aquatic species that are important components of biodiversity. Plastic garbage has become a major environmental issue in recent years as a result of increased consumption, manufacture, and disposal, as well as a lack of proper management. Plastic garbage is widespread, and it has a direct and indirect impact on ecosystem stability and biodiversity in most developing countries. Because production and consumption rates are increasing, the majority of plastic waste ends up in terrestrial or freshwater ecosystems, where it breaks down into micro and nanoparticles and spreads at a faster rate in our food chain, groundwater, surface water, and atmosphere, where it has toxic impacts on biodiversity, ecosystems, and ultimately the earth. Ocean gyres have become major hotspots for plastic trash in recent years, with macro and microplastics posing a serious threat to aquatic life. Plastic garbage is primarily generated on land, but it has a significant impact on aquatic life, such as sea turtles, which have been dropping in recent decades and are now classified as endangered species due to gastrointestinal tract obstruction and egg production blockage after ingestion. Many cetaceans, such as sperm whales, young tortoises, stickleback fish, beaked whales, humpback whales, and other aquatic mammals, are at risk of dying from plastic garbage in their bodies which causes a slew of serious problems. The ingestion of plastic garbage makes sea birds more vulnerable (Azzarello & Van Vleet, 1987; Gall & Thompson, 2015; Li et al., 2016; Schuyler et al., 2014; Serranti & Bonifazi, 2019; Sigler, 2014; Wabnitz & Nichols, 2010). Many planktivores and piscivores get their pray mixed up and consume the plastic which can cause them problems. The loss of birds, fish, and other water animals has a direct impact on species biodiversity. Plastic garbage ingestion and entanglement represent a threat to over 300 species of turtles, fish, mammals, and other aquatic animals, resulting in damage and mortality that suggest a significant loss of biodiversity. Plastic waste effects on fish, sea birds, whales, dolphins, and turtles have been studied as examples of ingestion and entanglement causing death in these aquatic creatures. These creatures are unable to remove themselves from plastic traps, and they die as a result. Small seals, sea lions, and small fishes were readily trapped in plastic debris and died as a result of malnutrition and lack of oxygen. Many of them have plastic fibers and microplastics in their bodies and are suffering from various disorders (Azevedo-Santos et al., 2021; Chowdhury et al., 2021; MacLeod et al., 2021; Seay & Ternes, 2022).

Effluents from the refinery are wastes largely used in the production of final goods like liquefied petroleum gas (LPG), kerosene, lube oils, gas oils, fuels, lubricants, and petrochemical intermediates from the refining of crude oil. These effluents contribute significantly to the pollution of the environment and aquatic life. The main components of the effluents include oil, grease, and numerous other dangerous organic compounds. The residue created by these effluents after refineries release them contains high oxygen demand (COD) levels, which is harmful to the environment. Because oil and grease are gooey, gluey, and sticky, they attach to the surfaces of pipes, clogging strainers, filters, and drain lines. They tend to move in a layer on top of the water and obstruct unit operations. Phenols pose a serious hazard to the environment since they are poisonous, have a high level of stability and accumulation, and can thus linger in the air for a long time, they cause cancer. These elements could seriously harm people's health while endangering the ecology of water bodies. Ammonia and hydrogen sulfide, are two extremely hazardous byproducts of nitrogen and sulfur, respectively (Chen et al., 2022). Sulfides significantly reduce the oxygen levels in the water bodies because they have a very high oxygen demand—roughly 2 moles of O_2 per mol of S_2. Therefore, discharging wastewater with high nitrogen and sulfur concentrations may increase fish mortality, especially if the limit exceeds 0.5 mg/L for freshwater or saltwater.

18.3 Available techniques to treat the pollutants

Different methods, including reverse osmosis, electrolysis, membrane filtration, sorptive floatation, precipitation, ion exchange, and activated carbon adsorption, can be used to remove the pollutants. The most popular method for removing hazardous metals from aqueous solutions up to the ppb range is precipitation. Some metal salts do not properly dissolve in water and precipitate when an appropriate anion is present. Although the method is cost-effective, its efficacy suffers when the pH is low and other salts are present (ions). The four approach requires the use of additional chemicals, which produce sludge with a high-water content and is expensive to dispose of.

Two categories of techniques are possible. since it is comfortable to use and has a lower running cost, heavy metal-containing waste effluent treatment. The removal of the metals in this procedure involves sedimentation and filtration after they have precipitated as insoluble hydroxides, carbonates, or sulfides. A different technique for eliminating heavy metal ions from contaminated water is flotation, specifically ion flotation. The foundation of ion flotation is the employment of surfactants to generate hydrophobic ionic metal species in wastewater, which are then removed by air bubbles.

a) Membrane technologies: Membranes for membrane adsorption use a dual membrane filtration and adsorption technique to efficiently remove minute amounts of nitrates, cationic heavy metals, and anionic phosphates.

b) Ion exchange: For the removal of heavy metals or the recovery of valuable metals, the ion exchange technique has become more and more popular. It is a flexible separation method with numerous potential uses in the realm of water and wastewater treatment.

c) Electrochemical technologies: Heavy metal ions are removed operating electrochemical treatment by electrocoagulation, electrooxidation, and electro flotation. It is a low-cost method, and the extraction of metals can be achieved; however, the operating cost is increased because of energy consumption.

Also, precipitation is not able to remove metals at low concentrations. Ion-exchange process is comparatively overpriced than other techniques for the removal of metals from the aqueous solution; it has the potential to attain a ppb range of cleanup while dealing with the comparatively huge volume of effluent. The drawback of this technique is that it is unable to deal with a concentrated metal solution as the matrix becomes fouled by other solids and organics present in the effluent. Additionally, the ion exchange procedure is non-selective and extremely sensitive to the solution's pH level. For the removal and recovery of metals from wastewater, the electrowinning process is frequently used in metallurgical and mining industrial operations, metal transformation, and electrical and electronics sectors. Heavy metals can be removed from wastewater using the electrochemical process known as electrocoagulation (Ayub et al., 2020). The discharge contains a variety of electrically charged contaminants. With the help of the electrocoagulation techniques given oppositely charged ions, these charged molecules are neutralized and precipitated (Shahedi et al., 2020). Semipermeable membranes must be used in reverse osmosis and electro-dialysis in order to extract metals from an aqueous solution. The methods discussed above have also been used to get colors out of aqueous solutions. However, these methods are not cost-effective for small and medium-sized businesses, necessitate significant installation and processing expenses, produce harmful by-products and end products, and in some instances, may not completely remove impurities. Therefore, it is necessary to create a method that is affordable for removing heavy metals and dyes from wastewater produced, especially for small and medium-sized enterprises.

The dual membrane filtration and adsorption technique used in membranes for membrane adsorption allows for the efficient removal of trace amounts of contaminants such as cationic heavy metals, anionic phosphates, and nitrates. Heavy metal ions are removed operating electrochemical treatment by electrocoagulation, electro-oxidation, and electro-flotation. It is a low-cost method, and the extraction of metals can be achieved; however, the operating cost is increased because of energy consumption.

18.3.1 Non-conventional methodologies

One of the finest methods for removing different pollutants, including heavy metals from water, is adsorption. Its great removal capacity, comparatively low energy consumption, operational technical requirements, and potential to prevent severe secondary contamination are only a few of its benefits. The use of organic matter found in wastewater to produce energy using a biocatalyst like bacteria makes microbial fuel cells (MFCs) a viable technology (de Sá Costa et al., 2021). Nanomaterials, which have a high surface area-to-volume ratio and have drawn particular attention in recent years due to their distinctive electrical, optical, and magnetic properties, are used in nanotechnology-based therapeutics (Ilame & Ghosh, 2022).

There are various feasible models and configurations developed and installed for refinery, and each is designed to attain a specific objective of converting raw crude into useful commercial products such as petroleum, naphtha, gasoline, diesel, kerosene, jet fuel, asphalt base, tar, and liquefied petroleum gas through the distillation of crude oil, cracking, reforming, and hydro-treating of unfinished petroleum derivatives.

To refine the crude oil, the refinery begins with the desalting operation of the crude and distilling it into different components and fractions. The next step is to convert these fractions to useful products by employing various complex processes like cracking, reforming, sweetening, hydro-treating, and alkylation. Other auxiliary operations include reformer catalyst regeneration, recovery of sulfur, i.e., sweetening process, and product mixing and blending. This section presents descriptions of these operations.

Refineries have been classified into three types based on the processing techniques and end products:

i. Topping refinery: It mainly consists of crude distillation to produce naphtha and other intermittent products except for gasoline.
ii. Hydro-skimming refinery: It refers to units such as hydro-treating units and reformers to produce finished gasoline but does not improve the heavier components of the crude oil that comes out from the bottom of the crude fractionation column.
iii. Upgrading or complex refineries: Long-chain, high molecular weight hydrocarbons can be broken down into smaller hydrocarbons using thermal and catalytic cracking/coking processes, which can then be used to make gasoline and other valuable products as well as feedstock for petrochemical complexes.

Among aerobic treatment, the activated sludge process (ASP) is the most frequently used biological treatment process to treat wastewater. ASP is an aerobic suspended cell system. To achieve a clean effluent from activated sludge treatment plants, the process should be capable of at least two major functions which are as follows: (1) stabilize the organic compounds by oxidation or conversion to biomass and (2) remove inorganic compounds such as ammonia and phosphorus or convert them to less harmful forms.

The “mixed-liquor” in the aeration tank is comprised of wastewater and microorganisms. An aeration tank and a sedimentation tank are used in the procedure (clarifier). A surface or sub-surface aerator system aerates the aeration tank. The wastewater flows through the tank while the microorganisms are consuming the unwanted organic matter from the wastewater. The liquid is then transferred to a clarifier where the microorganisms settle to the bottom.

18.4 Wastewater treatment plant

18.4.1 Primary treatment methods

To get rid of heavier elements like construction waste and floatable, inorganic trash, the primary treatment is essentially a physical procedure that uses gravity separation. As a result, the first stage of treatment always includes a screen, grinder, separator, sedimentation tank, etc. Heavy materials can drop down and lighter liquids can ascend above using these separators, which work on the basis of different specific gravities (Patel et al., 2020).

18.4.2 Secondary treatment methods

The secondary treatment methods may be classified as follows:

a) chemical method and
b) biological method.

18.4.2.1 Chemical method

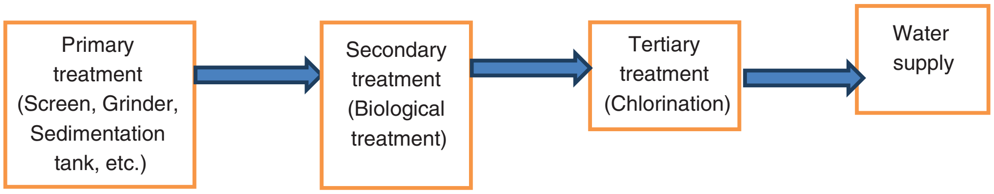
The major goal of a chemical approach is to remove emulsified oil with the addition of flocculating agents, as well as suspended particles and hazardous compounds, thus conditioning the effluents for biological treatment. After chemical treatment, sedimentation is usually used to remove suspended particles. The following four categories can be used to classify the various chemical approaches available:

a) neutralization,
b) method of precipitation and clarity,
c) method of chemical oxidation, and
d) regeneration technique.

18.4.2.2 Biological method

This is done to get rid of biodegradable organic compounds as well as hazardous chemicals like phenol. After the first treatment, the biological treatment also lowers leftover organic matter. Traditional methods such as trickling filters and ASPs, as well as low-cost waste treatment methods such as aerated lagoons and oxidation ponds, are used to treat wastewater biologically. Biochemical oxygen demand (BOD), hazardous substances such as chromium, lead, nickel, hydrogen sulfide, and others, as well as temperature, pH, and nutrition, all influence biological treatment procedures. Phytoremediation of polluted water is also possible by different plants (Aghelan et al., 2021; Ghosh & Manchanda, 2019).

A) Activated sludge: The activated sludge procedure is an aerobic biological treatment in which wastewaters are treated using microorganisms that are uniformly suspended within a reaction tank into which oxygen is injected mechanically. The oxidation process basically removes the organic content from the wastewater. An aeration tank is followed by a clarifier in the basic oxidation process. To maintain a high concentration of activated sludge, a portion of the activated sludge collected from the clarifier is recycled into the aeration tank. The activated sludge will continue to accumulate until part of it needs to be discarded (Waqas et al., 2020).



Flowchart of wastewater treatment.

Activated sludge is a mixed culture microorganism system. A large classification of microorganisms is present in the tanks. Major categories are as follows: bacteria, fungi, algae, protozoa, and viruses. Most common organisms are mesophilic and their sizes vary widely but are generally in the range of 0.5–3 μm. Higher species are also frequently observed in activated sludge systems such as flagellates, ciliates (free-swimming or crawling), and rotifers.

B) Trickling filter: A bed of broken stone or coarse material serves as the trickling filter. On the aggregate's surface, a gelatinous slime film formed from aerobic organism forms. Adsorption removes both dissolved and suspended organic debris when the wastewater trickles over the screen. During their metabolic operations, the slime creatures oxidize the adsorbed materials. By convection, air passes through the filter, delivering the oxygen required to sustain aerobic conditions. Before being discharged into a watercourse, the oxidized wastewater from the filter is cleared in a sedimentation tank (Deng, 2018).

C) Aerated lagoons and oxidation and stabilization ponds: In areas where land is plentiful, the oxidation pond is a popular type of biological waste treatment system. The bacteria in the oxidation pond are responsible for aerobically stabilizing the organic wastes that are added to the pond. The oxygen transport capability limits the organic loading on the oxidation pond. Oxidation ponds have been utilized to clean the effluent from different biological waste treatment procedures as well as to treat the total plant wastes. In oxidation ponds, retention times range from a few hours to more than 90 days. The reduction in organic matter is largely determined by the retention period and effluent concentration (Ali et al., 2020; Kaid et al., 2022). Surface aeration devices may be used in the first stage of oxidation ponds for refineries, allowing loadings up to 10 times that of typical oxidation ponds. In order to produce a high-quality effluent, conventional lagoons can be employed as a second-stage treatment. The "aerated lagoon" system is the name given to this system.

D) Membrane bio-reactor: A suspended growth-activated sludge system (biological reactor) is combined with an ultra-filtration (UF) or microfiltration membrane system using hollow fiber membranes in a membrane bioreactor (Gkotsis et al., 2017).

Organic wastes are degraded by microorganisms in the bioreactor, and the effluent is clarified by the membrane system. Carbon dioxide, water, chemical intermediates, and new microbes are all produced from waste.

- Inorganics, such as heavy metals, are removed from the biomass by sorption.
- To achieve de-nitrification, additional carbon will be added.

The bioreactor can handle larger biomass contents than traditional activated sludge systems while still producing high-quality effluent. This is achievable because the membrane works like an absolute barrier to sludge loss and, unlike a traditional settling clarifier, is not subject to upset at high biomass concentrations.

Using dedicated permeate pumps, clean water is pulled and released to a common collector header that empties into the treated effluent tank. This tank's permeate will be used to clean the membranes. Membrane tank drain pumps round out the system. These pumps are shared by all membrane trains and are used to drain the membrane tanks when necessary. The bioreactor using the activated sludge method will receive oxygen via a well-designed aeration system, such as diffused aeration. The membrane bio-reactor (MBR)-treated water is further polished in a reverse osmosis (RO) plant to produce product water that can be fed to the demineralization (DM) plant (Huang et al., 2022).

18.4.3 Tertiary treatment

If the effluent needs to meet strict restrictions for pollutants like odor and total suspended solids, tertiary treatment is required.

- Demand for chemical oxygen.
- Metals dissolved in water.
- Organic substances, such as poly-aromatic hydrocarbons, in trace amounts (PAHs).

Sand filtration activated carbon filtration and chemical oxidation have been used as tertiary treatment methods to remove taste, odor, and organics from biologically treated wastewater. These treatments, however, are highly expensive. Many refineries prefer to utilize oxidation ponds as a tertiary treatment following biological treatment. When adequate acreage is available, this is one of the most cost-effective treatment options (Crini et al., 2019).

The cleaned liquid wastes that meet the required tolerance criteria are then disposed of in a nearby stream, river, or sea by controlled dilution.

18.4.3.1 Sand filtration at high pressure (PSF)

The suspended particles' concentration in the effluent from the upstream secondary treatment is around 30–80 mg/L. In some nations, refineries must adhere to daily limits as low as 15 mg/L. In such cases, sand filters are one possibility. This involves putting wastewater through a sand filter material-filled filter bed. To release the trapped materials, the forward flow is occasionally stopped, and the filter is back cleaned. employing activated carbon for filtering (ACF) The dissolved organic components in refinery effluent that are not removed by primary and secondary treatment can be taken out using carbon adsorption. Activated carbon is generally used for the last "polishing" step. The organics in the wastewater are absorbed by the carbon bed as it transports the wastewater through a bed of granular activated carbon. The carbon bed is regularly refreshed to eliminate the organics from the exhausted carbon. In a chemical oxidation system, the following oxidation reagents are commonly used:

- Ozone
- Hydrogen peroxide (H_2O_2)
- Chlorine dioxide (ClO_2) (O_3)

18.4.3.2 Ultra-filtration

The hydrostatic pressure forces flow across a semi-permeable membrane in the UF process. The wastewater flows inside the shell or lumen of the hollow fibers system (membranes) in UF. Polyether-sulfone fibers are the most common type. Water and low molecular weight particles pass through the membrane, but suspended solids and high molecular weight particles are retained on the fiber. A UF system's average recovery rate is around 85–88% (Haghighat, 2018). UF system functions include reducing the silt density index, removing turbidity, and removing suspended and colloidal materials without the use of chemicals such as coagulants, flocculates, or pH adjustments.

At the molecular level, the reverse osmosis (RO) mechanism functions. The total dissolved solids (TDS) of the outflow permeate water is decreased because it separates the water's molecular impurities into two streams, one of which is rich in salt molecules and the other of which is poor in salts. TDS and silica will be removed to the level necessary to meet the refinery's TDS and silica requirements for recycling water. In industrial reuse applications, two-stage RO treatments are employed to create water appropriate for high-pressure boilers. TDS and dissolved organic matter are commonly removed by reverse osmosis in the range of 95–99.5% and 95–97%, respectively (Wenten, 2016).

Anaerobic wastewater treatment can be traced all the way back to the commencement of wastewater treatment. For well over a century, anaerobic techniques have been utilized to treat concentrated home and industrial wastewater. The most important factors to consider are the effect of oxygen, temperature, and pH on microbial cell growth. During the cell growth stage, these factors will have a significant effect on the physiological characteristics of the cells.

18.5 Water scenario at Himachal villages

Essential utilities including drinking water, sanitization, power, and drainage are necessary for a livable standard of living. In this article, rural households in India were highlighted using Census of India data from 2001 to 2011, but caste-based factors' contributions to the disparity in access to basic amenities among various social groups were estimated using the decomposition technique on household-level data and NSS unit record data during 2008–2009. Scheduled castes have been identified as the rural Indian households that are the most underprivileged, neglected, and spatially disadvantaged in order to improve the general level of life and wellness. The mean probability of access to basic amenities for upper group X (or scheduled tribes [STs], scheduled castes [SCs], or other backward classes [OBCs]) has been divided into "attributes' contribution" (contribution of non–caste-based factors) and "coefficient's contribution" (contribution of caste-based factors) for the purpose of examining the role of caste-based factors in the disparity in the accessibility rate of basic amenities among different social groups in rural India. The likelihood of receiving necessary facilities is lower for households in the others (livelihood groups). Comparing ST and SC homes to homes belonging to other ethnic groups, it was discovered that ST and SC homes were the least likely to have access to basic facilities, followed by OBC homes. These results on what influences rural households' access to necessities in the home demonstrate the wide socioeconomic gaps in rural India. The likelihood of having necessary amenities in the home was lower for STs, SCs, and OBCs as compared to the reference group of other households. The decompositions of the average gap between the probabilities of accessing basic services between different social categories point to discrimination and caste-based characteristics as the primary causes of these discrepancies. The results of breaking down differences in access probability to basic household utilities into characteristics and coefficient contribution reveal that coefficient contribution (or caste contribution) is important for STs and SCs. In India, 65% of rural families lacked access to clean drinking water in 2011. Throughout that time, 10.50 million more rural families did not have access to clean drinking water. Access to drinking water, restrooms, and closed drainage connectivity for wastewater output all improved more slowly between 2001 and 2011 than access to power in the home (Plan, 2008).

According to the study's findings, water resources need to be treated before consumption because they are susceptible to anthropogenic interference. For the Kullu Valley community in Himachal Pradesh to receive safe and sustainable water, it is crucial to regularly test the water quality and employ the appropriate treatment techniques (Thakur et al., 2018). The basin magnitude factor significantly influences the morphological management of the Giri watershed (Prakasam et al., 2021).

The growing population and a lack of suitable infrastructure for effective water treatment have led in the usage of accessible, sometimes contaminated, waters for human consumption, posing health risks (Loucks & van Beek, 2017). Many cases of water contamination have been recorded in the region's newspapers. There were reports of severe contamination of the Hathli stream in Himachal Pradesh. According to a study of 22 communities in the Kangra area, 20% of traditional water supplies are in disuse. The research was carried out in the districts of Hamirpur and Bilaspur, which are located in Himachal Pradesh's mid-hill submontane zone. The baories and wells are the primary traditional sources of drinking water, while the kuhls, khads, khatries, and nalas are utilized for other reasons. A baori is a centuries-old traditional drinking water source in Himachal Pradesh's lower area. According to the study, there are a variety of traditional drinking water sources in this Himalayan area. Wells, baories, and khatries are the primary traditional drinking water sources in the Hamirpur area, while Baories, wells, springs, and unlined wells are the main traditional drinking water sources in the Bilaspur area. Traditional water collecting technologies are more useful in situations where water shortage is severe or groundwater is too deep to be obtained affordably. With the development of piped water delivery, these methods have gone out of favor in many areas. The amount of water collected is limited by the size of the catchments. The revival of traditional sources will have to take into account the natural variety of the state. The people must have control over these systems, and the system must be founded on the people's wants and capacities. Groundwater recharge infrastructure should be developed in drought-prone parts of the state.

According to Patra et al. (2022), in Himachal Pradesh, gender ratio, annual family income, percentage of the below-poverty line (BPL) homes, percentage of pucca dwellings, and percentage of village population with a high school diploma all had a big impact on access to piped water in village households. There are 1553 different water sources in Himachal Pradesh, with piped water sources making up the majority—45.5% and communal taps the least—11.5%. Regarding Uttarakhand, piped water sources make up 45.3% of the total, while open wells account for 9.4%. Although piped water predominates in both scenarios, the water situation in Himachal Pradesh is far better than that in Uttarakhand. The number of distinct water sources varies depending on the population density, geographic location, and groundwater table accessibility. Urbanization and excessive resource consumption have indeed had a negative impact on sustainable use. Sewage treatment plants (STPs) are in charge of providing hygienic drinking water. Evaluation of groundwater potential for additional home uses is crucial since the development and management of groundwater are difficult tasks in both States (Patra et al., 2022).

For better drinking water, Uttarakhand is dependent significantly on its natural water sources. The ongoing deterioration of water quality brought on by unplanned urbanization, overfishing, rapid development, and other anthropogenic activities has made it easier for numerous species to invade. Numerous watery ailments like cholera, dysentery, and typhoid cause serious health problems in Uttarakhand. The goals of this study were to examine the health of the residents of Sumari village in Pauri, Uttarakhand, and to evaluate the water quality of the village's natural springs which are used for drinking water. These factors forced villagers in Uttarakhand to relocate to the neighboring plain region. They obtained data from five sampling sites in Sumari: SN1, SN2, SN3, SN4, and SN5 (Chauhan et al., 2020).

Urban (90%), other category of religion (84%) and each SC and non-SC (86%) and all quintiles have more than 90% and one member family (96%) used as septic tank/flush system as the source of drinking water. Freelance workers in urban areas (84%) in non-agricultural sectors (61%), other (60%), Phi SC (36%), a family of three (55%) and the richest (66%) used LPG is more than rural (21%) as a source of cooking fuel respectively. Sanitation and drinking water systems are gradually being installed in all districts of Himachal Pradesh. The government must regulate policy regarding drainage improvement and cooking fuel improvement in Himachal Pradesh (Rana, 2018; Rana & Chopra, 2013).

Also, another study indicated that 350 tons of waste are produced daily in Himachal Pradesh, although the daily waste generation rates in each study region (Sunder Nagar, Mandi, Baddi, and Solan) are reported to be between 18 tons/day and 22 tons/day (Sharma et al., 2018).

18.6 Conclusion and recommendations

Access to adequate housing and basic amenities, such as clean water and sanitation, is essential for evolution. In developing countries, such as India, access is unevenly distributed and the poor remain deprived of full housing. Traditional water systems must be re-examined, reinvestigated, and protected in order to fulfill the growing water demand caused by population growth, urbanization, and industry. Participation in public and environmental education is critical and should be promoted. The water quality of all traditional sources must be checked on a regular basis, and a database must be created.

Heavy metals are not biodegradable; which increases in concentration over a period of time as they tend to bioaccumulate and the concentration of heavy metals present in the water sources decides the treatment process which now and then is not economical. There are various methods to tackle heavy metal water pollution. It is essential to select proper detection and measurement methods, treatment technologies, and working constraints. Although we have several existing methodologies but there is a need for exploring fast, economical, reliable, and sustainable techniques to tackle this issue. Pollution abatement and reduction procedures may encompass effluent generation prevention and end-of-pipe treatment systems. Minimize total dissolved solids in the cooling water to reduce cooling tower blowdown. Removing calcium carbonate from makeup water, reverse osmosis, or electrodialysis treatment can help. Reduce evaporative losses, limit surfactant use, separate clean run-off water from process sewers, prevents particles from entering sewers, use mercury-free caustic in FCC, and replace chromate-based anti-corrosives in cooling towers and heat exchangers with less harmful options such as phosphates can be incorporated. Desalter makeup can be made from steam-stripped acidic water or other treated wastewater can be done. Makeup water from treated wastewater from off-site locations can be used.

A circular economy follows the 3R approach, which mainly includes reducing, reusing, and recycling. Waste production is minimized in this approach, as the goods are recycled and reused. These goods are used by a wider range of consumers. In this method, value is created by focusing primarily on preservation. The focus is on enhancing the eco-effectiveness of the system. The ecological impact is minimized as much as possible. Ecological and economical societal systems are strengthened as a result of it.

Rural households in India have seen a modest improvement in access to basic services but they still confront significant deprivation. When essential facilities are available, the household can save time spent arranging them when they are not available in day-to-day life. Its significance has been emphasized on a global scale since it was included in the Millennium Development Goals.

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Chapter 19

Water challenges in rural–urban fringe villages: A case of Potheri village near Chennai, Tamil Nadu

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19.1 Introduction

The rural–urban fringe areas are land tracts on the urban edge, outside but along a statutorily defined city's boundary (Gallent, 2006). These are highly valued land with the prospects and opportunities for future development associated with a growing and expanding urban area (Pryor, 1968; Scott, et al., 2013). The understanding of the rural-urban fringe lies in the characteristics of the development on the land. These areas see a rapid conversion of land cover from agriculture to non-agriculture urban-like use (Goel, 2011). However, these areas remain rural due to the rural governance arrangement.

The development of fringe areas pan out along the major transportation corridors and is characterized by the coexistence of modern shopping centres, educational institutes, service sector offices, and recreational facilities alongside rural uses of farming and pasturing. Disjointed construction activities are prevalent. There are stark differences in the housing of the traditional low-rise individual houses of village dwellers and the swanky gated apartment complexes developed for modern group housing. The influx of population with the urban culture is also distinctly different from the existing rural social fabric. In the fringe villages, there is an acute increase in population and population density in pockets (Nisha, 2015). The city's expansion outside the city's administrative boundaries is led by the demands of the economic activities in the city (Nallathiga et al., 2015). As buildable land is available and is comparatively cheaper in the fringe villages, new housing stock is built here to supplement the requirement of the population working in the city (Nadh, 2022). Industries that cannot afford land in the city, develop in the fringe villages with the additional benefit of easy access to regional transport corridors. Educational institutes require large land areas for recognizable campuses located on the fringe as they do not find space to expand in the city. However, urban infrastructure services such as water supply, sewerage networks, solid waste management, access roads, etc. are incomplete or absent (Clouser, 2015). In fast-urbanizing countries like India, the institutional setup to manage the fringe areas is fragmented. There may not be a clear or distinct authority for land management, infrastructure provisions, and other services in these areas. Even though these areas are transforming into urban settlements and demand urban provisions, they may still be governed by rural or regional institutions, which may be inadept to cope with the changing demands. Development is haphazard and lack the necessary basic amenities, forcing the dwellers to make alternate arrangements. Moreover, the rural-urban fringe may also suffer from hosting unwanted but necessary uses from the cities, such as garbage treatment centers, landfills, transit zones, and various distribution warehouses which has a negative impact on the dwellers of the fringe areas (Hara et al., 2008; Nadh, 2022). While the fringe areas struggle to meet their infrastructural needs, these negative externalities further degrade the environment through pollution (Gajendran, 2016). Water supply or access to portable water, a necessity for survival, is one such concern in the fringe villages.

19.2 Water challenges in fringe villages

19.2.1 India's rural water scenario

It was found in the 69th National Sample Survey Organisation (NSSO) survey in 2012 that 88.5% of rural, i.e., village homes have a reliable source of drinking water, including taps, wells, and hand pumps. This impressive proportion of water access was achieved as a result of revolutionary water

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supply programs of the Government of India in partnership with the United Nations International Children's Emergency Fund (UNICEF), where hand pumps and bore wells were installed at the community as well as household levels in the villages between 1967 and 1990. Hand pumps continue to be the principal source of water for a large proportion of the rural population in India, even today (Mudgal, 1997). The hand pumps serve the primary motive of access to water and are considered an improved technology over the traditional wells that are prone to pollution (Prasad & De, 2016). However, they are not completely reliable and do not guarantee protection from groundwater contamination. The use of handpumps is directly associated with the problems related to groundwater. India is the largest extractor of groundwater, and 25% of the total groundwater extracted in the world is in this country (Vora & Shetty, 2019). The excessive dependence on groundwater was, in fact, created by the very policy that enabled access to water. The development of newer groundwater sources for irrigation and consumption was promoted, resulting in unchecked groundwater extraction to a degree where extraction was more than the recharge rate, and the water table was reduced. Almost 40% of the talukas/blocks of India are at a critical level of groundwater extraction. This, in turn, risks the chances of hand pumps (the primary source of water for many) running dry and damages the aquifers. Several governments are in the process of regulating and restricting the use of bore wells and hand pumps to tackle groundwater depletion. Less water in the aquifers also means the concentration of ions and other minerals could be high, making the water unfit for consumption (Singh & Singh, 2022). The presence of arsenic or fluoride in water poses graves health challenges. Moreover, contamination of groundwater due to infiltration of pesticides and fertilizers from farms, untreated chemical waste from industries, and untreated human and domestic waste are also prevalent. The wear and tear of the hand pump itself is also a concern, with studies showing that rusting or uncleaned hand pumps may also lead to metal and microbial contamination (Ferguson et al., 2011). Occurrences of draughts have further worsened the groundwater situation, and the implementation of rainwater harvesting and groundwater recharge strategies is not widespread and fails to solve the problem. Contaminated groundwater is increasingly becoming a source of health hazards.

The National Rural Water Quality Monitoring & Surveillance Programme launched in 2005 was an attempt to check and address the water quality challenges. The National Rural Drinking Water Programme (NRDWP) launched in 2009, aimed to increase access to water in rural communities, schools and Anganwadi, and provide portable water through the piped water supply. The piped water supply of treated water is considered as an improved and safe source. However, it was reported in the census 2011 that only 30.8% of the rural households had taps receiving treated and safe drinking water. The per capita quantum of water considered for this proportion is only 40 lpcd, grossly less than the agreed benchmarks (Ministry of Drinking Water and Sanitation, 2015). Moreover, this figure indicates the installed capacity and the ground realities may be different. With the central government missions of Jal Shakti Abhiyan and Jal Jeevan Yojana, the proportion of rural households with tap connections has now reached a level of 53% (Ministry of Jal Shakti, 2022). Community participation in planning, implementing, and monitoring localized water supply projects are an integral part of the Jal Jeevan Yojana. In general, the trend is now of water access through the piped water supply. Groundwater use is unsustainable and does not align with our current Sustainable Development Goals, further supporting the cause of piped water supply. There is also increased advocacy and effort in regulating groundwater use.

Even though Jal Jeevan Mission is participatory in nature and encompasses most of the concerns of rural water supply, including monitoring and maintenance, by itself, it cannot resolve the entire gamut of rural water challenges. The water infrastructure construction with an installed capacity is remarkable, but the success stories of functional water taps remain few. If a dependable primary water source is not available, then running water in taps cannot be ensured. The gram panchayat would continue to depend on groundwater extraction for water distribution, and the underlying challenge of water quality may not be addressed (The Economic Times, 2021). Only intermittent water supply is expected in the villages, which may be cherished in draught and water-stressed areas that had women drudging for hours to fetch water. But for areas where the water tables are high, and hand pumps provide 24 × 7 water, the benefit of the water in taps for a scheduled or unscheduled few hours is lost on the villagers (Thakur, 2021). The reliability of running water is not yet established. Operating a village-wide piped water supply system costs money that has to be jointly managed through villagers' contributions, gram panchayat (village administration), and state governments. In poorer areas, even managing the operational finance could be a burden to the gram panchayat resulting in a disruption in the water supply. Moreover, a piped water supply system requires a sufficient and timely power supply, which is not reliable in the villages (Srivastava, 2022). In the fringe areas, while some of the challenges are consistent with the other rural areas, they also face unique capacity and governance challenges.

19.2.2 Water resource constraints in fringe villages

The water resource availability in a region is constant and limited. The unprecedented urban population growth and the resulting increase in water demand in a region cannot be matched by the augmentation of the water supply in the short run (Citizens Alliance for Sustainable Living [SUSTAIN], 2005). The increased demand for water in fringe villages is a combination of several aspects, some of which are mentioned below (Gajendran, 2016):

a) Domestic purpose of the previous village households and the additional households as a result of new development.
b) Water for construction activities as a result of city growth and increased development in fringe areas.
c) For irrigation of land that is still under agricultural use.
d) For industrial purposes. A city mainly grows as a result of increasing economic activities, and industries are one of them. Some industries are water intensive where water is the primary raw material, such as cold drinks, wineries, etc. These industries are mostly located on the fringe for easier access to agricultural produce (for raw material), comparatively lower land prices, and yet access to the market in the cities.
e) Commercial and institutional properties which require large land parcels are located on the fringe and have substantial water demand.
f) Gardening and public places, if they exist, will have a water demand.
g) Commercial use by water tankers, water packaging industries, and other private operators who supply water in the fringe area.
h) The water from the fringe also meets the demand for water from the central city. Tankers, private operators, and even authorities assimilate water from the fringe sources to meet the water demand of the main city (Deepika, 2017).

As the change and development in this area is rapid and unpredictable, there is no adequate infrastructure for bulk water generation or distribution, nor a set authority or method to manage the same. Laying dams or bulk water-boosting infrastructure are mega projects of long-term perspectives, and they eventually do not keep up with the increasing demand. The existing dams and reservoirs serving the region affect the area's hydrology because of fluctuating flow in the rivers. Additionally, the surface freshwater sources in the fringe area are prone to rapid degradation and loss in the form of pollution, encroachment and reclamation (Ramachandraiah & Prasad, 2014). The fringe areas downstream of the rivers emerging from the cities are highly degraded and unsuitable for use, especially during the low-flow season (Arya & Gupta, 2013). Therefore, the water from freshwater sources in fringe areas is inadequate and unsuitable but nevertheless exploited for use.

The situation has forced many private properties and even authorities also to pump water from the lakes, rivers, and other water sources using heavy-pressure pumping machines from deep aquifers due to the drying up of shallow aquifers in summers (Abia et al., 2017). Water extraction by gated residential societies and commercial and industrial establishments may go unchecked. Pumping of groundwater is an environmentally unsustainable practice and could lead to major environmental threats of hydrological draughts if the extraction is more than recharge. The unprecedented water extraction has become a concern and is posing several regulatory and compliance issues, especially in the fringe villages, as discussed in the next section.

19.2.3 Water governance challenge in fringe villages

A major challenge in meeting water demands is the spread of the responsibility across various institutions and ministries, requiring coordination and negotiation. Which authority should be responsible for providing water in the fringe area is debatable. While the 74th Constitutional Amendment Act of India requires Urban Local Bodies such as municipalities and municipal corporations to ensure treated water supply in its jurisdiction, the fringe is outside their purview (NITI Aayog, 2021). Metropolitan cities typically have a metropolitan or urban development authority that may be involved in creating urban infrastructure. The metropolitan authority has jurisdiction over areas surrounding large municipal corporations encompassing other urban and rural areas. But, these authorities do not have elected bodies, nor do they enjoy the taxation regimes of municipal corporations. Instead, they are more involved in land governance and management. Ensuring quality water supply does not figure in their priory responsibilities. The rural governments (gram panchayats) who otherwise spearhead the water supply projects in villages, on the urban fringes or in urban villages do not have the capacity or resources to address the rampant development and population growth needs. The fringe villages possessing features of urban areas, with the potential of joining the urban area in the future, desirably should have a modernized water supply system. A modern water supply system at par with the guidelines of the Ministry of Housing and Urban Affairs must have a system that is hydraulically modeled, smart with GIS and SCADA mechanisms, streamlined with a method for regularising connections, financially sustainable with metering, billing and user charges, etc. (Central Public Health and Environmental Engineering Organisation, 2021). A gram panchayat or a temporary agency does not have the capability or even the authority to implement such a project. In some cases, there may be parastatal agencies like water supply boards responsible for providing water in the urban as well as rural areas in the fringe and the metropolitan areas (Kumara, 2013). However, their roles are more associated with the operation of dams, distribution of water for irrigation and domestic consumption, construction of infrastructure, etc., rather than operating piped water supply systems at the local area or village level. They may not be able to address the needs of smaller demand units of villages. The implementation strategy of Jal Jeevan Mission is distinctly divided into rural and urban, leaving out the unique challenges of the rural-urban fringe where there is a combined demand for irrigation, industrial use as well as high domestic consumption. The governance of water supply in the fringe area is thus complicated and suffers from severe backlogs.

The attempts to regulate groundwater are vexed with lobbying and vested agendas of those who exploit it for commercial purposes. Until 1970, with water access in focus, much of the activity in groundwater was towards ways to use it rather than conserve it. The necessity of preserving and recharging it were later additions, and ring-fencing the acts, rules and institutions to do the same are not yet established. The Central Ground Water Authority (CGWA) was established as late as 1986 under the Environment Protection Act to regulate and protect groundwater. The CGWA issues renewable No Objection Certificates (NOC) for the use of groundwater. The status of the groundwater of the blocks plays a critical role in the decision. This creates uncertainty and is often influenced by economic decisions (Hindustan Times, 2020). The state groundwater acts were enacted with Punjab in 1998, Gujarat in 2001, Tamil Nadu in 2003, Bihar in 2006, Maharashtra in 2009, Karnataka in 2011, Uttar Pradesh in 2019, and so on. State and district groundwater authorities are to be established whose role will be to register sources of groundwater, including wells, bore wells, hand pumps, etc., monitor the groundwater levels, ensure recharging, regulate and license the use, etc. There have been instances where during a drought, the illegal extraction points were sealed and subsequently regularised, but largely, the institutional mechanisms and rules are not streamlined, and monitoring is extremely patchy. The most rampant lifters of groundwater in fringe village areas are the tankers which are mostly unregulated, and there is no distinct authority responsible for monitoring their business, service, and water sources (Cullet & Koonan, 2017; ELR; Gadgil, 2020).

19.2.4 Alternate water sources and associated issues

Piped water connection and running water in the taps are limited in the fringe areas. Hence the dwellers of the fringe areas are left with no choice but to depend on multiple, unreliable, and often unregulated water sources (Ranganathana & Balazs, 2015). Following are some of the sources of water in rural fringe areas and the problems associated with them:

a) Well water: Wells have traditionally served as the primary water source for domestic consumption. Many of the villages in the fringe area may have community wells as well as personal ones. However, they may not have water in the dry season and are exposed to contamination. The prevalence of construction of multiple basements underground may affect shallow aquifers and reduce the availability of water in these wells. If left open, they can also pose safety issues. For the fringe village's urbanized areas, water drawn from wells will have to be through pumps.

b) Hand Pump: Considered a primary source of water in rural India, in fringe areas, they may only supplement as public sources and in poorer areas and village hamlets. They are not a viable source for multistory residences and are not consistent with the urban lifestyle prevailing in the fringe villages.

c) Tap water by gram panchayat: They have limited coverage with intermittent supply. But if the gram panchayat or a water board provides treated potable water, it is common in fringe areas for people to use this water for drinking and cooking purposes. However, the main source of water for the gram panchayat itself may be unreliable, or they may not have the capacity to treat it before distribution. Some gram panchayat may manage the local distribution of water from a water board.

d) Private bore wells/pumps: In multistory housing societies and institutions, bore pumps may be present since the construction times and serve as a fallback option. However, apart from the environmental challenges, the groundwater in the fringe areas is not potable and poses health risks. Treating groundwater at home is an expensive affair and not possible for many. Private bore wells are not affordable for those who are not wealthy or do not stay in society.

e) Tanker water: The tanker water supply is one of the most widespread sources for societies and modern establishments in fringe villages. However, there are several concerns regarding them. They are only available for organized groups. Fetching water from them is a challenge for the poor, and infrastructure for storing this water for the affluent. Their cost is substantial, yet there is no guarantee for the water quality or their original source. They are not regulated, and no grievance redressal system may exist. Availing of water from these sources are expensive affair (Allen et al., 2006), and there is no guarantee or check on the quality.

f) Packaged water: Scepticism about the quality of water has led to a boom in the business of packaged drinking water which households and restaurants on the fringe mainly consume. There is a system of licenses for manufacturing packaged water, and it is regulated to maintain quality standards of Bureau of National Standard requirements IS 14543 and through ISI and FSSAI certification (Sudarsan & Renganathan, 2014). Studies have confirmed that most licensed brands maintain the required quality. But as they are pricy, people, mostly the poor, depend on local and cheaper packaged water whose certifications could not be ascertained, and their quality is below the required standards (Singla et al., 2014).

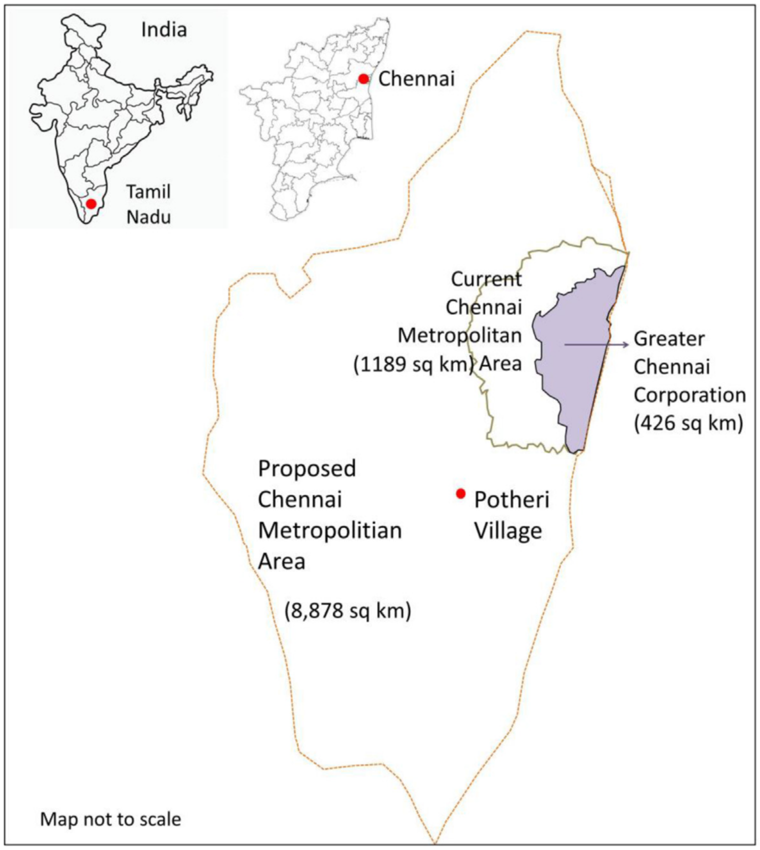

FIGURE 19.1 Boundaries of Chennai.

19.2.5 Water quality concerns in fringe villages

Given the additional lack of solid waste management and sewer systems on the fringe and the added industrial activity here, groundwater and water body pollution is high. Lack of sewer system means homes on the fringe have septic tanks or soak pits. Due to space constraints, many may have their rainwater harvesting tanks, wells, and underground water storage near their septic tanks. In such a scenario, if the septic tanks are not well maintained, then there is a high probability of leeches into surrounding areas contaminating the stored water and groundwater and worsening the microbiological quality of the water (Mondal et al., 2014). The water provided by the authorities undergoes a thorough treatment process and meets the required quality standards at the pumping stations. But the distribution network in the fringe areas is incomplete, inefficient and prone to breakdown due to fluctuating water flow led by irregular development and water demand. Contamination of the treated water is a huge concern as the quality of this water is trusted by the consumers, and tap water is generally not tested for its quality at the consumer end (Rasekh & Brumbelow, 2014).

Poor quality of water creates the burden of water borne diseases, and quality checks are essential (Gibson & Brammer, 2013). The next section examines water quality in and around Potheri village, located in the fringe area of Chennai, India. This study focuses on quality analysis of different sources of water used for domestic purposes in Potheri village and compares with prescribed standards to ensure available water quality.

19.3 Water challenges in fringe villages of Chennai

The Chennai Metropolitan Area (CMA) governed by Chennai Metropolitan Development Authority, is spread across three districts of Chennai, Thiruvallur, and Kancheepuram, covering 1189 km^2. It comprises the Chennai Municipal Corporations, 8 municipalities, 11 town panchayats, and 179 village panchayats (CMDA, 2022). This boundary of CMA was carved in 1975 and since then it has almost nearly urbanized, with nearly 50% under built-up land cover and only 20% under agriculture (Mathan & Krishnaveni, 2019). It has faced a decadal population growth rate of more than 33%. Although the boundaries of the Chennai district representing the core corporation area were expanded in the past, the boundaries of CMA were set to increase only in recent times after 45 yr (Srivathsan, 2018). This has resulted in fringe area development with urban-like characteristics even outside the CMA boundary. The boundaries of Chennai City and the current and proposed metropolitan area is indicated in Fig. 19.1.

Tamil Nadu Water Supply & Drainage Board (TWAD) is a statutory authority that plans and executes water supply projects throughout the state. Once constructed, it is the Urban Local Bodies that have to operate and maintain them. The Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) known as Metrowater is the statutory body responsible for water supply in the entire Chennai Metropolitan Area (CMA). The Metrowater sources the bulk water from various river basins, abstracts from groundwater, engaging private wells, extraction from lakes, desalination plants, etc, routes through various treatment plants and sends it into the distribution network. Chennai has also become one of the first cities in India to implement a water recycling plan to meet the demands of water for industrial use. With this, it is able to cover only half of the water demand of CMA (Citizens Alliance for Sustainable Living [SUSTAIN], 2005; CMWSSB, 2018) Thus, it is apparent that the CMWSSB will be unable to solve the water challenges in the areas of expanded CMA. Chennai and its surrounding areas suffer from chronic water shortages, and 66% of the households have private wells to meet their needs. Water tankers mainly extract groundwater from the fringe and rural areas to supply to the city residents, thereby making the surrounding areas further water stressed (Gajendran, 2016; Guntoju et al., 2019). For the chosen study area of Potheri village, the village Panchayat is the governing authority here that is responsible for water supply. They do so by extracting groundwater from the traditional village areas. In the recently developed areas, people employ multiple mechanisms, from rainwater harvesting and bore wells to packaged water to meet their demand for various uses, and the quality of water remains a major concern.

19.3.1 Case of Potheri village

Potheri village is 15 km from the current CMA boundary but will be in the CMA expanded boundary. It is along a major highway that connects Chennai with the satellite town of Maraimalai (4 km from Potheri) and further to the city of Nagapattinam. The area has traditional village settlements, farmlands, and village lake, along with large higher education campuses, industrial estates and modern residential societies. The village suffers from the typical water challenges of a fringe village. The gram panchayat provides limited treated water through the tap connection. The main source of gram panchayat water is groundwater which is disinfected with a basic procedure before distribution. Most properties in the area depend on bore well-extracted groundwater for regular needs and reverse osmosis (RO) or packaged water for consumption. Those unable to afford the same depend on less reliable sources of lake water extraction and community wells.

TABLE 19.1 Details of Samples collected and abbreviations assigned.

Samples	Source
A	Potheri lake
B	Tap water
C	Groundwater
D	RO water
E	Packaged can water

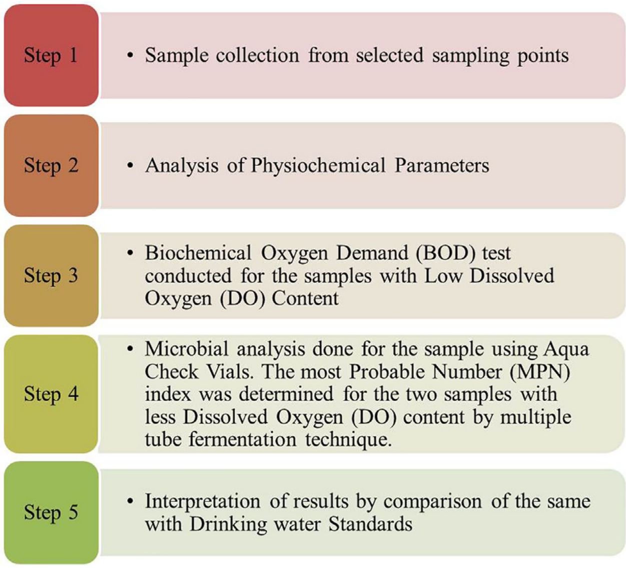

FIGURE 19.2 Flow chart showing methodology adopted for the water quality testing.

19.3.2 Water quality parameters, sampling, and testing

The parameters color, odor, pH, turbidity, alkalinity, dissolved oxygen, total hardness, chloride, and free residual chlorine and coliform bacteria are considered for water quality (Omer, 2020; Senthilnathan et al., 2011). Five samples from different sources of water used for domestic purposes were collected and analyzed for physicochemical parameters, and bacteriological analyses were done for those samples whose DO levels were found low (Senthilnathan et al., 2011). The sources of samples and their abbreviation are shown in Table 19.1.

Fresh samples were collected in sterile, sealed and labeled polyethylene bottles of 1 L. The methodology adopted is shown in Fig. 19.2. The samples were taken to the laboratory and analyzed for their physicochemical parameters using the methods listed in Table 19.2.

The parameters pH, turbidity, total dissolved solids, and dissolved oxygen were determined using a pH meter, nephew-turbidity meter, TDS meter and DO probe, respectively. The rest of the parameters were estimated by titration.

TABLE 19.2 Analysis method for water quality parameters.

S. no.	Parameters	Method of analysis
1	Color	Physical observation
2	Odor	Physical observation
3	pH	pH meter
4	Turbidity	Nephelo-turbidity meter
5	Alkalinity	Titrimetric method
6	Dissolved Oxygen (DO)	DO probe
7	Total hardness	Ethylene Di-amine-Tetra-Acetic Acid (EDTA) titration
8	Chloride	Titrimetric method
9	Free residual chlorine	Titrimetric method

Phenolphthalein and methyl orange were used as indicators for determining the total alkalinity of the sample by titrating against Hydrochloric acid (HCl). Erichrome black-T and potassium chromate were the indicators used in determining total hardness and chloride ions, respectively, whilst titrating against EDTA and a standard solution of silver nitrate in the same order. The water samples are against a standard solution of sodium thiosulphate using the starch indicator for analyzing residual chlorine.

The samples whose DO levels were found very low were analyzed for the Biochemical Oxygen Demand (BOD) test in accordance with IS: 3025 by determining day 0 and day 5 DO levels and subsequently finding out the BOD from the data thus obtained.

All the samples were subjected to microbial analysis. Samples C, D, and E were analyzed using aqua check vials and samples A and B were subjected to microbial analysis using the multiple tube method. The samples were analyzed using the multiple tube method, which proved very effective in the analysis of coliforms expressed as MPN or the most probable number. The sample is prepared in different dilutions and is inoculated into the culture medium contained in multiple tubes before incubating at a constant temperature for a definite period. The inverted gas tube provided inside the multiple tubes collects the gases produced as a result of microbial metabolism, indicating the presence of coliforms. The result is then expressed as the number of tubes that show a positive reaction (Odonkor & Ampofo, 2013; Omezuruike et al., 2008).

19.4 Findings and discussion on water challenges in Potheri Village

The water quality from different sources of water used in Potheri Village was tested and the results are explained in Section 19.4.1. The problems and possible solutions are then discussed.

19.4.1 Results of water quality testing

The result summary of the water quality tests conducted on different sources of water in Potheri village is shown in Table 19.3.

TABLE 19.3 Results of physiochemical analysis of water samples collected and tested.

Samples versus parameters	A (Mean)	B (Mean)	C (Mean)	D (Mean)	E (Mean)	IS standard (IS:10500-2012) desirable limit	IS standard (IS:10500-2012) permissible limit in the absence of an alternate source
Color	Creamy with a green tinge	No color	No color	No color	No colors	No color	No color
Odor	Nil	Nil	Nil	Nil	Nil	Nil	Nil
pH	8.13	7.5	7.29	7.3	8.4	6.5–8.5	No relaxation
Turbidity (NTU)	26.3	7.1	2.9	2	3.5	5	10
Total alkalinity (mg/L)	625	400	300	100	125	200	600
Total hardness (mg/L)	325	1060	575	140	150	300	600
Dissolved oxygen (mg/L)	2.8	2.5	3.1	3.9	3.5	–	–
Chloride (mg/L)	449.9	712.3	327.4	45.0	100.0	250	1000
Free residual chlorine (mg/L)	0	4.3	0.7	2.3	4.4	0.2	1

The pH value result ranged from 7.3 to 8.4, which indicates an alkaline pH, even though the pH of all samples are found within the desirable limits as prescribed for drinking water standards. The turbidity analysis showed that Samples A and B exceeded the desirable limits and hence could not be recommended for drinking purposes. The total alkalinity of samples varied from 100 mg/L to 625 mg/L. The prescribed limit of alkalinity of water is less than 100 mg/L. The high content of alkalinity is shown in Table 19.3 except for RO water, and packaged drinking can water. Total hardness studies revealed that the alkalinity of groundwater and tap water exceeds the safe limits. It is advisable to either remove the hardness or at least reduce it to an acceptable level with the help of any suitable treatment methods before consumption even though the hardness of water has not been known to cause any immediate adverse health effects, but prolonged use can definitely cause. According to IS, the maximum desirable limit for chloride is 250 mg/L. Three samples A, B, and C, yielded very high values compared to the desired water limits though within permissible limits. This may be mainly due to the high temperature during the summer season in which the analysis was done.

Analysis of DO content in water showed that Samples A and B's DO content is less than 3 ppm, which is not considered an adequate quantity of DO in a water sample. For a water sample to be used for domestic purposes, the DO content should be a minimum of 4 ppm. For further analyzing of the demand for dissolved oxygen in water BOD of Samples A and B are analyzed. The DO values for day 0 and day 5 for Sample A were 8.9 ppm and 8.1 ppm, respectively, and that of Sample B was 9.8 ppm and 8.6 ppm, respectively. The BOD calculated for Samples A and B was 6.09 ppm and 14.21 ppm, respectively. This clearly indicates that organic matter is present in these two samples, and bacteria are decomposing it, emphasizing the need for microbial analysis of water samples.

TABLE 19.4 Result of multiple tube test.

MPN index and 95% confidence limits for various combinations of positive results with five tubes per dilution (10 mL, 1.0 mL, 0.1 mL)

Samples	Combination of positives	MPN index/ 100 mL	95% confidence limits (approximate)	
			Lower	Upper
Sample A	5-4-1	170	70	480
Sample B	5-5-4	1600	600	5300

The bacteriological analysis using aqua check revealed contamination in Samples A and B. The samples are further analyzed using the multiple-tube method. The test gives the most likely number of coliform bacteria rather than the actual number. The results of the multiple-tube test are tabulated in Table 19.4.

The test confirmed that both the samples are contaminated with coliforms, with Sample A having an MPN index of 170 and Sample B having an MPN index of 1600. Fig. 19.3A–D shows the positive results for Samples A and B in double-strength and single-strength lactose broths.

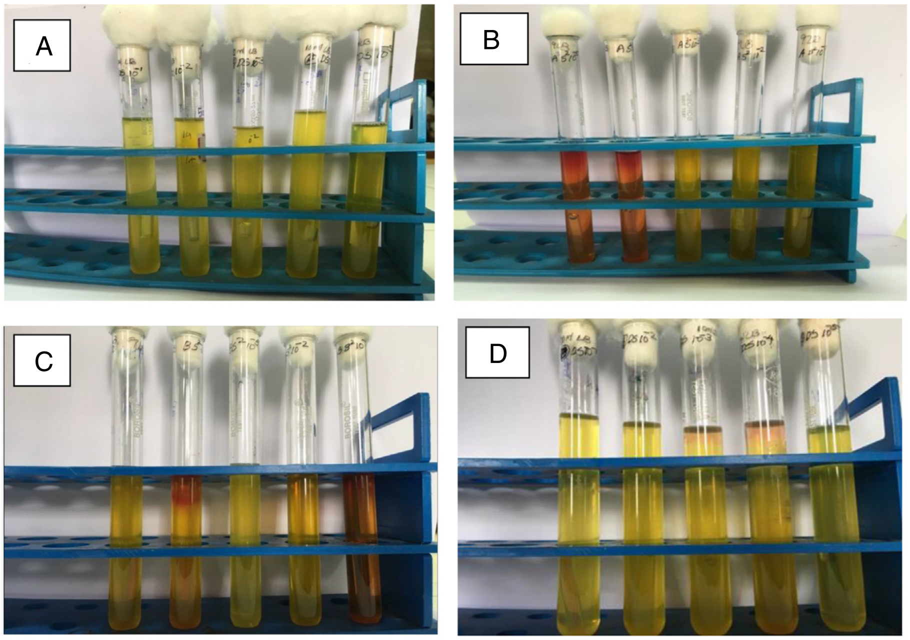

FIGURE 19.3 Figure showing a positive result for Sample A (A) single strength lactose broth, (B) double strength lactose broth and sample B, (C) in single-strength lactose broth, and (D) double-strength lactose broth.

Both the values exceed the IS standards (Sharan et al., 2011) and hence cannot be prescribed for drinking or other domestic uses such as bathing, cooking, swimming, etc. without proper treatment. Further evaluation through methods of enumeration in Legionella pneumophila, from potable and related water samples can be conducted.

19.4.2 Discussion

The installed capacity of the gram panchayat water supply system is insufficient and the water quality is not reliable as shown in the study. They cannot serve the requirements of the entire village, especially the rapidly urbanizing areas increasingly occupied by educational institutes and modern residential societies. There are two freshwater lakes in the area that had traditionally played a key role in water management. Firstly, the rainwater got collected in these lakes due to the natural topography. They, in return, ensured groundwater recharge and maintained a suitable water table. They were a source of water for irrigation as well as domestic consumption. Now, there are nearly 500 identified encroachments on the lakes (Sundaram, 2022). Stormwater drains constructed to flush out the rainwater carry untreated sewers that ultimately pollute the lakes. There is also waste from the bus depot and municipal waste for the surrounding areas being dumped here. Overall the environmental condition is grim, and the water quality of the lake are unfit for consumption without substantial treatment like RO. These, in return, can pose severe health challenges.

The quality and quantity of the current day water supply system are inefficient and ineffective. The problem is multi-layered, starting with the inability to gauge the demand for water in Potheri village, which is rapidly urbanizing. There is no institutional and governance clarity as to who should frame a water supply project for the area, how a water supply scheme should be envisaged for a dynamic area in the rural-urban fringe, how to finance such a project, who has the capacity to operate the project, how can the informal ways of meeting water demand such as packaged water and tankers be regularised and accounted for in a water audit, how the sources of water can be managed, and water balance in the region be maintained, are some of the questions that need to be answered.

19.4.3 Recommendations

To improve the water situation in fringe villages, it is crucial to augment the water availability in the region, improve the water governance system and reduce the overall water demand. Fig. 19.4 indicates some of the steps that can be taken to address the water challenges in fringe villages like Potheri.

19.4.3.1 Regional water balance

At a regional level, the hydrological process of maintaining a water balance between precipitation, infiltration and

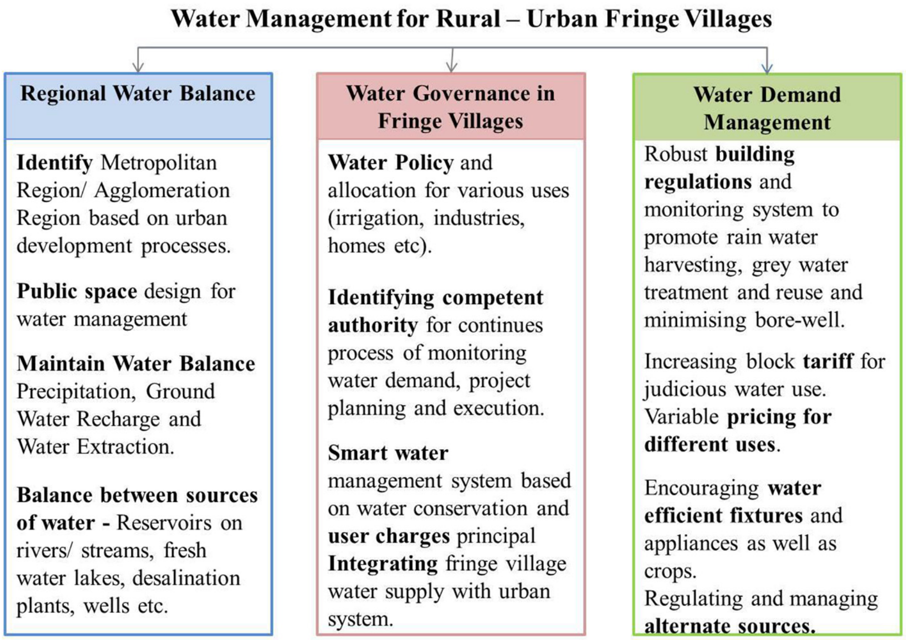

FIGURE 19.4 Water management recommendations for rural–urban fringe villages.

extraction needs to be maintained to ensure sustainable water availability. In urban and urbanizing areas like fringe villages, not only is the extraction beyond the natural replenishable capacity, the high presence of impervious surfaces increases run-off and reduces the surface available for infiltration and natural groundwater recharge (Kokkonen et al., 2018). Increased impervious surfaces are also becoming a major cause of urban flooding. Water balance in fringe areas is not maintained, as evident in Potheri village's case. An integrated water management system with robust stormwater drainage, swales/soft scapes and other public area design features, and treated wastewater would help maintain the water balance. In order to resolve the water problems of in-fringe villages, it is essential to recognize the unique water demand of these villages with growing urban uses of institutions, industries, commercial establishments, and agriculture. A water audit of current practices and available raw water sources needs to be conducted. Monitoring raw water sources, including rivers, water levels in dams, groundwater levels, and lake water levels, is critical in meeting the demand. At the same time, water consumption in the region must not go unchecked, and all forms of consumption must be monitored.

19.4.3.2 Water governance

In order to meet the water demand, first, it is necessary to identify the quantum of water demand by various uses (irrigation, domestic, commercial, industrial, construction, etc.) and locations in a region. In fringe villages, especially like Potheri, which are outside the metropolitan area, the authorities in charge, the gram panchayat, have no capacity to monitor the development and calculate the water demand. Ideally, urbanizing land around a city is part of the urban agglomeration and should be a part of the metropolitan area. The metropolitan area, therefore, must be regularly revised to encompass the urbanizing and urbanisable land (fringe) around a city (Srivathsan, 2018). A competent authority needs to be assigned/identified who would continuously monitor the water supply and demand in the fringe areas and accordingly propose, implement and operate the water supply systems, as well as regulate the informal water sources. Potheri village needs to be included in the Chennai Metropolitan Area, and the water supply there is to be managed by the Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB). The identified authority can then look at the different purposes for which water is needed and then optimize the supply accordingly. For example, recycled water for industries, gardening treated water for domestic consumption, etc. Monitoring water quality from all water sources must be an integral part of the water supply and management system.

An efficient water supply system has a cost of installation and operation. An advanced system would facilitate real-time monitoring of leakages and water levels, thereby reducing water wastage. But they need to be financially sustainable. The practice of bulk water charges, where every consumer pays a nominal amount of charge for water irrespective of the quantity of one's consumption, needs to be discouraged. The culture of free water needs to be changed in order to conserve it. Instead, a smart metering system of measuring water consumption with telescopic pricing (increasing block tariff where tariff per unit increases with increased consumption) would supplement the operating cost and discourage people from water wastage (Cominola et al., 2021). Smart metering helps the authorities to monitor consumption, monitor water quality, detect leaks and problems, regulate supply, remote operations, and forecast demand. It helps the consumers to rationalize water use, manage bills, know water quality, etc. The sensors in the smart water meters can detect variations in the water quality parameters and generate an alert when necessary that helps in timely action and prevents health implications. The leak detections and other features help reduce the non-revenue water, making more water available for consumption. These meters would help to record and produce real-time data and enable sound decision-making regarding interventions and new projects required.

The water supply in the fringe areas has to be integrated with the urban water supply as the water demand here is at par and more than urban areas and would eventually become urban areas. They can function as decentralized parts of a large system. The improved water supply system must be complimented with other interventions of regulations and attitude change.

19.4.3.3 Water demand management

To maintain the water balance in a scenario where the water source is constant but the demand is increasing as a result of economic and population growth, extraordinary steps deviating from natural human behavior will have to be taken. As water infiltration is reduced due to impervious surfaces in cities and fringe areas, artificial rainwater harvesting practices are necessary. Rainwater needs to be harvested and used for consumption or recharge and has to be practiced in public areas as well as on private property. The harvested water, if stored, can be used for irrigation, gardening, and other domestic purposes. Techniques like aqua box can be used to collect stormwater.

Similarly, grey water needs to be recycled at a community level as well as at individual properties (depending on the size of the property). Advanced technologies for greywater recycling are available. However, the primary requirement of a large facility for the community would require an extensive network of grey water/sewer lines, which is lacking in the fringe areas. At the decentralized level of a building, residential society, or large property, there can be segregation of kitchen wastewater and grey and black water. The wastewater from the kitchen and non-toilet areas can be easily treated through DEWATS and other nature-based techniques and reused for gardening and flushing.

To mandate compulsory rainwater harvesting and grey-water treatment and reuse, the building regulations should provide for the same. The Building regulating authority must incentivize such provisions and monitor their performance (Saka et al., 2021). Similarly, appliances and fixtures with low water consumption can be rated (similar to the power consumption of appliances) and accordingly incentivized. Community participation in demand management is crucial for the success of the policies as people should adopt the practices and adhere in the long term. Therefore, the creation of awareness of water footprint, advantages of water metering, water balance, etc. through community programs and campaigns should be conducted.

19.5 Conclusion

Supply of portable water has remained a challenge for India. The achievement of access to water through the widespread use of hand pumps and achieving the Millenium Development Goals is commendable. But, the use of groundwater has quality concerns and is not a sustainable practice. In order to meet the water demand and achieve the Sustainable Development Goals, India is now implementing Jal Jeevan Mission to provide piped water supply with functional taps.

Rural-urban fringe villages are located on the periphery of large urban areas, are rapidly developing areas, and possess the feature of rural as well as urban but are governed by the gram panchayat. They do not have the capacity to implement robust water supply systems as required by urban development. Hence, the community is forced to meet its water demand through alternate sources of groundwater extraction, tankers, and packaged water. The quality of water from this alternate source is questionable. Moreover, the water crises in the fringe villages are coupled with the encroachment of fresh water sources, pollution of the sources due to untreated sewer discharge, pollution of groundwater due to infiltration of fertilizers and pollutants from garbage dumps to the city. The water sources from the fringe villages are also exploited to meet the city's water demand.

The study done on quality analysis of five samples from different sources of water used for domestic purposes in Potheri and comparison with prescribed IS standards led to the conclusion that lake water exceeds the turbidity, alkalinity, and DO standards, with a microbial count exceeding the limits. Tap water showed low DO content, high values of total hardness and chlorides. The microbial count was high among all five samples collected. Hence this water from the lake and tap are not suitable for domestic use unless it is properly treated. In the case of samples from groundwater, the total hardness and chloride content exceed the desirable limits; hence, it can be categorized under hard water. Therefore, houses that rely on groundwater for their daily requirements are forced to use RO water systems and also large whole-house water filters which treat water throughout the entire home. Even though it is commonly believed that the presence of essential minerals, specifically calcium and magnesium, are good for health, the type of hardness the water is associated with is important to consider before use. Water from packaged drinking water and RO points have mild hardness within the permissible limits and hence are safe for domestic purposes as they meet all the other parameters within the range.

It is concerning that the water provided by the authorities in the form of tap water is not suitable for consumption. The poor quality of water may have adverse health effects. Using different self-sourced water for different domestic purposes is a burden on the consumers. It can be concluded that ineffective water governance mechanisms in the fringe area of Chennai have led to the scarcity of treated and regulated water. This forces the dwellers of fringe areas to make unreliable alternate arrangements whose water quality cannot be ensured.

It is recommended that the unique demand for water in fringe villages, including irrigation, domestic consumption, industrial use, construction, commercial, etc. be first recognized and specialized treatment of metropolitan areas be given to these villages. A competent authority needs to be identified for water supply that can gauge the increasing demand, plan water supply projects, operate the system, monitor and regulate alternate sources, etc. A modern system of smart metering can be implemented through which water quality can be monitored in real-time and the user consumption-based water tariff can be used to make the system financially feasible. Private wells/bore wells should be enumerated and regulated.

Techniques of rainwater harvesting, greywater recycling and reuse, and stormwater management for groundwater recharge should be promoted and incentivized. All systems together would enable the maintenance of water balance and improve the environmental conditions as well as affordable water access in the fringe villages. Programs like Jal Jeevan may provide the infrastructure, but meeting the water demand would require coordination among various urban and rural water agencies, community participation, continuous monitoring and re-thinking of our water governance strategies.

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Chapter 20

Rural water management status, threats, and prospects: A case study of Sierra Leone

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20.1 Introduction

Water is a priceless natural resource that is necessary for survival, growth (Agedah et al., 2015; Izah et al., 2022; Seiyaboh et al., 2020a, b) and the preservation of the environment. All governments around the world have been very concerned about providing mankind with access to clean drinking water. Between 2000 and 2015, local, regional, and international initiatives raised the percentage of the world's population who had access to at least basic drinking water services to a significant number. According to the United Nations in 2018, this number shows that over 800 million people still do not have access to any form of clean water source, which lowers their quality of life (Hunter et al., 2009). According to WHO/UNICEF (2017), rural areas are one of the main challenges in this area, especially in the least developed countries. If best practices are not followed, expanding present water services or developing new local water services may be challenging because rural people are frequently located in remote locations. Braimah et al. (2016) stated that decision-makers need to pay more attention to these areas and work harder to make sure that Sustainable Development Goal 6, which says that everyone should have access to safe drinking water by 2030, is met.

Humans require a substantial liter of water every day to meet their physiological and sanitary needs (Rumalongo et al., 2017; WHO, 2011). People who are confined to an inadequate quantity of water per day will be at risk of developing major health issues. This is because water and sanitation often go together. Rural communities frequently have poorer economic conditions than city dwellers, which affects the amount of water utilized (Bain et al., 2014). Rural communities are those where water shortages are most severe. Water scarcity and poor quality have been cited as major concerns jeopardizing the future prosperity of the population (Bekturganov et al., 2016). Additionally, the water supply coverage in urban and rural areas is noticeably different. In different regions of the world, a higher number of rural dwellers have inadequate access to safe drinking water, while a lower number of people who live in cities do. In many developing nations, water used for domestic purposes and drinking is mainly from surface, ground, and rainwater (Izah & Angaye, 2016a; Izah & Ineyougha, 2015; Izah & Srivastav, 2015; Izah et al., 2016).

Rural people heavily rely on rivers, streams, ponds, and shallow wells to meet their water needs. Many of these sources dry up during the dry season, forcing residents to spend a considerable sum of money to obtain water of questionable quality. This has serious implications for the economic advancement and social well-being of the populace. The first is the massive economic waste that is produced when people spend so much time and effort looking for water. Second, a lack of water frequently has a negative impact on personal hygiene and environmental cleanliness. Third, lack of access to water limits people's options for making a living because water is necessary for the bulk of productive activity (IDRC, 2002). So, it is hardest to make sure that everyone in rural areas has access to clean water to drink.

The most vital and significant requirement for the sustenance and maintenance of healthy living is a sufficient and drinkable water supply. The public's health improves in direct proportion to improvements in water supply (Park, 2015). Undoubtedly, having access to clean water is a necessary condition for every nation's sustainable development (Fayiah et al., 2020). Water quality, which poses the greatest threat to man's health and longevity, is more important

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than water availability, which is necessary to maintain appropriate personal and household hygiene. The spread of water-related diseases like schistosomiasis (Izah & Angaye, 2016b), cholera, guinea worm, bilharzia, yellow fever, hepatitis, dengue, dysentery, leprosy, typhoid fever, sleeping sickness, malaria, river blindness, giardiasis, guinea worm, and ringworm has also been linked to poor water quality, which has a significant negative impact on public health (Peter, 2013). The population and health service systems of many countries around the world, and in particular the rural areas, are socioeconomically burdened by water-related diseases (WHO, 2015). Around 2.1 billion people worldwide lack access to enough clean drinking water (WHO, 2017). According to recent estimates, around 844 million people do not have access to basic drinking water services (WHO, 2017), particularly those who live in rural areas in many developing nations. The proliferation and usage of several water sources due to the lack of access to safe and clean drinking water pose a health risk (Sojobi et al., 2015).

Toxicants such as metals and other chemicals that are released into the environment via human activities end up in the surface water. Several studies have shown that water quality in many developing nations does not meet the regulatory limits for basic physicochemical (Aghoghovwia et al., 2018a,b,c; Ben-Eledo et al., 2017a; Ogamba et al., 2015a,b,c, 2017a, 2021; Seiyaboh et al., 2017a; Srivastav et al., 2022) and microbial characteristics (Ben-Eledo et al., 2017b; Izah et al., 2021; Seiyaboh & Izah, 2017a, b; Seiyaboh et al., 2017b). The sediments of the water also contain chemicals (Aigberua et al., 2020; Seiyaboh et al., 2016a,b, 2017c) and microbial contaminants. Fishes that are found in the surface water contain traces of toxicants such as metals (Aghoghovwia et al., 2016; Aigberua et al., 2021; Ogamba et al., 2015d, 2016a,b,c, 2017b) and polycyclic aromatic hydrocarbons. When high concentrations of some of these chemical contaminants are ingested via food, it could impair the human body system and cause diseases. Furthermore, the toxicants found in the water can affect plankton composition and diversity in surface water (Ogamba et al., 2019a,b). It should not come as a surprise that one of the main causes of rural-urban migration is a lack of adequate drinking water and sanitary facilities. Rural locations have terrible conditions; hence, urban and metropolitan areas have dense populations. When there is not enough clean water to wash and clean with, and there is not enough help with sanitation, infections, and re-infections keep happening in a cycle of mouth-to-poop contamination and waterborne illnesses. Rural water management has emerged as a hot topic amidst global warming wrath on humans and the environment. Exploring rural water management opportunities and challenges in Sierra Leone is critical in managing water resources in rural communities. Therefore, the goal of this chapter is to assess the, status challenges and opportunities of rural water management in Sierra Leone. This review intends to bridge the knowledge gap on rural water management opportunities and challenges in Sierra Leone and proffer solutions to the century-old problem.

20.2 Rural water management challenges

In Sierra Leone, there is overwhelming evidence that rural communities need improvement in rural water supply, management, quality financing, and operationalization (World Bank, 2003). During and after the civil war, the nonexistence of sufficient intervention in rural areas in relation to safe and clean drinking water led to limited access to the supply and distribution of clean and quality drinking water and, by extension, poor infrastructure and sanitation (World Bank, 2011). According to Sustainable Development Goal 6, adequate access to safe, clean, and affordable drinking water, especially in deprived rural communities, is a basic human right (Holtz & Golubski, 2021). Nonetheless, in Africa and Sierra Leone in particular, access to clean drinking water remains a widespread challenge across the country. The fundamental reasons for the lack of clean drinking water in Sierra Leone are poverty, mismanagement, and climate change uncertainties, among other reasons. Sierra Leone has a 6-month rainy season each year, but the torrential rain is difficult to harvest and store properly (Barton, 2021). In addition, flood and wastewater filled unprotected water wells and streams, hence making the management of water in rural communities difficult. In addition, Sierra Leone has been experiencing a sequence of repeated erratic rainfall patterns, floods, mudslides, sea rises, and landslides. Over the past decade, for instance, there has been evidence of extreme weather events leading to changing weather patterns and torrential rains in Sierra Leone. However, those in deprived and rural communities are disproportionately affected as compared to urban communities residents. Approximately every district in Sierra Leone lacks adequate access to clean drinking water. This situation has led to rural communities suffering from waterborne-related disease outbreaks and other health insecurities. The poor management of rural water in Sierra Leone could be attributed to weak water policies, inadequate facilities and funding, poor management of water facilities, population growth, lack of proper monitoring of water facilities, and limited staff with low salaries, among other challenges (Amara & Kansal, 2021). However, the biggest threats to water availability and management are population growth and climate change uncertainties, especially in the rural parts of Sierra Leone. In the western areas of rural Kenya, for instance, water management is faced with water wastage due to leaking pipes damaged by heavy vehicles or deliberately by disgruntled water hustling agents. As such, informal settlements located within the western area rural district are more challenged in terms of water availability due to their hilly terrain and population density. Furthermore, most rural populations in the country are generally scattered with like-minded small groups living together in remote places. These settlement patterns have made the already difficult water access struggle worse for these communities. According to the World Bank (2011) report, only 30% of rural communities across Sierra Leone had access to clean and safe drinking water supplied mostly by springs, water points, rainwater, gravity-fed systems, among other sources. Most of these sources were polluted and unprotected, and most rural households had to walk more than 5 km to reach their nearest water sources (Government of Sierra Leone, 2007; World Bank, 2011).

20.2.1 Pollution and contamination challenges

In Sierra Leone, most of the drinking water utilized by rural communities is from polluted sources (Barton, 2021). Basically, the major sources of drinking water in Sierra Leone are rainwater, streams, hand-dug wells, and springs (Mansaray et al., 2018). According to the 2017 report published by Statistics Sierra Leone (Stats SSL, 2017), almost all of these sources of drinking water, especially open-source water, contained *Escherichia coli* bacteria (Pujeh et al., 2022). Poor water quality in Sierra Leone is mostly associated with poor waste disposal and aerial dust particles (Mansaray et al., 2018). Most cholera outbreaks in recent decades have been directly or indirectly linked to contaminated or waterborne sources. Furthermore, the poor handling of waste and open sources of water from streams across Sierra Leone posed a grave health challenge for vulnerable citizens, especially those living in rural communities. In some communities within Sierra Leone, drinking water is polluted by sewage deposits aided by runoff. As such, polluted water serves as a threat to basic sanitation practices and rural livelihoods in peri-urban and rural communities in Sierra Leone and beyond (Mansaray et al., 2018; Pujeh et al., 2022; WHO, 2015). Other sources of water pollution in rural communities across the country are surface water runoff, debris from wildfire outbreaks, and unsustainable fishing methods adopted by women during the dry season. These activities, especially fishing, leave open-source water polluted until the commencement of the rainy season. Furthermore, most rural communities water sources are stagnant, hence harboring any aerial particles deposited in the well or spring. Factors such as complexity and uncertainties, coupled with intensive anthropogenic actions, are the causes of both surface and underground water pollution in developing countries like Sierra Leone (Sharon et al., 2002). Climate change impacts cut right across many aspects that support rural livelihoods. Scientific literature suggests that the availability of adequate drinking water in rural settlements across Africa is linked with favorable climatic and weather conditions (Dixit et al., 2022; IPCC, 2014; Rankoana, 2020). Climate change is putting a strain on rural water availability through erratic rainfall patterns, droughts, floods, and temperature increases (IPCC, 2014; Rakona, 2020; Srivastav et al., 2021). Although Sierra Leone is not a net emitter of greenhouse gases, the country is vulnerable to climate change due to global warming risks and uncertainties. Flooding, changes in rainfall patterns, drought, and coastal erosion, among other events, have wreaked havoc on Sierra Leone in recent years, affecting water availability and access, public health, water, and energy (World Bank, 2020). The rise in sea level along coastal communities in Sierra Leone threatens the sustainable livelihood of these communities and renders them vulnerable to climate change uncertainties, especially in rural and coastal communities (World Bank, 2020). Water scarcity, flooding, seasonal drought, high winds, changes in rainfall patterns, heat waves, and thunderstorms are some of the key vulnerabilities that Sierra Leone faces as a result of climate change (Trzaska et al., 2017). Climate change impacts across Sierra Leone and beyond have contributed to the reduction of the water table, and increased evaporation has forced the watershed to dry up completely during the dry season. Climate change is exacerbating the problem and putting communities in a management bind. Polluted water and poor sanitation have contributed to chronic health problems in rural Sierra Leone. For example, when the Rokel River was tested for pollution, 7 of the 12 water sections sampled were found to be contaminated, failing to meet the good quality standard expected of rivers.

20.2.2 Access to clean and safe drinking water challenge

Statistics about the proportion of Sierra Leoneans having access to clean and safe drinking water across the country vary greatly among reporting agencies. For instance, the Centers for Disease Control and Prevention (CDC, 2019) reported that only 2% of Sierra Leoneans have access to clean and safe drinking water. According to the Water Aid (2017) report, 6 out of 10 people (3.7 million people) across Sierra Leone do not have access to clean drinking water. Moreover, the World Bank (2020) report stated that only 1% of the Sierra Leone population has access to safe and clean drinking water. However, WHO/UNICEF (2017) reported that about 57% of Sierra Leoneans have access to safe and clean drinking water. This signals that almost half of the population lacks access to clean and safe drinking water. According to Bennet et al. (2011), approximately 40% of the rural population in Sierra Leone gets access to drinking water from unprotected sources. The authors further stated that, from 2002 to 2009, access to drinking water fluctuated between 47% and 57% accordingly. The variation in percentage may be attributed to the different measurement techniques employed by different bodies of water. What is clear, however, is that hard-to-reach and remote communities are the most vulnerable settlements in terms of a water crisis.

The 11-year civil war in Sierra Leone negatively impacted the sustainable development of a country that was already progressing at a snail's pace. The war destroyed almost all pipe-borne water facilities across the country, hence making access to clean and safe drinking water a major challenge. However, some rural communities across Sierra Leone have access to water but not clean and safe drinking water. Besides pipe-borne water, deforestation due to urban settlement, farming, and other industrial actions has exposed watershed/catchment areas to massive evapotranspiration. These actions, among others, have made access to clean and safe drinking water in Sierra Leone challenging and frustrating, especially in rural and deprived communities. Most rural communities in Sierra Leone are not accessible by vehicles and motorbikes as a result of a bad road network. These scenarios have made these communities hard to reach through international and local water agencies that provide clean and safe drinking water for free. Similarly, most rural communities can't afford water purification and treatment chemicals, hence making access to safe and clean drinking water challenging. Access to clean and safe drinking water is a big problem for informal settlements within Freetown municipality and peri-urban communities (Marcarthy et al., 2018). For instance, some rural communities lack access to water due to their terrain and topography, as in the case of Western Area Rural and other remote communities in Sierra Leone. Kailahun district is considered the most vulnerable district in terms of access to clean and safe drinking water in the country (Magrath, 2006). This might be attributed to the fact that the Kailahun district experienced greater destruction from the civil war than any other district in Sierra Leone. This has left the district with the greatest poverty incident (Government of Sierra Leone, 2004).

Fig. 20.1 below shows the trend in clean water access across Sierra Leone from 2000 to 2017. According to Fig. 20.1, access to clean drinking water in Sierra Leone is improving, although at a slow pace. Recent years show more access to clean water as compared to 2000.

20.2.3 Policy challenges

Sierra Leone is among developing countries that are constrained by policy challenges in the sustainable management of water resources. The lack of a comprehensive sectoral policy in the water supply and sanitation sector lead to large intervention gaps (World Bank, 2011).

Large policy gaps in the water supply and sanitation sectors lead to large intervention gaps (World Bank, 2011). The absence of sound policies (Fayiah, 2021) over the past decades has made access to safe and clean drinking water in rural communities challenging. The Sierra Leone Water Company (SALWACO) was designated to handle rural water services while the Guma Valley Water Company was responsible for water services within Freetown and the surrounding peri-urban areas (World Bank, 2011). Among the few water management policies and legislatures being instituted to manage water in Sierra Leone are: The Guma Valley Water Company Act (2017), National Water Resource Management Agency Legislation (2017), Sierra Leone Water Company Legislation (2017), and Sierra Leone Electricity & Water Regulatory Commission (2022). These water management legislatures were all ratified and approved by Parliament in 2017. However, critics argue that this legislature's enforcement and implementation is a daunting task for water sector agencies due to logistics and staff capacity. As such, most of these policies are left on the shelves of higher

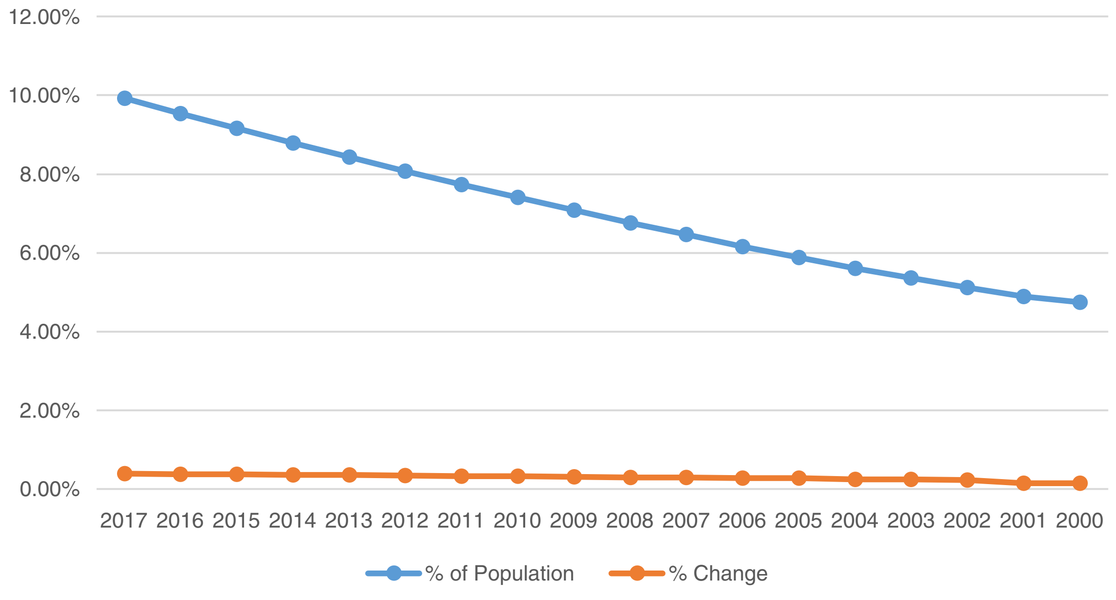

FIGURE 20.1 Sierra Leone clean water access 2000–2017. (*From:* World Bank, 2022).

TABLE 20.1 Water policies and legislation in Sierra Leone.

S. no.	Title of policy/legislation	Date enacted
1	The Guma Valley Water Act	1961
2	The Water (Control and Supply) Act	1963
3	The Sierra Leone Water Company Act	2001
4	The Water and Sanitation Policy	2008
5	The Bumbuna Watershed Authority and Bumbuna Conservation Area Act	2008
	Water-related policies	
6	The Public Health Ordinance, 1960	1960
7	The Environmental Protection Act	2000
8	The Forestry Regulation Act (2001)	2001
9	Public Health Act 1996 and the 2004 Addendum	2004
10	Local Government Act (2004)	2004
11	Poverty Reduction Strategy Paper (PRSP)	2005
12	Establishment of Water Supply Management System in Kambia District	2006
13	Agenda for Prosperity	2007
14	Bumbuna Watershed, Management and Conservation Authority Acts 2008	2008
15	Wetland Conservation Act of 2015	2015
16	Forestry Act of 2022	2022

authorities to gather dust in perpetuity. The Water (Control and Supply) Act (1963) is over a century old and is practically inoperable. Prior to the millennium era, most of the water management policies and legislatures were obsolete and, as such, made access to clean and safe drinking water in remote communities across the country challenging. The National Water and Sanitation Policy 2010 was designed to provide adequate access to drinking water in all corners of Sierra Leone (Government of Sierra Leone, 2010). Nonetheless, the policy failed to adequately cover the plight of hard-to-reach rural communities constrained by water shortages. In most hard-to-reach communities across Sierra Leone, local bye-laws are the only instruments being used to manage and protect water resources in these communities. The weak enforcement of water policies in Sierra Leone has made access to clean and safe drinking water across the country a privilege rather than a fundamental human right. In the late 2000s, Sierra Leone's lack of a sectoral development strategy and a solid institutional framework for water management kept potential key water players at bay (World Bank, 2011). The various water policies enacted in Sierra Leone are listed in Table 20.1.

20.2.4 Population increase and water availability issue

There is a strong nexus between population growth and water resource availability globally (Fayiah et al., 2020; Okello, 2015). According to the 2015 Housing and Population Census, around 50–60% people have access to drinking water, especially those living in urban areas. Besides population growth, other human factors such as technological advancement, industrialization, socio-economic development, water pollution, and clean energy, among other factors, are exerting huge pressure on water resource availability, especially in developing countries (Polimeni, 2006). Although Sierra Leone is endowed with both ground and surface water, the growing demand by the population is exerting great pressure on the resource. In Sierra Leone, the increase in the population is affecting the abundance of water, especially in rural communities. Furthermore, the population increase posed a noteworthy threat to the abundance and quality of water, especially surface water resources (Liyanage & Yamada, 2017). The obsolete colonial water provision facilities and the civil war destroyed the limited rural water services. Therefore, the country is faced with a huge challenge in providing adequate drinking water for its masses. The problem of available water resources in Sierra Leone is not only associated with rural and hard-to-reach communities; even the urban cities are still plagued with frequent water shortages, especially during the dry season. The rapid increase in population growth, coupled with low water harvesting technologies and expertise in Sierra Leone, is fanning rural water availability problems.

20.3 Rural water opportunities

Safe and clean drinking water is a fundamental natural resource capable of sustaining human life while at the same time stimulating socio-economic development and good human health (Government of Sierra Leone, 2010). During and after the civil war, several international non-governmental organizations (NGOs) and community-based organizations (CBOs) worked on the water working in remote areas, although in small-scale rehabilitation of water facilities, improvement of sanitary facilities, and the reconstruction of water points across Sierra Leone (World Bank, 2011). According to the Water and Sanitation Policy 2010, Sierra Leone's renewable water on an annual basis stands at 160,000 mcm. Sierra Leone's internal renewable water resources per capita are approximately 21,172 m^3 per person/year (World Data Atlas, 2022). If sustainably harvested and utilized, Sierra Leone has high water per capita capable of meeting the water needs of an emerging population (World Data Atlas, 2022). A report by the World Data Atlas (2022) stated that about 150 cm of water is produced internally in Sierra Leone. This source of water is derived from the surface through direct runoff from rain and underground water. The groundwater produced internally stands at 25 bcm per year, while the overlap between ground and surface water stands at 15 bcm (World Data Atlas, 2022).

20.3.1 Sources of water in Sierra Leone

Sierra Leone is endowed with enormous water resources (both surface and underground) across the country (Government of Sierra Leone, 2010). The availability of adequate surface water resources in Sierra Leone could be attributed to the many river systems and long rainfall seasons. Sierra Leone experiences six months of rain (Fayiah, 20220), with July and August being the wettest months. Sierra Leone has over 20 rivers, but the most important are (1) the Great and Little Scarcies River, (2) the Rokel river, (3) the Mano River, and (4) the Moro River, to name a few. In particular, the Rokel River is considered the longest river in Sierra Leone (440 km) and originated from the Loma mountains. Other rivers flowing in Sierra Leone are Sewa, Moa, Pampana, Soa, and Jong, among others. These rivers have, over the years stimulated both the social and economic importance needed for the sustainable growth of Sierra Leone. However, water resources management responsibilities are on a sectorial basis, where different institutions handle different management aspects. Rural water supply coverage in Sierra Leone is less than 50%, and this could be attributed to the limited and inadequate water infrastructure facilities across the country. Most rural communities have multiple sources of water besides rain and river water. A good number of these rural communities get water from local catchment areas, stagnant ponds, wells, lakes, swamps, and streams, among other sources.

Despite the country's vast groundwater deposit, sustainable groundwater harvesting has remained a challenge in recent years. The country's average precipitation in terms of volume over the past four decades has remained stable at 183 bcm per year. The national rainfall index stands at 2546 mm per year, while the average depth of precipitation stands at 2526 mm per year (World Data Atlas, 2022).

Scientific literature suggests that Sierra Leone has abundant underground water that is found in the four corners of the country. This groundwater endowment has made it easy to locate water a few meters below the earth's surface across the country (Government of Sierra Leone, 2010). However, the depth of groundwater reached differs by region. For instance, groundwater can be easily reached in the southeast as compared to the northwest. In order to make water available to all, many projects have been undertaken in Sierra Leone over the past decades (Table 20.2). The end goal of these projects is adequate access to clean and safe drinking water in Sierra Leone, especially in deprived rural communities.

20.3.2 Unprotected water sources and disease outbreak in rural communities in Sierra Leone

Clean drinking water is considered a necessity for human survival with absolutely no real substitutes. In Sierra Leone and beyond, unprotected water or contaminated sources of water have exposed vulnerable rural populations to preventable health risks, leading to untimely death (Von Nguyen et al., 2014). Over the past decades in Sierra Leone, unprotected water sources have ignited diseases like cholera, diarrhea, dysentery, typhoid, and hepatitis A outbreaks, especially in rural communities (Von Nguyen et al., 2014). In recent times, Sierra Leone has experienced cholera and other water-related outbreaks. However, the largest outbreak of cholera was experienced in 2012, when approximately 296 deaths were reported (Von Nguyen et al., 2014). All these outbreaks over the years were scientifically linked with "unsafe water, street-vended water, and untreated water mostly found in slums and deprived rural communities in Sierra Leone." Unprotected waters in remote communities in Sierra Leone cause most water-borne diseases. The absence of pipe-borne water in rural settlements across the country has given leverage to springs, boreholes, streams, rivers, and dugout wells to serve as the ultimate source of drinking water in these communities. These unprotected water sources of pollutants are mostly from sewage efflux and surface run-off. Since these unprotected water sources are the ultimate source of drinking water in rural settings, waterborne disease outbreaks are common in these localities. In some big remote communities, this unprotected water from springs, dugout wells, and boreholes is used for both domestic and drinking purposes. In the past, polluted rivers and streams have affected the

TABLE 20.2 Water projects over the past decades.

S. no.	Project title	Objective and scope	Timeframe
1	Urban Water Supply Project (Cr. 2702-SL)	Aimed at urban water supply and sanitation sector, helping to expand the water production capacity in Freetown	1995
2	Sierra Leone: Water Supply Project	To enhance water and sanitation services in Freetown	2005
3	Three Towns Water Supply and Sanitation Project	to provide improved access to adequate, safe, and reliable water supply and public sanitation services for the three cities in Bo, Kenema, and Makeni	2010
4	Rural Water Supply and Sanitation Project (RWSSP)	To expand sustainable access to clean drinking water and basic sanitation in rural regions and to develop a holistic national framework for rural water and sanitation services	2013
5	Building Adaptive Capacity of Water Supply Services to Climate Change in Sierra Leone	Enhancement of the capacity for climate-resilient decision-making in the water sector through policy reforms	2013
6	Rehabilitation of Freetown's Water Supply System	To enhance sustainable access to clean drinking water in the capital, Freetown.	2016
7	Freetown Wash and Aquatic Environment Revamping Project	Aims at contributing a 15% increase in access to safe water supply and a 7% increase in access to improved sanitation in Sierra Leone	2018
8	The Freetown-Blue Peace project	The provisions of water kiosks across Freetown, and improve on sanitation in an informal settlement	2020
9	Increasing Community Access to, and Quality of, Water, Sanitation and Improved Hygiene Practices in Freetown and Kenema	To increase community access to water and water quality, and improve sanitation and hygiene practices in Freetown and Kenema	N/A
10	World Changing Centre water project (Sierra Leone)	To provide clean drinking water to communities in the Eastern of (Freetown)Sierra Leone	N/A
11	Water Sector Reform Project (WSRP)	Aim to improve sector coordination, strengthen commercial practices and enhance the Guma Valley Water Company's (Guma) service provision	2021

livelihoods of downstream communities. Exposed water sources in remote communities are mostly a death trap for vulnerable and deprived communities in Sierra Leone (Centre for Disease Control and Prevention, 2022).

20.3.3 Government's role in providing safe and clean drinking water for rural communities

The binding policy charged with the responsibility of providing clean and safe drinking water for rural communities in Sierra Leone is the Local Government Act of 2004. The Local Government Act of 2004 is tasked with ensuring that every local council has an adequate water supply for its people. In addition, the Sierra Leone Water Company (SALWACO), a government agency, is devolved with the responsibility of providing clean and safe drinking water to rural communities across Sierra Leone via local councils. Specifically, the agency is charged with the responsibility of assisting locals with clean and safe drinking water, building the capacity of local water departments, and advising on the sustainable maintenance of water facilities across the country.

Over the past decades, the government of Sierra Leone has received millions of dollars in aid and loans to boost water accessibility across the country (Government of Sierra Leone, 2015). The aid packages covered aspects such as the national water supply scheme, infrastructural support, capacity building, and management support respectively. However, the government of Sierra Leone has been facing difficulties in ensuring that clean and safe drinking water is accessible in rural communities across the country since independence. As such, the government is trying to build strong institutions with good policies and plans. These institutions, in turn, will strive to allocate water resources for everyone regardless of their geographical locations. To do this, the government of Sierra Leone has received several water funds from the World Bank, African Development Bank, Department of International Development, United

Arab Emirates, European Union, and United States Agency for International Development (USAID), among others. That notwithstanding; the country is ranked at the bottom in terms of the percentage of rural communities with clean and safe drinking water in Africa. Sierra Leone is still among countries with a high percentage of rural settlers not having access to clean drinking water.

The government has initiated many projects and programs aimed at tackling the inadequacy of safe drinking water in rural communities across the country. After the 11-year civil war that left many dead and displaced, the government re-established water supply services across the country, especially in deprived communities. The government then made access to clean and safe drinking water a key development pillar to stimulate economic development and improve sanitation. Over the past decades, the government has given general guidelines as to where and which type of hand pump should be dug and used country-wide and proposed sustainable operation and maintenance training. The Sierra Leone Water Company (SALWACO) has been charged with improving water access and sustainability across the country. Also, the government has embarked on several awareness-raising campaigns on the right to water for all its citizens.

20.3.4 The role of rural communities in ensuring water security in Sierra Leone

In Sierra Leone, "the rural-poor" social and economic well-being is a controversial topic among politicians. The majority of rural communities in Sierra Leone are water-insecure, but overcoming this problem has been a daunting task for past and present governments. Safe and clean drinking water is a fundamental human right that applies regardless of social, economic, or geographical status (UNICEF/WHO, 2019). The availability of clean and safe drinking water is an integrated part of rural development in third-world countries like Sierra Leone (Bah, 1992). Community self-help and mobilization have played a vital role in ensuring that deprived communities have access to safe and clean drinking water. Most communities dig their own water wells and design bye-laws that compel all community members to engage in the cleaning of water catchment areas periodically. On the other hand, peri-urban communities in Sierra Leone have devised an alliance mechanism with international organizations engaged in water provision partners to dig and build wells in their communities. These communities, in return, pay for the water well service over a period of time until the cost of the well is repaid. Upon the completion of payment, the well becomes the property of the community.

Rural communities in Sierra Leone are characterized by water being managed by the community for the use of the entire population for various purposes (Hope et al., 2020). Most rural communities across Sierra Leone have improvised ways of ensuring water security through sustainable rainwater harvesting, ponds, dug wells, streams, etc. These tap water alternative sources have eased the problem of water availability in these rural communities. However, the choices as to which alternative source of water to secure are purely based on individual household decisions. Alternately, rural communities failure to access clean and safe drinking water mostly creates health crises that affect households and sometimes entire villages and communities. Furthermore, factors such as year-round availability, water facility maintenance costs, ease of construction, and cost consideration, among others, influence suitable water availability (Bah, 1987).

In rural communities, water management is mostly governed by local bye-laws instituted by stakeholders of these communities (Fayiah et al., 2018). Some of these bye-laws prevent people from fetching water from streams, and ponds, and well preserved for drinking and domestic work such as brick making during the dry season. Other communities allow water to only be fetched in the morning and evening hours. Alternately, some communities prohibit any community member from reaching the water source with slippers or shoes on. People are advised to remove and leave their slippers meters away from the water source. Furthermore, some communities engage in a monthly cleaning of the water sources as well as the surrounding environment, and a fine is mostly levied on defaulters. Some of the water management practices adopted in Sierra Leone are presented in Fig. 20.2. Fig. 20.2 presents some of the water management practices undertaken at a different level in Sierra Leone.

20.4 Recommendations

- The implementation of rural water projects should be consistent with the improvement of sustainable rural water supply to rural communities for the best results.
- For sustainable water security, the government should prioritize access to safe and clean drinking water for all, irrespective of socio-economic status and geographical location.
- The government should employ sound rural water management strategies in order to ensure the availability of water throughout the year.
- Local bye-laws and restrictions should be adopted within these communities to ensure the effective monitoring of water usage and security.
- Increasing the capacity of each district and chiefdom local community by providing adequate water harvesting, supply, and management training.
- More international funding should be sought.

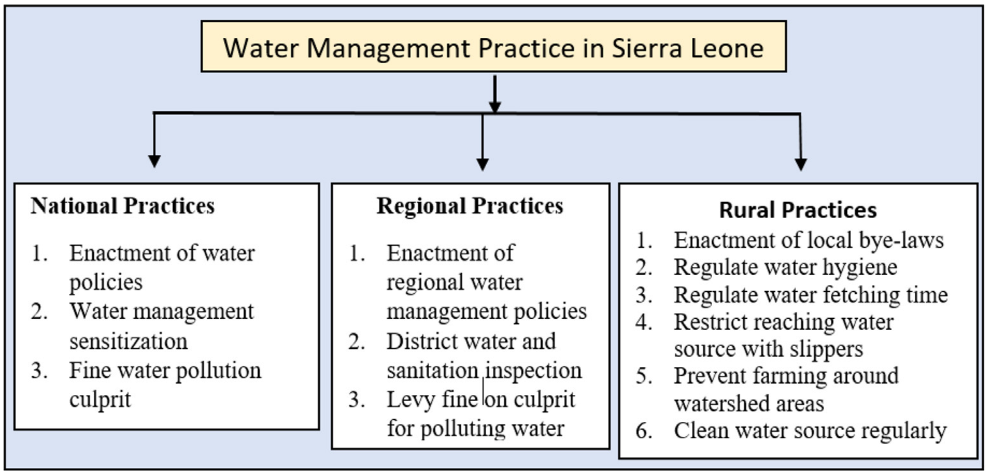

FIGURE 20.2 Water management practices in Sierra Leone.

20.5 Conclusion

Clean and safe drinking water is a fundamental human right irrespective of social, economic status, and geographical location, with no suitable alternative. Sierra Leone's social and economic development has faced a series of obstacles, such as civil war, pandemic outbreaks, inadequate safe drinking water, extreme weather events, and an exponential population. These events have left the country shattered and vulnerable to water-related disease outbreaks and sanitation. The country is currently characterized by poor water quality, unprotected and polluted water sources, and contaminated drinking water, especially in rural settings. Rural communities across Sierra Leone mostly obtain their water resources from springs, wells, ponds, freestanding water, rainwater, and streams. These sources are mostly polluted and contaminated due to poor management of these unprotected sources. As such, water from unprotected sources is the key culprit for past major water-borne disease outbreaks in rural communities across Sierra Leone. The major challenges hampering the countrywide availability of water, especially in rural communities in Sierra Leone, are poor management of water sources, weak water policy implementation and monitoring, pollution, increase in populations, inadequate funding, poor water infrastructure, and climate change, among other challenges. Another major barrier to clean and safe drinking water in rural Sierra Leone is the poor road network, iron content in well waters and inadequate funding. Similarly, the rapid deforestation of vegetation around watershed areas in remote communities due to land surface exposition to direct sunlight could potentially lower the water table. Although Sierra Leone faces many challenges in managing rural water resources, the country is endowed with abundant surface and underground water. The country has over 20 active river networks running together with abundant groundwater. These water sources, if managed well, can supply the water needs of the entire country's population. On the other hand, poor management of water resources compromises health security in remote communities.

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Chapter 21

Occurrence and management of toxicity associated with parasitic pathogens in drinking water sources in rural areas in the Niger Delta, Nigeria

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21.1 Introduction

A significant water quality problem around the world occurs due to contamination by chemical compounds (Aghoghovwia et al., 2018a,b; Aigberua et al., 2021; Izah & Srivastav, 2015; Izah et al., 2022a,b; 2016; Ogamba et al., 2015a,b,c, 2021; Seiyahoh et al., 2017a) and waterborne microorganisms (Agedah et al., 2015; Ben-Eledo et al., 2017a,b; Izah & Ineyougha, 2015; Izah et al., 2021, 2015; Seiyaboh et al., 2020a,b, 2017b). These water contaminants exist in different forms. For instance, the chemical contaminants commonly detected in water include trace metals (arsenic, copper, cadmium, lead, chromium, manganese, zinc, nickel, cobalt, etc.), polycyclic aromatic hydrocarbons (PAHs), and, to a lesser extent, agrochemicals such as pesticides, polychlorinated biphenyls (PCBs) (Fig. 21.1). Trace metals are the most commonly studied of these chemicals found in water, and they have been found in a wide range of waters, including groundwater, rainwater, and surface water systems such as lakes, ponds, creeks, streams, creeklets, rivers, and so on. Chemicals get into the body when waste from cities, factories, and farms is not taken care of properly. As a result, millions of people drink chemically contaminated water. The chemical contaminants found in surface water have been reported in the sediments of many aquatic ecosystems (Aghoghovwia et al., 2018c; Aigberua et al., 2020; Seiyaboh et al., 2017c, 2016a,b).

The microorganisms found in water are often grouped into bacteria, fungi, protozoans, and viruses (Fig. 21.1). Among this group of microbes, bacteria are the most commonly studied in water quality. This may be due to the ubiquitous nature of bacteria and their ability to survive in broad environmental conditions with diverse metabolic, physiological, and molecular strategies. Many of the microorganisms found in water are of public health importance because they have the ability to cause diseases in humans. Other water contaminants are physical (appearance and turbidity) and radiological (cesium, plutonium, and uranium) (Fig. 21.1).

A frequent global issue is poor water quality. Poor sanitation frequently makes problems with water quality worse. Cholera, diarrhea, dysentery, hepatitis A, typhoid, and polio are just a few of the illnesses that can spread due to contaminated water and poor sanitation. Therefore, many people are exposed to health risks that can be prevented when water and sanitation services are unavailable, insufficient, or poorly maintained. Poor water quality encourages the spread of infectious diseases, especially in rural regions. The WHO, 2022 reported that infections occur in 15% of hospitalized patients, and the number is much higher in developing countries.

An estimated 829,000 people die each year from diseases linked to diarrhea as a result of poor hand hygiene, sanitation, and drinking water (WHO, 2022). Although diarrhea is generally preventable, addressing these risk factors could help save 297,000 infant deaths under the age of five each year (WHO, 2022). When water is scarce,

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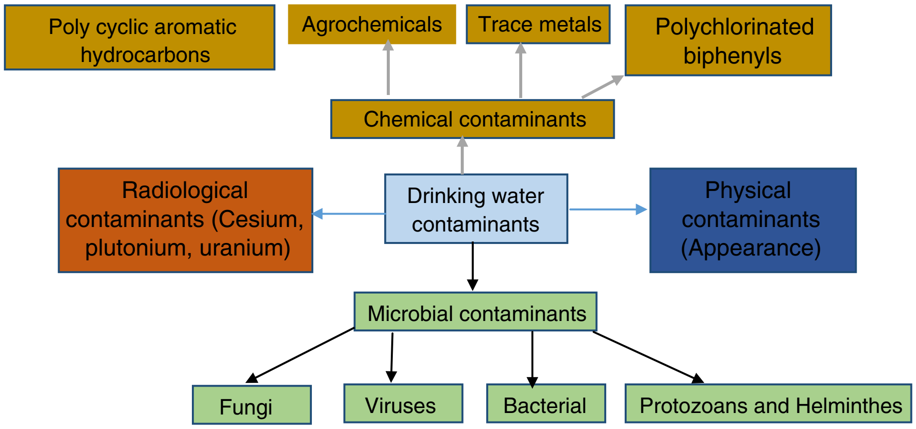

FIGURE 21.1 Water contaminants.

people could decide not to wash their hands, which increases the risk of illness and diarrhea. In many regions of the world, parasitic worms that dwell in water cause water-borne illnesses, which are widespread. For example, more than 220 million cases of schistosomiasis caused by different Schistosome species happened around the world in 2017 (WHO, 2022). In these cases, preventive medication was needed.

Diseases like human African trypanosomiasis, which is caused by *Trypanosoma brucei rhodesiense* and *Trypanosoma brucei gambiense* and is vectored by the tsetse fly, and Onchocerciasis, or river blindness, which is caused by the nematode *Onchocerca volvulus* and spread by infected female black flies, are carried and spread by aquatic-dwelling insects. In addition, some diseases such as Dengue, Zika, Yellow Fever, Chikungunya, Malaria, or Nile fever are vectored by different species of mosquitoes (Bassey & Izah, 2017a,b; Ndiok et al., 2016). Mosquito basically completes some of their life cycles (larva phase) in an aquatic ecosystem (Izah, 2019; Izah & Youkparigha, 2019; Seiyaboh et al., 2020c,d; Youkparigha & Izah, 2019). Some of these pests, referred to as vectors, can breed in home drinking water containers and prefer clean water over dirty water for breeding. Covering water storage containers is a straightforward intervention that might decrease vector reproduction and potentially reduce fecal pollution of domestic water supplies.

Globally, it appears that there have been increasing outbreaks of parasite diseases that are water-borne diseases in recent years. The community's failing or badly maintained sanitary and water supply systems appear to be the root of this. Smaller treatment facilities also infrequently or never perform protozoa tests. Several studies have been carried out in the Niger Delta region of Nigeria (Izah et al., 2022a,b), but most of the studies focus on the physicochemical and microbial quality of potable water. Therefore, this chapter focuses on protozoan toxicity in drinking water sources in the Niger Delta region of Nigeria.

21.2 Drinking water sources and group of waterborne pathogens

Globally, drinking water supplies are inadequate. Inadequate treatment of drinking water is the primary cause of water-related epidemics. It goes without saying that epidemics of parasitic protozoan diseases spread by water occur disproportionately more frequently in low and middle-income countries.

Generally, the drinking water supply emanates from two major sources, including surface and groundwater. The surface water includes rivers, streams, lakes, creeks, creeklets, etc., while the ground aquifer includes the well water and others that are brought to the surface with the use of submersible pumps. Sometimes, rainwater is also classified as another type of drinking water, but through the processing of rain formation or hydrological cycles involving evaporation, condensation, and precipitation, we can now say that rainwater is a type of surface water. However, after the precipitation, the water now percolates into the ground aquifer. In the Niger Delta region of Nigeria, the ground, surface water, and rainwater are the major drinking water sources (Izah & Srivastav, 2015; Izah et al., 2016). Furthermore, there are many surface water resources with different names in the area. The water is home to a diversity of fish. The fish species has the tendency to bioaccumulate toxicants from their environment (Aghoghovwia et al., 2016; Aigberua et al., 2021; Izah & Angaye, 2016a; Ogamba et al., 2017, 2016a,b,c, 2015d; Moslen, 2017; Moslen et al., 2019; Moslen & Miebaka, 2017; Moslen & Miebaka, 2018).

The main causes of water-borne illnesses are microbial pathogens including viruses, bacteria, and parasites, mainly from protozoans and some helminths. Though, bacteria are commonly studied in drinking water sources in the area. The pathogens enter the drinking water sources through feces in the water supply and poor hygienic practices. Feces can enter the water through a variety of channels, including market and abattoir activities (Seiyaboh & Izah, 2017a,b), agricultural effluent, sewage overflows, damaged sewage systems, contaminated storm drains, and wastewater overflows. Along with the bacteria that cause protozoan diseases, liquid sewage from dirty toilets and livestock farms seeps into the soil and aquifers. Untreated livestock waste from nearby facilities poses a serious threat to towns that rely on the upper aquifers for their water supply. Therefore, enclosed water is the most dependable water in terms of parasitology and sanitation.

21.3 Common parasitic pathogens associated with open wells and surface water

The essentiality of water makes its use inevitable in the life of living organisms. The presence and importance of pathogenic parasites in drinking water remain a very important issue. This is due to the fact that water-borne parasitic infections constitute a serious threat to public health, particularly in developing countries. It is, therefore important to have water of good quality, free of parasitic pathogens that could lead to toxic effects. The prevalence, nature, and types of parasites found in water also depend on the source of the water. Different sources of drinking water include streams, open wells, rainwater, boreholes, dams, municipal water supplies, rivers, and pond water sources. The degree of pathogenic contamination varies with different water sources depending on the prevailing circumstances around the water source, including abiotic factors like pH, temperature, conductivity, nitrate, phosphate, and turbidity. Pollution of water sources with pathogenic parasites is mainly attributed to being a result of migration or introduction of fecal matter either from humans or animals into the water source (Simon-Oke et al., 2020). Surface water sources are most prone to pathogenic contamination due to unprotection and exposure. Pollution of fecal origin can also get to groundwater from various concentrated pond water sources like landfills, cesspools, leaking sewer lines and filled septic systems (Sadallah & Al-Najar, 2014). Research has reported the isolation of several parasitic pathogens from several drinking water sources, especially in rural communities around the world, including the Niger Delta region (Simon-Oke et al., 2020; Umoh et al., 2020). Some of the common parasitic pathogens in drinking water sources in rural communities of the Niger Delta include *Giardia spp., Enterobius vermicularis, Entamoeba histolytica, Dracunculus medinensis*, and *Cryptosporidium parvum*. In addition, some parasitic protozoans that infect humans and are spread through the water were enumerated by Lane and Lloyd (2002). These included *Toxoplasma gondii, Entamoeba histolytica, Cycloporacy iranensis, Isospora belli, Blastocystis hominis, Balantidium coli, Acanthamoeba, Sarcocystis*, and *Naegleria* species. These parasitic pathogens could be seen at different development stages or phases of their life circle. Open streams and rivers often have often been found to account for higher pathogenic parasites compared to others sources. Simon-Oke et al. (2020) in a study of parasitic contamination of water sources within the Niger Delta, reported stream waters with the highest parasitic pathogen prevalence of 45%, secondly by well water at 24%, then rainwater at 21%, and borehole water with the least prevalence of 10%. The researchers (Simon-Oke et al., 2020) also reported that parasites of protozoa isolated with their respective prevalence included *Cryptosporidium parvum* (33.2%), *Giardia* species (19.9%), and *Entamoeba histolytica* (13.0%) while helminthic parasites like *Dracunculus medinensis* and *Enterobius vermicularis* had a respective prevalence of 10.3% and 4.0%, respectively. It was observed that the occurrence of the parasites in the water sources was affected by the water parameters such as temperature, pH, and turbidity.

21.4 Parasitic water-related infections: symptoms and incubation period

In developing countries, including the Niger Delta region of Africa, morbidity and mortality are mainly caused by pathogenic parasitic diseases of water. About 80% of illnesses or death are linked to water-related diseases in developing countries of the world, killing about 5 million people annually (UNESCO, 2007). In both developing and wealthy nations around the world, parasitic disorders caused by pathogenic protozoa that are spread by water give rise to epidemic and endemic illnesses. The enteric protozoan parasites are significant causes of diarrhea disease, and these pathogens cause human disorders worldwide (Apichai et al., 2005; Fontanet et al., 2000). Many of the oocytes in the intestine yield protozoan parasites that hinder gastrointestinal tract activities in humans (Baquiet et al., 1992). Some of the parasitic water-related infections are as follows:

Amoebiasis (amoebic dysentery): This is an infection or one of the enteric diseases caused by *Entamoeba histolytica*. This disease is common in tropical areas with poor sanitation and hygiene and could be acquired via contaminated food or water. This protozoan parasite lives in the intestine of humans where it could cause problems for infected persons. Most times, often harmless, the parasite could become hostile attacking the mucous membrane of the intestine, reproducing, increasing in number and eating into the affected tissues. The incubation could be said to be variable; it is mainly between 2 weeks and 4 weeks but could also vary between a few days to years. There may be no symptoms or mild to severe symptoms as the case may be. Some of the notable symptoms may include abdominal pain, tiredness, loss of weight, ulcerations, and diarrhea. The center for disease control and prevention has stated that between 10% and 20% of those infected with *Entamoeba histolytica* become sick and manifest any of the symptoms given above. Amoebic colitis, an infection caused by the same organism with the invasion of the colonic mucosa, may also present similar conditions to those of amoebiasis.

Giardiasis: It is also another infection or diseased condition related to poor sanitation and hygiene in rural and even some urban areas. Flagellate parasitic pathogens are one of the most common causes of water-borne diseases like diarrhea globally. It can also be acquired through exposure to contaminated food and water. It is caused by a parasitic organism (*Giardia lamblia*), and the infection can also be spread via contact with infected people, including through anal sex. Giardiasis could also be zoonotic due to the fact that animals like pet cats and dogs can also contract the disease and spread them to humans around them. This parasitic pathogen infects the intestine of humans by attaching to the surface of the small intestine, mainly in numbers large enough to severely obstruct the absorption of nutrients. This condition could cause severe problems in some cases if untreated. The incubation period may be between 1 day and 14 days, with an average incubation period of 7 days. The parasite can be found on soil surfaces, in soils, food, and water. It also forms a cyst that is a potent infective agent of the parasite. Symptoms may appear with mild to severe irritations. Common symptoms of giardiasis include diarrhea, stomach cramps, fatigue, nausea, weight loss due to dehydration, and bloating. Stool examination of *Giardia* parasites is a common diagnostic method, as well as the use of endoscopy. Symptoms may disappear on their own, but appropriate antibiotics are also an effective treatment option for the disease.

Cryptosporidiosis: It is a diseased condition caused by the microscopic parasite *Cryptosporidium* species is an apicomplexan protozoan parasite of the genus *Cryptosporidium* that affects a range of animals, including humans, by infecting their lungs and digestive systems. (Campbell et al., 1982). Human cryptosporidiosis is caused by infection with apicomplexan protozoans of the genus *Cryptosporidium* (Checkley et al., 2015; White, 2020). Hence several species of the parasite exist that infect both humans and animals. This protozoan parasite causes an infection that is spread by spores that are environmentally resistant in contaminated drinking water and food sources, which may lead to significant outbreaks of diarrhea that generally lasts below two weeks in individuals with immunodeficiency conditions (Leitch & Heb, 2011). The parasite has a protective shell that enables it to survive outside the host for a reasonable length of time, and it could become intolerant to disinfection with chlorine in water treatment, including drinking and recreational water, which are also means of spreading the disease to humans.

Cryptosporidium hominis is among the common species that humans are the only natural host while *Cryptosporidium parvum* infects a variety of mammals, humans inclusive also (Bouzid et al., 2013; Checkley et al., 2015; White, 2020). Cryptosporidiosis can be transmitted by orofecal routes like exposure to contaminated/undercooked food, recreational/untreated water and ingestion of the parasite's cysts. The incubation period of *Cryptosporidium* is between 2 days and 10 days, with an average of about 7 days, similar to those of other enteric diseases mentioned earlier. Some of the symptoms of the disease include diarrhea, fever, abdominal cramps, and discomfort while some victims may be asymptomatic—not showing any symptoms. However, other immunocompetent persons may have the symptoms gradually disappear in them, while immune-compromised persons like pregnant women, children, and cancer patients may experience prolonged illness.

Toxoplasmosis: Toxoplasmosis is also a related diarrheal disease that can cause problems in domestic and wild animals, humans, and even aquatic fauna. The disease is caused by a parasite, *T. gondii.* Infection and transmission of *T. gondii.* are mainly due to the nature of the oocysts which greatly aid the contraction of this disease due to its resistant and persistent nature. The oocysts are predominantly found in soil, water, and even foods which also widens the contraction and spread of the disease. The disease is prevalent all over the globe, with a sizeable proportion of adults affected, though it has not been commonly reported within the Niger Delta region. Toxoplasmosis is also zoonotic, as it is horizontally transmitted to humans by the unintentional ingestion of oocysts in cat feces or by eating raw meat or undercooked meat which contains the cysts (Tenter et al., 2000). Bahia-Oliveira et al. (2003) also reported that drinking unfiltered water was found to increase the risk of seropositivity in the lower socioeconomic level of people by an odd ratio of 3.0. The disease can also be vertically transmitted from an acutely infected pregnant mother to the unborn child (Remington et al., 2001). A hitherto acquired *T. gondii.* can be restarted, resulting in a severe illness, including encephalitis particularly, in immunocompromised individuals (Luft & Remington, 1992). The incubation period of toxoplasmosis is between 5 days and 23 days. The major transmission route is the ingestion of contaminated food, water, and soil laden with the oocyst of *T. gondii.* The infections of the parasite have often been reported as asymptomatic, but *T. gondii* can cause major diseases and even death in animals and humans (Carme et al., 2002; Jones et al., 2012;

Kreuder et al., 2003). Other symptoms may be prolonged fever, weakness, lymphadenopathy, lymphocytosis, and elevated liver enzyme conditions.

Schistosomiasis: This parasitic illness is brought on by blood flukes or trematode worms of the Schistosoma genus (Izah & Anagye, 2016b). It might appear acute or chronic, and it is also known as bilharziasis. The condition, which is frequently linked to poverty, can be contracted by coming into contact with contaminated freshwater that has been infected with the parasite's larval forms, called cercariae. When the parasites are released by their vector, freshwater snails, they do so in their larval stage. Most of the eggs laid by the adult parasite are left in the tissues and organs of the human and animal body, where immune reactions of the body to this can cause serious problems in the body. The adult worm is actually found living in the veins draining the intestines and urinary tract in the infected person or animal. Diagnosis is by biopsy, urine or fecal examination and identification of characteristics eggs of the parasites, as well as serologic examinations to ascertain pathogen identity. It is also important to note that the chronic stage of the disease could lead to complications in various organs of the body like the gastrointestinal tract, urinary tract, liver, and even heart. Many people that develop chronic schistosomiasis may show symptoms within months or years later than the initial exposure to the parasites. The disease has an incubation time of 14–84 days for those with acute schistosomiasis, but many others are symptomatic with subclinical diseases (CDC, 2020). The disease is common around the globe but mainly in tropical and sub-Saharan regions where communities are without potable water and good sanitation. The WHO has reported millions of people around the globe infected with the disease, with some areas as endemic to the disease. The species *Schistosoma haematobium* cause urogenital schistosomiasis while any of the species, *Schistosoma mekongi, Schistosoma intercalatum, Schistosoma guineensis, Schistosoma japonicum*, and *Schistosoma mansoni*, is responsible for intestinal schistosomiasis. The common symptoms of the disease include headache, weakness, bloody diarrhea, abdominal cramps and discomfort, chills, cough, fever, and even blood in the stool or urine. Seizures, paralysis, and change in mental status could also show as symptoms of chronic schistosomiasis. The use of antiparasitic drugs like praziquantel, albendazole and ivermectin can often be an effective treatment for schistosomiasis, particularly during the acute stage of the disease. The strategy of the WHO on the use of anthelminthic drugs also ensures effective control of schistosomiasis in rural communities. Regular treatment of those who are at risk particularly, in endemic areas, can help prevent the diseases in line with WHO standards.

21.5 Prevalence of parasitic water-related diseases in the Niger Delta

One of the main causes of morbidity and mortality worldwide is the prevalence of waterborne diseases. This is because places with a high frequency of water-borne diseases lack access to drinkable water. A report on world development indices by World Bank (2015) showed that 2.5 billion people worldwide lack access to appropriate sanitary facilities, while 1 billion people lack access to drinkable water. Worldwide, 4 billion occurrences of water-related illnesses result in 3.4 million fatalities each year. This is the main reason for water-related illnesses and mortality, especially in children under the age of five. In most developing countries' rural areas have worse conditions (WHO, 2014). WHO's (2017) study on drinking water found that 423 million people acquire their water from unprotected springs linked to the spread of water-borne diseases, while 159 million people depend on surface water sources, including rivers and streams. Consumption of these microbiological pathogens found in contaminated, hazardous water causes water-related illnesses such as typhoid, diarrhea, dysentery, and paratyphoid (Vaziri, 2010). Incidences of epidemics and a high frequency of parasitic water-borne diseases impact coastal settlements in several rural communities in Africa, particularly the Niger Delta region of Nigeria, and ultimately result in elevated rates of morbidity and mortality there.

The majority of people living in these areas with a high prevalence of parasitic water-related diseases do not boil or even filter their drinking water before use. This predisposes them to morbidity and consequent mortality conditions. Poor living conditions and sanitation, absence of potable water supply and indiscriminate dumping/excretion of wastes around drinking water sources also predispose communities to disease conditions leading to endemicity and high prevalence of water-related parasitic diseases in most rural communities of the Niger Delta region of the world. Atting et al. (2019) in a study of a community (Akwa Ibom State) in the Niger Delta, reported prevalence of water-related diseases as follows: typhoid fever, 24.0% (adults) and 13.5% (children); diarrhea, 11.0% (adults) and 30.0% (children); dysentery, 15.0% (adults) and 22.5% (children); and cholera, 8.0% (adults) and 4.0%, (children). Another study of a community in Bayelsa state of the Niger Delta reported a prevalence rate of water-related diseases between 2005 and 2007 as diarrhea (44.94%) and dysentery (16.85%). Another study of different drinking water sources in Ondo state of the Niger Delta found several parasites related to waterborne diseases and their prevalence, including *Cryptosporidium parvum* (38.4%), *Cyclospora cayetanensis* (1.6%), *Entamoeba histolytica* (33.6%), and *Strongyloides stercoralis* (0.9%) (Simon-Oke et al., 2020). In terms of the water sources, examined prevalence of parasites was reported as stream water (45%), well water (24%), rainwater (21%), and borehole water (10%) (Simon-Oke et al., 2020). Umoh et al. (2020) also reported an overall prevalence rate of 8.0% for urinary schistosomiasis in school children of Ebonyi state (near the Niger Delta) of eastern Nigeria. The prevalence of *Entamoeba histolytica* (4.6%), *G. lamblia* (9.2%), and *Strongyloides stercoralis* (1.4%) had also been reported in a study of preschool children in the Niger Delta (Arene & Akabogu, 1986) while Omorodion et al. (2012) reported prevalence of *G. lamblia* (0.51%) and *S. mansoni* (0.51%) in school children of Delta State in Niger Delta, Nigeria. In Edo state of the Niger Delta, Mordi (2007) observed the prevalence rate of some water-borne parasites as; *Entamoeba coli* (6%), *Entamoeba histolytica* (4%), and *G. lamblia* (3%) while *Schistosoma haematobium* (2%), *Loa loa* (1%), and *Enterobius vermicularis* (1%). Cockroaches were also identified as vectors that could transmit food and water-borne parasites with prevalence of *Giardia intestinalis* (23.07), *Entamoeba histolytica* (19.00), *Cryptosporidium parvum* (2.95), and *Taenia* species (2.02) in a study in Otefe-Oghara, Delta state in the Niger Delta region of Nigeria.

21.6 Effective management of parasitic pathogens in rural drinking water supply

The effective management of parasitic pathogens in rural drinking water is key due to the morbidity and mortality associated with such parasitic pathogens. For us to have the desired result in the effective management of rural water supply, there must be improved sanitation and hygiene as well as water quality. These three factors must be effectively managed to yield the desired result. The improvement of any of these without the other may not lead to an effective and sustainable goal in water quality management. It is also important to state that management of pathogens in rural water supply varies from place to place, depending on factors like specific pathogens particular to each area that could resist certain types of water treatment methods. Millions of people die annually due to preventable diseases earlier mentioned in this chapter, resulting from lack of portable water, poor hygiene, and poor management of rural water supplies. According to Bartram and Cairncross (2010), improvement in water quality, good sanitation practices, and personal/general hygiene may prevent the deaths of more than two million children who are under the age of five every year. The majority of these deaths are recorded in rural areas of most developing countries, including the Niger Delta region of the world. South-East Asia regions and Africa account for 78%, which is about 1.46 million of total deaths coming from disease in most developing countries of the world (Boschi-Pinto et al., 2008). The parasitic pathogens of water-borne diseases are mainly the cause of about 1.7 billion cases of diarrhea, responsible for about 842,000 deaths of people annually (Baldursson & Karanis, 2011; Efstratiou et al., 2017). Though diseases caused by parasitic pathogens could also be endemic and epidemic in both advanced and developing countries of the world (Cotruva et al., 2004), advanced countries have better hygiene and sanitation conditions leading to reduced deaths. Apart from improvement in water quality, hygiene, and sanitation, an institutional approach is also necessary for an effective rural water management system.

In terms of the improvement of drinking water quality, several methods, both conventional and unconventional, could be used to achieve the aim of improving water quality. Practices that lead to the settling out of particles (coagulation and flocculation) under gravity are quite useful in water treatments, even in rural areas. Coagulants that are put into the water cause suspended particles to collect together into bigger and weightier masses of solids flocculated together. Alum (aluminum sulfate) is a commonly used coagulant when purifying water. Ferric sulfate and sodium aluminate could also be used as coagulants to flocculate suspended particles. Most of the parasitic pathogens in water could be coagulated and flocculated before eventual removal in the treatment process. Such methods have been effectively used to remove the oocysts and cysts of common causes of parasitic water-borne disease related to *Cryptosporidium* and *Giardia*, respectively (Gregory et al., 1999). The efficiency of coagulation methods in the removal of oocysts of *Cryptosporidium* was also ascertained in a study by Plummer et al. (1995).

Boiling water is one of the most common and easy means of water treatment in many households. Education and awareness could go a long way in achieving this in rural and urban areas with poor water quality conditions. Reasonable achievement of this practice could further reduce the risk of morbidity and mortality of waterborne diseases due to parasitic pathogens in many developing countries. Many people in developing and even developed countries usually boil their drinking water due to a lack of confidence in the safety of their drinking water supply (Lantagne & Clasen, 2012). However, the availability of energy for the regular boiling of water is also a major challenge to the poor in rural areas of developing and developed countries.

Filtration is another technique for the removal of particles during water purification processes. In rural areas, physical sieving is practiced and found to be effective in water treatment depending on the available mesh size of the filters used. Depending on the size of the filter used, this technique can effectively block off parasitic pathogens in water during treatment. Mesh sizes used in water treatment and purification range from 0.01 μm to 0.5 μm, which is at least an order of magnitude less than the size of protozoan cysts, which range from 4 μm to 15 μm (Betancourt & Rose, 2004; Jacangelo et al., 1997). Swertfeger et al. (1999) stated the efficiency of this method to depends on factors like the size and density of microorganisms, size and surface charge of organisms, suspended particles coagulating, and filtration rate and depth of the filter material. Certain filters may not be effective in removing parasitic pathogens, but others like diatom filtration may be quite effective in the removal of the cysts and oocyst of *Giardia* and *Cryptosporidium* compared to others like granulated media and conventional filters (Ongerth & Hutton, 2001; Ongerth & Hutton, 1997). The use of microfiltration membranes has also been good in the effective removal and management of parasitic pathogens in water. Microfiltration, ultrafiltration, nanofiltration, and reverse osmosis are effective alternative treatment methods to other local water treatment methods aimed at getting rid of the cysts of pathogens (Jacangelo et al., 1997). Reverse osmosis is used for the treatment of drinking water obtained from the sea, brackish water, and groundwater mainly due to the capacity to remove monovalent ions (Thorsen & Flogstad, 2006).

It is also very imperative to state that coagulation and filtration techniques alone in water purification cannot remove certain pathogens. Therefore, additional techniques like disinfection may be necessary to complement other methods. One of the commonly used disinfecting agents is chlorine. The effective use of chlorine is quite long in water treatment history both in developing and advanced countries. It has been found effective in the treatment of both drinking and recreational water. Due to its affordability and quite ease to use, chlorine treatment in water purification is also recommended for individual households' usage (Arnold & Colford, 2007). Though chlorine has been an effective disinfecting agent in water treatment, odor and taste associated complains arise due to its use. Medeiros and Daniel (2015) stated that some disadvantages of using chlorine include resistance by protozoans and objectionable odor and taste due to the presence of organic material in the water. Another issue with household use of chlorine is that of unquantifiable use of chlorine where overdose use of chlorine could also have effects on the consumers of chlorine-treated water.

Another effective method of water treatment is the use of UV rays/light. The key principle here is the penetration of UV rays into the cell, where it is capable of impairing DNA and RNA functions, rendering the pathogenic cell useless. Though this method is also effective and used in various household water treatment, the cost of providing this and the electricity to power it may be major hindrances in the rural water treatment process.

Sanitation is key to achieving rural water treatment and sustainable management. Sanitation and hygiene are closely related and will be discussed together here. Activities of humans at all levels generate certain kinds of waste both in developing and developed countries of the world. Such wastes generated if not properly handled could pose a serious threat to humans particularly, sanitary wastes. In rural areas, the indiscriminate disposal and discharge of fecal waste is a major challenge related to effective water treatment and management systems. Earlier in this chapter, the orofecal route was identified as a major means of infection and contraction of waterborne diseases. Poor sanitation methods particularly in rural areas are a major empowerment that enhances and escalates the transmission and spread of waterborne parasitic diseases. It is therefore very important to state that the provision of basic infrastructure and necessities of life including affordable houses with proper sanitary and waste disposal systems, effective drainage systems, provision of potable water, provision of electricity and adequate/appropriate waste disposal systems is vital in delivering effective and sustainable water management in the rural areas. Even in industrialized countries where wastewater treatment plants exist, if the waste is not properly treated before discharge to the environment, it can constitute a pollution threat to people (Hambidge, 2001). Personal hygiene is also very important. Good management, handling, and diffusion of animal and human feces remain significant for the hygiene and safety of both recreational and drinking water (Omarova et al., 2018). The use of pit latrines should also be discouraged and gradually phased out due to the high risk of groundwater contamination it poses. In many countries that still use pit latrines commonly, more than two billion persons use groundwater as a drinking water source (Graham et al., 2013), thereby, making contaminants enter groundwater from pit latrines and become a threat to public health (Omarova et al., 2018). Certain factors are critical to the location of pit latrines particularly, groundwater flow direction, the distance between the pit base and groundwater level, and the distance between the pit latrine and drinking water sources. Dzwairo et al. (2006) emphasized the consideration of three vital factors in terms of pit latrines, including analysis of some serious factors, like depth of permeation layer and groundwater flow direction, providing alternative sanitation like raised or leveled pit latrines in order to reduce the impact on groundwater and use of hydrogeology and geo-technology to resolve problems of sanitation. Different studies have also recommended different minimum safe distances between groundwater levels and pit latrines. Franceys et al. (1992) proposed a 15 m safe lateral distance between wells and pit latrines, but Water aid (2011) recommended at least 50 m apart between toilets and water sources, while Sphere project (2011) recommended a minimum of 30 m standard for the lateral distance between water supply sources and local sanitation systems. Breeding grounds for pathogens and waterlogged areas should be regularly cleaned and sanitized for healthy living.

Personal hygiene works hand in hand with sanitation. It is a very important component of effective management of parasitic pathogens in water. Personal hygiene involves the personal practice of taking your bath regularly, regular hand washing, trimming fingers and toenails as well as brushing of teeth, among others. This is due to the fact that we encounter millions of germs including, pathogenic parasites, that could pose a threat to our health. People can protect themselves and others via the practice of personal hygiene, and this can be achieved particularly through awareness campaigns and education in rural and urban areas. The motivation and Education of people to change their hygienic behavior should be encouraged from the family setting (Newson et al., 2013) and then spread to the larger society. According to the Centers for Disease Control (CDC, 2017), good personal hygiene habits like routine hand washing before preparing and eating food, after using the bathroom, after changing diapers, and before and after attending to sick people can protect people and others from water-related protozoan diseases. Water storage containers/tanks should be regularly washed and disinfected, and drinking cups and food plates should be regularly washed clean before use. Direct contact with taps should be greatly discouraged to avoid contamination. Fecal wastes from children should be properly managed to avoid contact with food and drinking water sources either directly or indirectly. People should be discouraged from drinking from open wells, streams, rivers, and other sources of contaminated water. Community sanitation should be encouraged to strengthen and support personal and family hygiene.

21.7 Conclusion

The fact that water is very vital in domestic, commercial, and industrial applications/uses cannot be over-emphasized. Therefore, it becomes very imperative to make water available and potable for humans. Rural areas, particularly, in many developing countries of the world have no access to potable water. The option in most cases is to depend on open wells, streams, and rivers for their drinking water sources and other household activities. Such open wells, streams, and rivers are prone to contamination and toxicity by both chemicals and biological pathogens. Exposure of rural people particularly in densely populated communities to contaminated water sources is a serious public health concern. It is therefore, very important for the proper management of our sources of water, to forestall the occurrence of toxicity associated with parasitic pathogens. Occurrence of toxicity related to parasitic pathogens in our drinking water sources, especially in rural area leads to increase morbidity and mortality rates, particularly among the vulnerable groups of the affected population. Some of the diseases include gastroenteritis, such as giardiasis, amoebic dysentery and others like schistosomiasis. The prevalence rate of water-related parasitic infections appears to be higher in the rural areas of developing and developed countries, including the Niger Delta region of Africa. Common methods like boiling, filtration, flocculation, and chlorination in addition to institutional management (water treatment plant/process) approaches, have been applied to solve the problem of parasitic water-borne pathogens. It is important to note that sanitary inspectors/health officers were also very useful in achieving both public and private sanitation and hygiene in the rural and urban areas of the Niger Delta, Nigeria. This was key in the aspect of enforcement. In this chapter, we, therefore, conclude that there is a need for adequate provision of potable water and improved management of occurrence and toxicity associated with parasitic pathogens in drinking water sources in rural areas of the Niger Delta, Nigeria. This shall lead to sustainability in the management of water-related issues in the rural areas of the Niger Delta and other parts of the world.

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Chapter 22

Sustainable water use and management for agricultural transformation in Africa

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22.1 Introduction

Water is an important substance to all forms of life and contains diverse chemical elements which may be suspended or dissolved. Water can exist in various forms as solid, liquid, or gas and it is very important in agricultural production and food sustainability. These processes can be achieved by increased investment in irrigation facilities and intensification in agriculture which can ensure that water is efficiently used and hunger is eliminated as opined by the Sustainable Development Goals (SDGs). Worldwide, it has been reported that production from irrigated agriculture contributes to 40% of total food production and it represents a fraction of 20% of cultivated lands. This approach enables increased production and diversification of crops per unit of land. The competition for the use of water has increased and is due to population growth and climate change has been reported; therefore, to meet food demand measures of transformation in agricultural practices are required for food production. By 2050, the human population is predicted to exceed 10 billion, and food production is required to increase by 70% (World Bank, 2016).

Generally, ground and surface water are the most commonly utilized water types (Izah & Anagye, 2016a; Izah & Srivastav, 2015; Izah et al., 2016; Izah et al., 2022a,b). Water resources are being depleted due to poor handling and human activities in the water systems. As such, the microbial and physicochemical quality of water resources from different regions has been compromised about many of the determinant parameters (Agedah et al., 2015; Aghoghovwia et al., 2018b,c; Ben-Eledo et al., 2017a,b; Izah & Anagye, 2016b; Izah & Ineyougha, 2015; Izah et al., 2015, 2021, 2022a,b; Ogamba et al., 2015b,c,d, 2017; Ogamba et al., 2017a, 2021; Seiyaboh & Izah, 2017a,b; Seiyaboh et al., 2017a,b, 2020a,b). Also, when the characteristics of the surface water are polluted, it affects the overall sediment quality (Aghoghovwia et al., 2018a; Aigberua et al., 2020; Aigberua et al., 2020; Seiyaboh et al., 2016a,b, 2017c). The pollutants found in water, especially in surface water, could bioaccumulate in the tissues of aquatic organisms such as fish (Aghoghovwia et al., 2016; Aigberua et al., 2021; Ogamba et al., 2015a, 2016a,b,c, 2017b), and planktons (Ogamba et al., 2019a,b). These toxins could enter the human body through the consumption of contaminated water or aquatic food contaminated with the toxins. Water transformation is required to address issues associated with water insecurity such as water accessibility, water stability, water availability or scarcity, water utilization, etc. The sustainable development of Africa requires water security alongside biodiversity management and this may be achieved through agricultural transformation (Ogwu 2019a,b; Ogwu & Osawaru, 2022, Osawaru & Ogwu, 2020; Imarhiagbe & Ogwu, 2022; Imarhiagbe et al., 2022). In Salem et al. (2022) waste was included in the nexus required for sustainable development alongside energy and food. In Africa, water is important in addressing some non-communicable diseases due to utilization patterns, homeostasis, and hydration status (Ogwu & Oladeji, 2014). Agricultural transformation encourages better management of development, food issues, and environmental challenges like agricultural pollution (Erinle et al., 2021; Ikhajiagbe et al., 2022a,b; Izah et al., 2022;

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Massarelli et al., 2021; Ogwu et al., 2014; Osawaru et al., 2013). Sustainable agriculture centers on practices and technologies with little to no adverse effects or legacies on biodiversity, environmental goods, and services while improving food production and income security of farmers (Ikhajiagbe & Ogwu, 2020; Ogwu et al., 2014, 2018; Ogwu & Osawaru, 2015; Ogwu, 2019c; Pretty, 2008).

The chapter assesses agricultural transformation practices and the role of water use and management toward sustainability in Africa. The chapter will look at steps involved in agricultural transformation as well as the types of agricultural transformation and implication of water use, sustainable strategies involved in agricultural transformation and implications of water use, challenges in agricultural transformation and implication of water use, and adaptive strategies to toward sustainable use of water during agricultural activities.

22.2 Water usage and challenges in agriculture

The movement of water for agriculture can be both physical and virtual.

- Physical movement refers to the changes that may arise which deviate from the initial allocation of resources from surface and groundwater examples of such are the changes in resources from agricultural to urban, environmental, and industrial users.
- Virtual movement of water involves the trading of produced goods, foods, and services with water in scarce localities.

The reallocation and shift of inter-sectorial waters away from agriculture should be accompanied by improved water use efficiency and delivery systems. This improvement will depend on the matching of improved off-farm systems which are aimed at improving the management of soil and water. Water management may be improved by establishing a good water delivery system and using advanced technologies for soil management such as soil moisture sensors and satellite measurements. Constraints such as inadequate policies, limitations in the financing, under-performance of institutions, and the lack of an enabling and functioning environment can be encountered when implementing a water management approach in agricultural transformation.

To curb these constraints, it is important that the management of the agricultural water sector must align with the modern and sustainable approach to water management. An approach to building resilience, water services, and sustainability is essential, not limiting the risks associated with the social and economic impacts of water-related issues. Some of the issues are governance, service provision, and greening which can be controlled by providing incentives for innovation, reforms, and accountability (World Bank Group, 2022).

22.2.1 Rural water resources and management in Africa

Around 300 million people in sub-Saharan Africa lack access to safe and clean water which has necessitated diverse ongoing local, national, regional, and international efforts to eliminate or reduce water inaccessibility on the continent (Armah et al., 2018; MacDonald, 2005). However, the reports of Hope et al. (2012) suggest despite the water being a human right rural water insecurity in sub-Saharan Africa may be elusive to achieve if pursued as a standalone challenge as it is connected to human development and natural environmental challenges. Rural water resources in sub-Saharan Africa are mainly from the harvested surface, ground, or rainwater. Safe and clean water refers to the healthy quality of water as well as the accessibility in required quantities (Jagals, 2006). Rural water challenges in sub-Saharan Africa are connected to the high spatiotemporal variability of water resources and the overall limited amount of water and unsustainable uses. Sustainable rural water development and management would require a balancing of resources, developmental pursuit, boundaries, and ecosystems (McClain, 2013). This is supported by the integrated water resources management strategy such as the setting, perspective, intervention, comparison, and evaluation or SPICE structure model proposed by Dirwai et al. (2021). A dominant feature of their model is the existence of a defined structure for rural water management and the connection of the socio-economic development agenda through a multiplicity of oaths. Another consideration is that shared in MacAllister et al. (2020) where groundwater access is prioritized with a myriad of available and growing technologies. Analysis of integrated water resources management suggests a lack of implementation framework as reported in Nigeria or a singular structure as reported in Kenya will exacerbate rural water challenges in sub-Saharan Africa (Ngene et al., 2021). There is a need for cooperation and commitment among stakeholders to ensure rural water suitability in sub-Saharan Africa. One such cooperation and commitment among stakeholders would be agricultural transformation through a balance of contemporary and indigenous approaches.

22.3 Agricultural transformation

It refers to a process in which the food systems in agriculture change over time from an approach that is farm centered and uses subsistence equipment to a more productive, commercial, and use of improved equipment and facilities which is more centered on off-farm (Jayne et al., 2019). The process of transformation is usually gradual in which agricultural farms gradually transcend from production systems, which are subsistence oriented into an approach that is more specialized and the production processes involved are more profit-oriented. It is dependent on the rate at which the adoption of new technologies that can improve growth and productivity is done. In this approach, the labor force is perfected; resources and investments are properly allocated and used efficiently. Efficiency is also increased by connecting raw materials and farmers to appropriate markets and resilience can be enhanced against issues of market pressure, climatic fluctuations, and political issues (Hope & Ballon, 2021; Mukasa et al., 2017).

22.3.1 Agricultural transformation in Africa

In the last decade, agricultural transformation in Africa has been based on the increasing need and necessity of land and labor production so the gap of scarcity can be addressed (Adamon et al., 2017; World Bank, 2007). International agencies and donors are concerned about the low productivity in Africa and they attributed the causes to the use of primitive implements rather than adopting new technologies for improved yields. To boost production, vulnerable African countries must be able to tap into the processes of Green and Industrial Revolutions to boost agricultural and food products and tackle issues of poor finances and poverty. The Green Revolution for Africa approach argued on the models of agricultural transformation and stated that the ability of small farmers to increase their yield can be improved by the provision of off-farm industrial inputs such as improved seeds and chemical fertilizers. These farmers will also have the capacity to export products and compete favorably (World Bank, 2007).

Proctor and Lucchesi (2012) have reported that the process of transformation in agriculture is currently ongoing at various stages in some African countries. It is being observed in these countries that there has been a constant shift of the employment force from the agricultural to non-agricultural sectors, and this movement poses a serious challenge to structural and agricultural transformation in these countries. A decline of 3.4% in the share of employment in the sub-Saharan agricultural force between 1999 and 2009 has been reported by the International Labour Organization (ILO). Between 2009 and 2010, there was a decline from 61.6% to 49.8% in the share of employment in agriculture (Proctor & Lucchesi, 2012).

22.3.2 Channels of agricultural transformation

The growth of the economy can be dictated by agricultural transformation and there are three channels involved (Fig. 22.1):

- Multiplier effects on local and domestic sectors that are connected to agriculture directly and the food systems indirectly (Snodgrass, 2014).

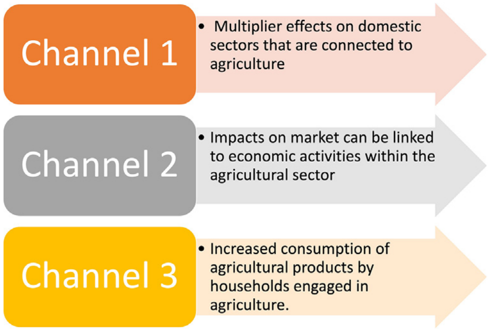

FIGURE 22.1 Channels of agricultural transformation.

- The impacts of factor markets can be linked with economic growth from agriculture.
- An increase in income can impact the growth of the economy through increased consumption of agricultural products by households engaged in agriculture.

In the first channel of transformation, the increase in demand for various agricultural goods, fuel, transportation, services, and modern agricultural input such as improved seedlings, fertilizer, and other agrochemicals, and services can stimulate growth in the agricultural sector. This growth will assist industries to meet up increasing demand most especially in the food processing sector of agriculture. A directly proportional relationship exists between the contribution to economic growth and the value placed on agricultural production; this is so because these improved activities can stimulate increased production. It has been reported that the multiplier effect on agriculture in sub-Saharan Africa was 1.5 between 1989–2014 and it translates that the national income increased by USD 1.5 as a result of the increase in income from agriculture as a result of innovation, investments, and technology by USD 1 (Farole & Winkler, 2014).

In the second channel, factor markets play a direct association with economic growth from agriculture. This is possible because the process of transformation in agriculture requires less force of labor to achieve increased agricultural output. This is achieved by technological change, increased knowledge and investments, and excess labor can be diverted to other sectors of the economy for productivity (Adamon et al., 2017).

Finally, the third channel explains how economic growth can be increased when agricultural households consume more products with an increase in income. With this, demand by the non-agricultural sector will increase thereby raising drive-in economic growth and national economy demands (Adamon et al., 2017). Agricultural transformation can be seen as a potential tool that can achieve growth that is inclusive in Africa. It can stimulate employment, boost investment and income, and help increase the standard of living of people involved in agriculture.

TABLE 22.1 The contribution of the manufacturing sector to sub-Saharan African gross domestic production.

Year	Contribution (%)
1980s	14.3
1990s	12.5
2000–2015	10.8
2017–2018	<10
2019–2020	11
2021	12

However, in East Asian countries where structural changes are experienced in agricultural labor, rapid increases in manufacturing are the order of the day with a lot of African workers divulging into the services sector and vacating the vacating agricultural sector (Kormawa & Jerome, 2015). As reported by World Bank (2016), the present contribution of the manufacturing sector to the gross domestic production (GDP) of sub-Sahara Africa is declining as compared with the 1980s and this suggests that the continent is de-industrializing (Table 22.1).

Transformation in agriculture can take different forms and environments can be created as a result of new opportunities which are more conducive to a rural-centered agricultural transformation. The decline in employment in the manufacturing sector and the increase in competition for export markets have provided an opportunity for growth based on export-led industrial development that may be limited for sub-Saharan economies (McMillan et al., 2014).

22.3.3 Measures for agricultural transformation

22.3.3.1 *Improving agricultural value chain*

In terms of agricultural practices and the export of processed foods, Africa lies at the bottom of the value chain. As reported by Webber and Labaste (2011), the agricultural value chain tends to have dual component that is more or less connected with each other. The components are:

- The formal components comprise services and products offered by large farms and processors to domestic consumers that are high-income earners.
- The informal component services the lower-income consumers in local markets.

Agricultural transformation is required for inclusive growth and it is dependent on growing agricultural performance and connections between essential value chains and stakeholders. The lack of an adequate agricultural value chain poses countries with the risk of low productivity, producing products, services, and skills that are of low value and have less significance in the global trade share. The share of agricultural imports in the developing sub-Saharan Africa region has increased rather than decreased, thereby creating imbalances between the revenue generated from export revenues and importation bills. Adamon et al. (2017) reported that economic growth in sub-Saharan Africa is significantly affected by redistributive capacity and measures that address sustainable and inclusive growth should be adopted for a successful agricultural transformation.

22.3.3.2 *Mechanization of agricultural practices*

For an improved agricultural business activity, it is essential to transit from a subsistence-oriented production approach to a mechanized agricultural production approach. This expansion has assisted in the transformation of the agricultural systems and sectors in many Asian and Latin American countries through subsistence-oriented practices to an industry with the competitive ability both in the local and international markets. The rate of adaptation and involvement in agricultural mechanization in African countries is very low. World Bank (2016) reported that most African countries use 13 tractors per 100 km^2 of land for agricultural purposes as compared with the global average of around 200 tractors per 100 km^2 of land. Food and Agricultural Organization of the United Nations (FAO, 2008) reported that there was an increase of 28% in the rate of mechanization (the use of tractors) by sub-Saharan African farmers when compared with values from the Caribbean, Latin America, and Asia between the periods of 1961 and 2000.

Africa is a continent rich in natural resources which are untapped and 25% of the world's fertile lands can be harnessed for improved agricultural mechanization. Despite these resources, Africa accounts for only 10% of the global output in agriculture. It was projected by McKinsey and Company (2014) that Africa can potentially triple its derivable net annual value from agricultural output to around US$ 880 billion by 2030. The continent uses less than 5% of water resources and 6% of agricultural lands are irrigated. Therefore, Africa has potential and promising markets for increased sales of agricultural machinery and prospective investments. No doubt, this will significantly contribute to the transformation of agricultural practices and the nature of the output produced.

22.3.3.3 *Youth and women*

The role of women cannot be neglected in the contribution to agricultural development and rural activities in most African countries. Their presence goes a long way in market interaction and their percentage contribution to African agriculture stands at 62%, compared with the results from other developing countries of the world which stands at 43%

TABLE 22.2 Institutional capacity initiatives by African countries toward agricultural transformation.

S. no.	Institutional capacity initiatives	Year launched	Action plans
1	The Comprehensive Africa Agriculture Development Program of the Africa Union's New Partnership for Africa's Development	2003	The program represented the effort of the continent to improve policies in agriculture so as to achieve sustainable agriculture growth and reduce poverty
2	Alliance for a Green Revolution in Africa	2006	The African leaders should strive to modernize agriculture for increased production, productivity, value addition, as well as shared prosperity
3	The Grow Africa Initiative of the African Union, the New Partnership for Africa's Development and the World Economic Forum	2011	
4	The agenda 2063 of the African Union	2013	
5	The Africa Development Bank's High-level conference on "Feed Africa"	2015	
6	The Africa Development Bank's "Feed Africa" Strategy	2016	

From: Adamon et al. (2017).

(Palacios-Lopez et al., 2017). Consequently, women's involvement in agricultural transformation and subsequent economic growth is very important. Youth are the greatest assets for Africa's transformation in agriculture and economic growth. It has been projected that the population of African youths is rapidly growing and figures will double to over 830 million by the year 2050. Aging population problems is the least concern in the sub-Saharan African population is rejuvenating and currently has the highest population of the world's youngest age groups and has over 420 million young people in totality. On average, two out of three randomly selected individuals are underage 25 while 44% of the entire population is below the age of 15 (Brooks et al., 2014). Alliance for Green Revolution in Africa (AGRA, 2016) reported that rural areas are responsible for around 70% percent of the youths with 65% of them employed primarily in the agricultural sector.

To address challenges and constraints affecting improvement in agricultural productivity, the resilience approach of the vibrant African youth and women can be seen as a great opportunity. Africa can leverage the strength and energy of youths by channeling them into creating an agribusiness venture which is productive, competitive, and more profitable. With this, African countries can record an increase in agricultural productivity, economic power, a better system of food production, and increased returns from agricultural enterprises.

The transformation of agriculture can offer employment opportunities to women and youth which are very attractive. Activities such as transport, marketing, processing, supplies, information, and communication technology are areas of opportunity along the agricultural value chain. Their participation in agribusiness and general agricultural practices can boost economic growth, and reduce or eliminate poverty and food insecurity challenges across the continent. It is important that adequate mobilization, education, and equipped with the need for skills and tools for agricultural transformation must be impacted by the women and youth populace (Adamon et al., 2017).

22.3.3.4 Institutional capability

The agricultural transformation agenda can be facilitated and driven by the strong efficient component of institutions. These institutions are charged with ensuring the prompt delivery of agricultural inputs, services, and resources that are essential for the transformation and modernization of agriculture (Dorward et al., 2004). The effectiveness of agricultural policies, outcomes, and strategies is a function of the quality of the institution. Quality institutions are mandated to moderate the activities of actors such as farmers, agropreneurs, agro-processors, and dealers or industrialists at various agricultural value chains; which in turn causes the agricultural sector to modernize and transformed. Institutions are important in the following areas:

- Increasing productivity.
- They add value to agricultural products.
- They help in reducing harvest loss.
- They can facilitate policies in terms of formulation, implementation, and reinforcement which can result in developmental improvement (Haile-Gabriel, 2015).

African leaders have been encouraged to boost agricultural performances, and production, increase competitiveness and improve governance. There are reports of evidence in the commitments made by African countries to increase their ownership and ways of implementing agricultural initiatives. These were made Maputo Declaration in 2003 and the Malabo Commitments in 2014. Other initiatives as elaborated by Adamon et al. (2017) are presented in Table 22.2.

22.3.3.5 *Climate-smart agricultural practices*

Changing climate is a global phenomenon that affects all spheres of life and the negative effects on agricultural outcomes are more pronounced in Africa and higher than in other parts of the world. Agricultural productivity in sub-Saharan Africa is seriously affected and an expected 13–15% turn-around is expected (Barnard et al., 2015). The approach of climate-smart agriculture (CSA) ensures strategies that will improve the long-term growth of an area without affecting future generations negatively (Branca et al., 2012). Based on this, awareness and enlightenment of the public are essential to ensure sustainability and the development of Adaptative and mitigative strategies for climatic issues.

Africa's agriculture is mostly rain-dependent, and it is a focal point that climate change affects; therefore, urgent measures are required by local farmers for climate change adaptation and mitigation. This led to the inclusion of various programs such as the NEPAD program and the African Climate Smart Agricultural Coordination Platform in 2014. With these programs, the management approach of CSA has increased from zero in the year 2000 to a million hectares in 2014. This increase resulted in better yields, high-profit returns, better soil usage, and fertility, and reduced vulnerability of women involved in agriculture. It is evident that the adoption of CSA practices by African farmers offers a great opportunity to increase agricultural productivity while adapting to and mitigating climate change (Adamon et al., 2017).

22.3.3.6 *Intra-African trade*

The world is a global village and African agricultural systems can benefit from one another through trade relations. This helps to expand the existing farmers' markets and create new ones for the diversification of products which can enhance economic growth. This integration can also promote and attract new investment sources to countries. Farmers from each country can learn from the other and also share the experiences they have gathered during their farming practices. This will go a long way in ensuring sustainable agriculture by harnessing the full potential of the sector through collaboration and sharing of knowledge which can boost growth and productivity in African countries (UNCTAD, 2013).

The strong intra-Africa trade between countries can help in cushioning against all forms of shocks that may be generated from agricultural engagements. This shock is evident in African agricultural enterprises because the continent relies heavily on international trade of primary commodities which are vulnerable to external shocks and trade policies. This problem is very observable in the agricultural sector because the African continent has been a net food importer since the mid-1970s. In recent years, the leaders in African countries have made great efforts to harness the great potential of intra-regional trade which involves employment creation, boosting investment, and stimulating economic growth. In January 2012, the African leaders committed themselves at the African Union Summit to boosting intra-African trade and fast-tracking the establishment of a continental free trade area. It is worth noting that some Regional Economic Communities (RECs) have been able to achieve the commitments stated at the African Union Summit (African Union, 2012). Further incentives that ensure the achievement of the commitments by the African countries are presented in Table 22.3.

TABLE 22.3 **Agencies created as a result of commitments made by African countries at African Union.**

S. no.	Agency	Commitments
1	Southern African Customs Union (SACU)	• The free movement of production factors • It created a common tariff on goods from external countries • Elimination of all forms of intraregional barriers
2	West African Economic Monetary Union (WAEMU)	• The creation of a shared accounting structure • The establishment of a stock exchange that spans the African region

Some approaches for agricultural sustainability in Africa are presented in Fig. 22.2 and include intra-African trade, value chain improvement, mechanization of agricultural practices and processes, incorporation of women and youths into farming, improving institutional capacities, and adoption of CSA.

22.4 Indigenous knowledge and agricultural transformation

Indigenous knowledge is a very popular word used throughout the world today (Diao et al., 2017). Generally, it has been interpreted in several different ways across different continents, but it can be understood to be traditional or local knowledge that indigenes of a particular community or area have passed down to generations mostly through oral and not written tradition. According to Warren (1991), Indigenous knowledge is the knowledge used by local community people to ensure proper livelihood in a particular environment. Johnson (1992) defined indigenous knowledge as an entity of knowledge built by a group of individuals living together in a particular environment over a number of decades. Such type of knowledge develops in the local environment so that it becomes specifically adapted to the

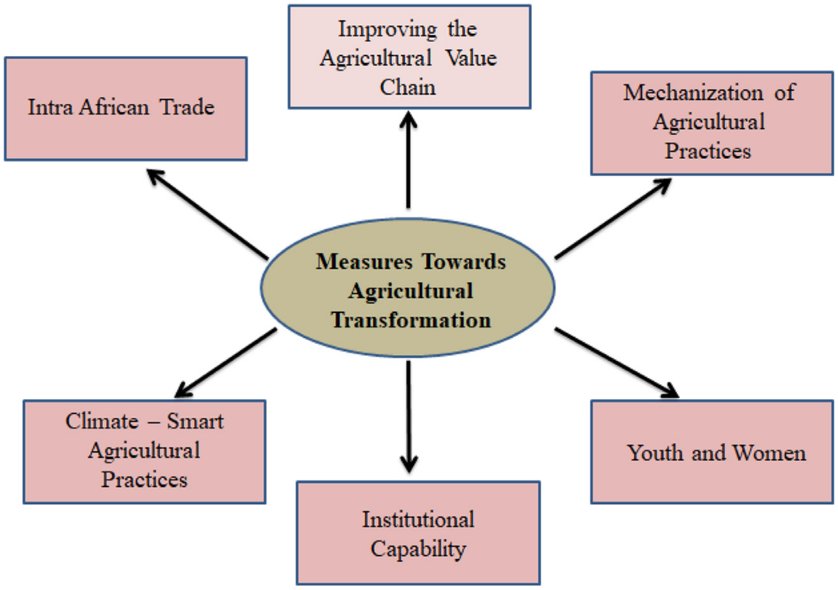

FIGURE 22.2 Measures toward agricultural transformation.

basic requirements and conditions of the local community people. In simple terms, indigenous knowledge is location-specific and so many people make the mistake of thinking it is archaic or stagnant.

The actual knowledge of a particular set of people, showing several experiences based on local traditions and also including recent experiences with modern technologies can also be referred to as indigenous knowledge (Haverkort & de Zeeuw, 1992). It is a product of adapting different farming practices in the local environment, producing exceptional indigenous farming practices and food culture. Indigenous knowledge can play a vital role in the scheme to establish sustainable agricultural systems; thereby increasing the chances that the rural populace will accept, develop, and maintain new ideas and interventions.

Farming accounts for about two-thirds of the budget allotted for livelihood and food, thereby making agriculture part of the most important socio-economic sector in Africa (Africa Progress Report, 2015). This simply means that there is a high dependency on the agriculture sector for improvement in the well-being of Africans. Despite the high level of dependence on agriculture and continued rapid growth in the economic sector over a number of years now, production from the agriculture sector is low in many countries in Africa, and hunger keeps looming across the continent. As a result, many rural areas have become extremely vulnerable to poverty, having low resilience to the impacts of climate change and food security is zero. Hence, the need for agricultural transformation in Africa is expedient in order to address these challenges.

Agricultural transformation can be simply defined as the process by which agriculture has evolved over a period of time. This evolution is from subsistence agricultural practices using local or traditional knowledge into more commercially-oriented agricultural production practices with the use of highly efficient agricultural machines that ensures the production of a product that is sustainable and of good quality. In developed countries, immersed support for agriculture is the most efficient means of improving the livelihood of millions of individuals living in abject poverty. Transforming a nation's agriculture sector can bring about an increase in revenue generation, and the creation of employment for youths; ensure the sustainable production of more crop food, thereby reducing malnutrition and boosting the economy in a gradual process, on the path to middle-income growth. In so many industrialized countries, notably Brazil and China, the rise in their economic growth began with a transformation in the agriculture sector. Each of these countries has been able to double the value of its agriculture sector just within a space of 20 years since the inception of the transformation process. Many countries in Africa, Asia, and Latin America are earlier on the path of transformation. Africa, Latin America, and Asia all have many countries just in the early stages of their agricultural transformation process.

In some countries, the process of transforming their agricultural sector has not progressed as planned because the complexity of the process is very tough for some governments. In view of wanting to achieve multiple objectives simultaneously through the transformation agenda, the government chokes itself sometimes. Governments are currently focusing their agricultural transformation plans on Sustainable Development Goals (SDGs) by considering, climate-smart strategies for sustainable agricultural production, women's economic empowerment, and biodiversity management.

22.5 Agricultural transformation in Africa and sustainable irrigation practices

In recent years, there has been a snail growth in the level of agricultural production in Africa, and for some reason, irrigation has not been able to help in bridging the disparity between the demand and supply of crop food, to the benefit of farmers in form of increased income and creating jobs for the youth. The large expanse of land and water potential in Africa is a known knowledge to decision-makers and donating bodies. But the investments channeled toward irrigation have been very low in the last few decades. It is therefore imperative to examine and understand the places or countries where irrigation has contributed immensely to their agricultural development and why it has failed to improve agricultural production in other countries. Knowledge of this will help policymakers to ensure that the benefits derived from irrigation by countries are reasonable and sustainable. Considering the available land and water resources, Nigeria has the greatest potential to irrigate a large expanse of land up to about 2.5 million hectares out of the 42.5 million hectares that Africa could irrigate. According to FAO Aqua Stat (2005), other countries in Africa such as Niger, Cameroon, South Africa, Ethiopia, Chad, Mali, Sudan, Tanzania, Uganda, and Togo each have the potential to irrigate about 100,000 hectares of available land.

In Africa, the human population rises by 2.2% every year exceeding the world's average population growth which is 1.2% per year. Also, about 56% of the economically active population in Africa is fully involved in agriculture compared to 21% of the world's average active population engaged in agriculture. This can only mean one thing, the dependency on agriculture and irrigation will continually increase to ensure adequate food security and healthy nutrition for the populace. This is viewed as an opportunity for the total transformation of agriculture whenever decisions on making investments in irrigation are made astutely to improve production and create employment for the active agricultural population. History has it that Africa had about 7.4 million hectares of irrigated land area under cultivation in the early 1960s and though this area, after almost 50 years, has nearly doubled to 13.6 million hectares of land, African countries were just able to irrigate about 5.4% of their cultivated land in 2006 as compared to a global average of around 20% and almost 40% in Asia. This simply affirms the relatively low contribution of the irrigation sector to the eventual agricultural production.

In the Southern part of Europe, Asia, and the United States of America, a large proportion of the budget meant for agriculture was directed towards irrigation projects (Rosegrant & Perez, 1997), with the regular deployment of new improved seed varieties and fertilizers to enhance yields, also with the use of machines and new irrigation technologies combined with proper management approaches. As a result, these regions have been able to sustainably provide adequate feed for their growing population through irrigation and intensifying efforts on agricultural production. In Asia, irrigation boosted their agricultural output in what is referred to today as Green Revolution. The increase in agricultural output experienced in most of the developing countries did not experience the same pathway in Africa and this was largely due to low investments in the irrigation sector.

There are several reasons why investments in sustainable irrigation and irrigation systems have been very low in the past few decades in Africa.

- African governments and donors interested in enhancing agricultural output have failed to prioritize irrigation in agriculture.
- The cost of investing in irrigation is relatively high. In the year 2000, an average total cost of 8374 USD was expended on irrigation in the Sub-Saharan Africa region. For a country to plan for huge projects involving substantially high investments, it would be in millions of US dollars and governments will have to assess such enormous loans from banks (e.g., The National Fadama Development Project that was initiated in Nigeria in the year 2000, intended to irrigate 50,000 hectares of farmland with a budget of 104 million USD and a loan of 67.5 million USD was obtained from World Bank).
- Practicing irrigation requires a huge quantity of water (The quantity of water required to irrigate 1000 hectares of land in a peak period is relatively equivalent to the amount of water that will cater as drinking water for about three million people for daily use). The development of water resources for irrigation needs to be geared in areas like the construction of large-sized expensive infrastructures such as dams (for multiple purposes) and other infrastructures for conveying water and water pumping stations to households and other industries. Also, the need for appropriate technical know-how for proper handling, operating, and maintaining of the infrastructures is very paramount.
- The extremely large amount of money incurred on failed irrigation projects combined with the low prices of food on the international market is among quite a number of reasons for the government's reluctance in prioritizing irrigation among a number of other exigent and visible projects like potable drinking water and sanitation. It is important to understand the factors, both at the national and local level, that affect the cost of irrigation projects and possibly identify means to reduce the cost to make investments into irrigation projects more attractive and lucrative.
- Specialized establishments exhibit weak capacities thereby undermining their ability to carry out projects for multi-purpose water infrastructures and irrigation schemes.

- Poor performance emanating from the investment made in irrigation is mostly on the large scale. The large level is sometimes due to errors made in the design of the project, the inefficiency of the institution, unpredictable water supply, and difficulties having access to and being able to afford inputs such as mechanical spare parts for agricultural machines and fertilizers.
- There is also the issue of having difficulties in accessing profitable and close markets. This is constantly influencing the cropping pattern to cultivate more cash crops in order to respond to foreign markets and their standards of having quality agricultural products.
- The decision-makers at the helm of power were unable to realize relevant returns from the enormous investment in irrigation projects with the involvement of the public sector. Government officers, basically politicians, tend to be more inclined towards the short-term and visible results of projects and macro-level profits, but they are also concerned about the need to address the challenges properly in order to increase the productivity of some crops, such as cereals, maize, and rice, that are of economic benefit to the nation. The absolute fact remains that crop yields are relatively low and there are opportunities to make lots of gains through yield increases.
- There were cases whereby irrigated crops such as cereals were unable to compete with subsidized foreign exports. From the perspective of the government, cereal as a strategic crop requires irrigation to be able to contribute to the effort of self-sufficiency at the macro level. From a farmer's point of view, cereal farming is not profitable. In view of this, it is imperative that the government must deploy incentives in order to meet up with the farmer's objective of maximizing their net profit at the end of a production season. It is important that decision-makers need to understand that irrigation is definitely contributing to the social welfare and food security of the people, though may be less than impacts from some other economic sectors. Most developing countries adopted agriculture as a means to generate income and irrigation was very important for development in the agricultural sector. The European Union, up till today, is still supporting small-scale farmers and protecting several sectors of agricultural production. In addition to investments made towards irrigation, Africa needs to devise strategies to protect small-scale farmers against subsidized foreign products. Those strategies may include having subsidies for maintaining the irrigation system, purchasing spare parts, supply of quality seeds, and assured the minimum price of farm products.
- The Commission for Africa Report, in 2005, called for irrigated areas to be doubled by the year 2015 (You, 2008). Although the data for 2015 could not be obtained, the level of public investment in irrigation projects has remained very low, and assistance from foreign investors to the irrigation sector drastically declined in 2010, despite several donations from private bodies and government commitment. There is an incredibly significant gap in assembling resources and the public sector have remained the main financier for large-scale irrigation projects.
- Policymakers should be aware of different experiences relating to irrigation under different scenarios. Every African country has different historical bequests that definitely shape their irrigation sector today. These historical heritages vary from large-scale irrigation systems that were developed during the colonial period for farm products meant for exportation, such as cereals, cocoa, and cotton, irrigation management transfer, and market policies. The enlarged farm area under cultivation also increased to about 80,000 hectares, enhanced the settler population by over 220%, and amplified the paddy production per capita from 0.9 tons to 1.6 tons, thereby reducing poverty and increasing food security.
- Stability in the nation's politics had a great impact on developing institutions that were committed to irrigation, and the poor coordination of national or sub-regional agencies that are in charge of irrigation did not do enough to help in advocating for the irrigation sector. For instance, in so many countries, the irrigation sector is usually managed between two ministries: Agriculture and water resources, which need synchronization and organization on the field. In recent years, the political stability and resolve in many African countries is beneficial for long-term development in the irrigation sector, mobilization of resources, and capacity building. So many countries that have been able to make substantial progress in developing their irrigation potential are stable politically and have shown so much commitment towards the development of their irrigation sector with investments from governments and donors (For instance South Africa and Mozambique have developed, to a large extent, their irrigation potential).

22.6 Conclusion

The importance of agriculture to the economy cannot be over-emphasized, as it creates employment opportunities, revenue generation, and economic development. It is being faced with several challenges and water being a crucial factor is at the center of the puzzle. Water is a major component in agricultural processes as it eliminates food scarcity and improves the well-being of humans. The competition for the use of water has increased as a result of industrialization and population, therefore, measures to judiciously use water are essential. Transformation of agricultural practices such as improved knowledge in irrigation and water management approaches will go a long way toward water sustainability. These measures can be stimulated by appropriate policies, investments, and proper management by stakeholders and relevant agencies in the water management processes. Other measures such as improving the agricultural value chain, mechanization of practices, institutional capacity, training of youth and women in agriculture, and climate-smart practices are some other measures that can boost agricultural transformation.

Conclusively, a major key to agricultural transformation and water usage is the improvement of irrigation services. Several countries have adopted these measures and they have attracted institutional donors and investors into the sector. With this, the sustainability of water resources can be assured as emphasized by the United Nations Sustainable Development Goals towards Agenda 2030. Life dependency will be increased as all forms of life on Earth depend on water and agriculture.

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Chapter 23

Citizen science and technological approaches for sustainable drinking water supply and management in rural areas

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23.1 Introduction

More than being a basic need of humans, water is something that we cannot live without. In this fast-growing modern era, we are living in a world where human beings face the accessibility of clean water and its resources as a challenge (Barzegari & Malekinezhad, 2019; Rabbani & Kazemi, 2022). Water supplies with a sensible cost will become the top agenda for the city decision-makers as well as for rural area management. Many rural areas of underdeveloped and developing countries like India are facing the problem of catering to sufficient and safe drinking water due to various obstructions like failed foundations, inaccessible resources, the fragile regulatory framework for water distribution, unpredictable climate change, political uncertainty, and water pollution (Brewis et al., 2019). In a report by United Nations Development Programme (UNDP), it is identified the necessity of effectual, or quality, water governance in the form of innovative new regulations and enhanced policy productiveness for the goal of mitigating the water crisis in the rural region (Pani et al., 2021; Shivaraju et al., 2020). For the achievement of a water-secure society, the management part should be strengthened with a multidimensional and integrative perspective to solve the water supply and associated health issues including household-level supply, socio-economic-environmental and flexibility to water-related and climate change hazards (Shivaraju et al., 2016). For the improvement and rising of knowledge regarding safe and sustainable water supply and distribution Swedish Foundation for Strategic Environmental Research (Mistra) commenced a long-term research program in 1999 (Croese et al., 2020). It is programmed into the vision right to access clean and safe drinking water for every human for a healthy livelihood. The rural region water supply and conservation program aim for water management where the water and its constituents should have to be made availability of safe and clean drinking water, proper distribution, and treatment (Dinka, 2018). Is the water crisis threatening or not, provisions need to be taken to taper the pressure over the water resources well in advance of their destruction. It is evident that with no adequate drinking water and treatment access in the rural community, issues such as health-related risks are of major concern (Shivaraju et al., 2018). Due to the lack of resources, access to potable water in rural regions can be challenging and time-consuming.

A vigorous link between water monitoring the enhanced sequential and dimensional resolution is vital for decision-making related to sustainable rural water management (Bhaduri et al., 2016). To ensure that the set policy is met, inclusive water-related data is essential to illustrate water management in rural regions. But, employing traditional techniques for water management is not feasible economically. Therefore, the expense of the implementation can lead to irregular management of water. At times, unapproachability in rural areas restricts achievable information resulting in poor availability of drinking water and management in the area (Omarova et al., 2019). Since rural areas have limited resources, achieving sustainable water management can be time-consuming (Robinson et al., 2018).

Currently, an alternative data collection technique for viable data collection technique for gain information

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regarding water management in rural regions is necessary (Fritz et al., 2019). Reports have suggested that the involvement of the community has helped achieve sustainable development goals. Attention is focused on citizen science for monitoring rural water supply (MacAllister et al., 2020). Citizen science has gained attention around the globe over the years since it is a promising method for rural water management monitoring in the long run (Fraisl et al., 2022). Citizen science can help fill the knowledge gap related to water management, limiting the cost of monitoring and enhancing data availability, eventually sustaining decision-making (Johnson & Hendrikx, 2021). But, concerns about the lack of data quality impended from employing citizen science data for decision-making resulted in a lack of approval within the scientific group. Therefore, the complete capability of citizen science is not yet recognized regardless of enhancement in open science and numerous citizen science-based projects (Gilfedder et al., 2019). Citizen science is considered to be a capable approach to enhancing water science research, especially in water management in rural areas as well as the sustainable supply of drinking water (Walker et al., 2021a).

Further, the issues related to inadequate drinking water supply in rural areas can be solved by adopting suitable technologies (Gupta et al., 2020). This can include water purification which can be executed, functioned, and preserved by the responsible authority. Often, such technologies are employed if relative stability is achievable as well as allotting time to involve the local rural community (Kotoku & Kumasi, 2022). Herein, the local community is conferred for their preferred technology besides skills and resources that are accessible in the local area are also reflected. The objective of this chapter is to ponder upon the issues faced by the rural region concerning drinking water supply and water management, correlating the concept of citizen science with rural water management and reflecting on the role of technologies in overcoming the issues of water supply in rural areas.

23.2 Overview

23.2.1 Citizen science

Citizen science refers to the engagement of the public who is not professionals or amateurs in actual research and scientific activities that ranges from large-scale projects to personalized projects (Fraisl et al., 2022; Fritz et al., 2019). It refers to the involvement of the local/public in the prompting and creation of awareness and the use of scientific knowledge to understand the concern of rural issues (Silvertown, 2009). Variable approaches which are operating in citizen science range from auxiliary and data collection through the participation of the public to entreating contributions and executing the scientific tasks with the support of general people through the internet, mass communication, and so on (Hicks et al., 2019; McKinley et al., 2017; Wiggins & Wilbanks, 2019). Even though citizen science has existed from the beginning of scientific practice, there was a wide range of new opportunities for public participation in the research work through the development of sensing technology, data processing technology, and visualization techniques. The European Commission 2013 rephrased the definition of citizen science as *"general public engagement in scientific research activities where citizens actively contribute to science either with their intellectual effort, or surrounding knowledge, or their tools and resources"* (Follett & Strezov, 2015). Phrases like monitoring by volunteer, crowd participation, monitoring via community, citizen viewpoints, involved perception, and so on are correlated to the various categories of public involvement (Aristeidou & Herodotou, 2020; Bonney et al., 2016; Fraisl et al., 2020). In different fields, the perception of citizen science differs in the execution of data delivery, framing the objectives, implementation, and communication preferences to engage with the public (Phillips et al., 2019). Though the insight of citizen science varies throughout the field, the participation of the public is common in serving the delivery of scientific knowledge which helps in offering opportunities for partnerships and learning.

23.2.2 Technological approaches

Technological innovation and support are needed for integrated sustainable water management (Nieuwenhuis et al., 2021). There are several technologies are available for water treatment as well as for management purposes in rural areas (Wang & Corbett, 2021). Technological developments can be utilized for water administration; therefore, they will be able to keep track of the economic aspects of water management by keeping track of water loss-like issues (Prabagar et al., 2022). Demand and supply analysis is one of the important processes in water management, identification of failure in the system is possible through the proper supply system analysis (Sneha et al., 2022). Various software is available for the ease of this analysis. WEAP is one of the software that is adopted for the simulation and analysis of water demand and supply in an area (Kandera et al., 2021). It is hired as a decision-making tool by taking current and reference data from the point of view of water distribution concerning various socio-economic-environmental parameters. The goal of many studies is to maximize the productivity of water supply by improving methods for uniformly spreading flow from the front compartment and the pumping station's water intake, as well as developing productive measures to improve the hydraulic situations of the fluid supply to the pumps (Yang et al., 2021). The involvement of technologies in water management and water supply in rural regions is further discussed in the later part of the chapter.

23.3 Drift in sustainability affecting the rural environment

Sustainability is a diverse concept of conservation value, strenuous to measure and assess (Liu, 2017). Vital importance in terms of rural and urban water channel development is to estimate how much sustainability the distribution and supply system will precisely work (Khurshid & Deng, 2020). To implement that, checks on social, economic, and environmental issues need to be investigated. Considering the water supply in urban areas, drastic changes in urbanization have been observed leading to heavy water demand (Well & Ludwig, 2020). The poor quality of drinking as well as domestic water, uneven and insufficient water supply, and distribution, discrimination, ambiguous policy for pricing, and water utility are the major issues related to the sustainability of water management (Hutton & Chase, 2017).

The rural water supply areas are characterized by a lack of advanced technology and infrastructure development, alongside a lack of knowledge and experience among the rural citizens who operate and manage the particularize (Salom & Khumalo, 2022). A substantial rate of water project failures has occurred at a pre-matured stage of development. A very common reason for the failure is investigated to be negligence and underestimated concepts of sustainable development and lack of communication within the community (Zikargae et al., 2021). Community input is generally undermined and neglected in terms of the design and administration of the water supply system development (Hira & Busumtwi-Sam, 2021). Nevertheless, efficient tariff collection, equity, intermittent services, and sustainable strategies to maintain the water supply are still problematic in nations with pretty widespread access in rural areas. Finances play quite a role in rural water systems, the fees cover the expenses required for maintenance and repair (Crispim et al., 2021). In the last decade, there has been a rising corpus of studies on the primary issues affecting the sustainability of rural water supply and sanitation, in concert with the growing data on low sustainability (Arora et al., 2018; Bartram et al., 2014; Nitivattananon & Srinonil, 2019). Although significant progress in understanding the factors involved in rural water supply management is being viewed likewise revenue collection, community participation, demand, gender consideration, etc., there is no general agreement which how sustainability can be interrelated one another (Chowns, 2015; de la Torre-Castro et al., 2017). Other general problems which affect the rural water management foreseeing sustainability are (1) the policy of allocating cash from the central government to each level of government administration, (2) the technologies used to give the service, and (3) the evolution of water point functionality.

To understand and address the issues, studies on indicators of sustainability in the case of rural water supply systems should be included like the physical condition of the system, operation and management techniques, financial management, and customer satisfaction (Dzulkifli et al., 2021).

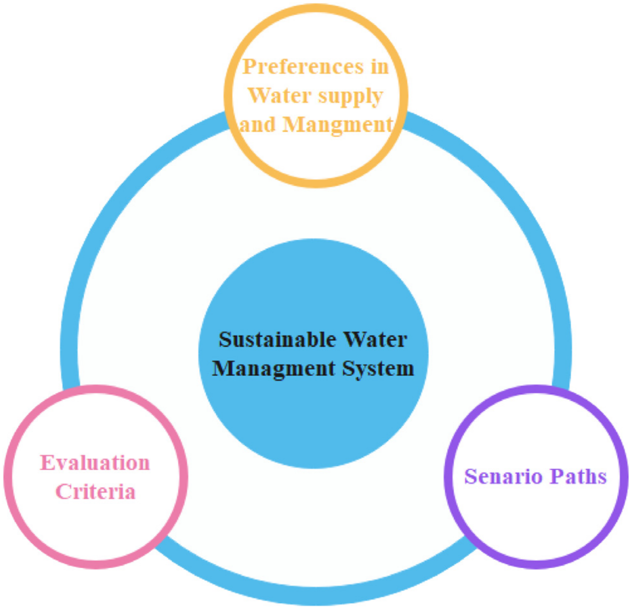

FIGURE 23.1 Components for achieving sustainability in water management.

The lack of knowledge amongst the rural people can be narrowed to two main reasons. The local authorities (municipal or district) tend to choose which sub-project category the locality will receive in particular instances (Saarikoski et al., 2018). In other circumstances, non-governmental organizations (NGOs) or the private industry are in charge of promoting and planning subprojects to get a deal for their eventual implementation (Gain et al., 2017). Also, incorporating concerns like health, economic, political, ecological, and other social issues among rural citizens involves awareness. Rural communities in developing countries around the world remain underprivileged, with eight out of ten people without improved access to water (Spencer, 2021). The problem of long-term rural water supply is well-known, yet compromised.

23.4 Evaluation criteria to assess water supply

Attaining sustainability in a water management system can be studied by using three components (Fig. 23.1).

- **a)** Water supply and management preferences.
- **b)** Situations are measured.
- **c)** Assessment criteria that are used to evaluate sustainability.

Considering studies conducted on water management, three categories account for undergoing a cost-benefit analysis of water management decisions; such as social, economic, and environmental (le Coent et al., 2021).

23.4.1 Social criteria

Among the three major classes, the category of social sustainability established the least consideration. Although, voluminous social factors are needed for studying the assessment of water supply and management options important in policy evaluation frameworks (Zhao et al., 2021). Considering the launch of stormwater harvesting projects in Melbourne for reference, appealing values, capacity to furnish learning, and detrimental effects upon the civic, like bad odor and pests are the social factors reflected by them (Inamdar et al., 2018). In a report by Baldwin and Uhlmann, the factors they considered for their study include administrative effectiveness, efficiency, and development for directing effects such as public participation in the study (Baldwin & Uhlmann, 2010).

23.4.2 Economic criteria

The maintenance, cost of capital, and operation of the water distribution system counting the storage and distribution come under this category (Radmehr et al., 2022). Among the main three categories, the cost is considered as key for water supply options. Other than the water capital, operational cost and maintenance of water supply opportunities included disposal costs by understanding the life cycle cost (Dong et al., 2022). When planning for a sustainable water management system it is important to account for indirect economic influences like aesthetic and recreational impressions, ameliorated stream flows, and loss of agricultural land to city areas (Ebad Ardestani et al., 2020). In addition to these, the value of by-products like energy and fertilizers associated with various water supply options can be undertaken for economic criteria.

23.4.3 Environmental criteria

This category includes the highest number of criteria than economic and social criteria. This will account for the physical aspects of the environment that are affected by water cycle management (Tork et al., 2021). Such as:

I. Environmental flow requirement.
II. Impact on natural flow regimes and groundwater patterns by urbanization of catchment.
III. Impact on water quality by pollution load from runoffs.

The impact caused by wastewater treatment such as eutrophication, ecotoxicity due to higher concentrations of heavy metals, and depletion of fossil fuels due to the energy consumption for power generation all have to consider here (Pesqueira et al., 2020).

23.5 Citizen science in water science

Citizen science is increasing rapidly in the field of hydrology with more public participation in tracking water sources, climate factors, quality of water, and mapping and modeling actions (Walker et al., 2019). The increase in reports identified the application of citizen science in water science, besides the scientific benefits to the investigator, there are numerous benefits for the community that corporate with the research (Walker et al., 2021b). By participating in studies, the public will receive the benefits of education, improved knowledge, empowerment, and satisfaction of being a part of the research, or contributing to science (Tauginienė et al., 2020). So far, literature in citizen science claims that water sciences have emphasized the latest advances and possibilities for research gain instead of the effects on the public (Little et al., 2021; Rautio et al., 2022). Although a limited number of articles have attempted to summarize the effects of participation for members in the environmental sciences widely. Furthermore, only a few hydrology case studies were used in these evaluations, with the majority of them focusing on water quality. As a result, this fusion, which uses varied case studies to reflect on the benefits and drawbacks of citizen science participation in varied sectors of water sciences is needed.

Herein, we discuss the probable benefits involved in citizen science related to water management.

- Engagement of the public: Most citizen science initiatives make this obvious, and it is typically argued that it is essential for empowering science, increasing public understanding of environmental concerns, and reestablishing public science's credibility (Phillips et al., 2021).
- Creating awareness: When involvement in a project result in education, it is likely to increase public awareness of the subject being researched. Increased awareness is recognized to be related to environmental management and communities' readiness for natural disasters (Van Noordwijk et al., 2021). Nevertheless, people who volunteer for a project, though, are probably already aware of the problem, which accounts for their interest.
- Liberalization of science: The need for involvement in the creation of scientific knowledge is emphasized by the liberalization of science, which is similar and involves public engagement and awareness-building (Vasiliades et al., 2021).
- Trust relationship between the public and the scientific community: Considering that we are existing in a "post-truth world," then this relationship may be more crucial than ever. The need for genuine collaborative citizen science initiatives is highlighted by many writers, who advocate for increased public participation by scientists to foster trust (Heigl et al., 2019).

- Skill and knowledge development: Citizen scientists may improve their understanding of the problem at the project's core through practical learning, training, as well as through feedback. According to numerous articles education and its understanding are considered a benefit (Bonney et al., 2009; Peter et al., 2021). Citizen scientists are typically aware of the issue, although, as with promoting awareness, involvement is frequently aimed toward interested groups.
- Behavioral changes: More responsible environmental behavior, or management, especially concerning the sustainable use of natural resources, may result from increasing knowledge and understanding (Santori et al., 2021; Van Noordwijk et al., 2021). In contrast, behavior change might entail improving one's social capital by encouraging engagement from new groups or enhancing one's political participation or empowerment.
- Developed environment: Changes in behavior can lead to improved environmental responsibility and awareness via the gathering of relevant data, which can result in things like (1) recognizing and prosecuting polluters (Nelms et al., 2022) and (2) strict environmental rules, and regulations (König et al., 2021).

23.6 Role of citizen science and technology in rural water supply and management

Hydrology is a complicated scientific topic that can be applied to citizen science due to the sophisticated technology required to monitor key parts of the water cycle (Spasiano et al., 2022). However, the emergence of more resilient, affordable, and low-maintenance technology provides fresh possibilities for data acquisition in the context of citizen science. Likewise, the challenges faced through climatic change, freshwater pollution, and other stresses, as well as the significance of water resources for development create the need for developing novel methodologies that uphold the knowledge of water supply and management, thus promoting sustainable development (Wu et al., 2021).

Citizen science must address the vast array of individuals whose activities engage with hydrological systems and participate in the implicit or explicit administration of assets if it is to be productive in having beneficial impacts on the management of natural assets like water (Vasiliades et al., 2021). Subsequently, general governance of the natural asset, say water, is an integrally multi-scale-based project which generates the need to have complicated technographic models (Shunglu et al., 2022). Thus, the need for scientific knowledge incorporated towards decision-making amongst citizen scientists should be governed by a higher technocratic state providing a multi-scale system in the social and economic wings of the society. Unlike researchers, individuals are not experts in hydrology; individuals are not solely concerned about water, even though it may be of the greatest priority. This means that people's behaviors are often not influenced by highly specialized or narrowly focused institutions or ideas. However, most scientific research is unavoidably a deductive approach and must concentrate on specific assets, it is also likely to search for or aid in the formation of professional organizations for the control of that specific resource (Mantere & Ketokivi, 2013).

23.6.1 Model design for joint knowledge among citizens and scientists

While queries from the citizens and scientists intersect possibilities to maximize the benefits amongst each other, creates a productive partnership (Heigl et al., 2019). The inquiries of the citizens and those of experts in the field can diverge significantly. Nevertheless, citizen science initiatives may be effective if the advantages to both sides exceed the compromise of changing the research topics to suit their interests (Rotman et al., 2012). From the viewpoint of a research scientist, instant advantages frequently include assistance through data gathering and evaluation to generate broad knowledge. However, for interested people, the key benefits could emerge from the significance of the acquired data for rural problems (Conrad & Hilchey, 2011). A broader form of mutual advantage, one that depends on collaborative knowledge generation and exchange, however, may be made possible through citizen science, as suggested previously. There are many different types of knowledge in rural societies, particularly from the perspective of managing ecosystem services (Hecker et al., 2018). This can comprise indigenous practices, such as the beliefs and ancestral comprehension of habitats, and more contemporary contextual interpretations of environmental services and related administration approaches and individual perspectives drawn from personal experience (Brown & Williams, 2019b; Kythreotis et al., 2019a). This kind of indigenous knowledge stands in contrast to more structured scientific information on ecological systems, which would be frequently produced by exterior organizations and is focused on the development and testing of hypotheses. Merging these many types of information needs ongoing contact between people and scientists so that technical and rural knowledge systems may mutually enrich one another (Kythreotis et al., 2019b). This interaction goes beyond merely recording data.

The advantages of knowledge generation, both within distant rural societies and outside organizations, are confirmed by research on water management (Richard & David, 2018). Among them is the creation of a hybrid between rural and science, user-oriented insight, which may enable more effective and efficient asset use in rural regions; increased community engagement within minority groups, which results in increased social value and perseverance;

and performance benchmark and mutual benefit between rural communities and external agencies (Robinson et al., 2020). Citizen science projects that support the political involvement of underprivileged communities in society might choose issues that were initially presented and articulated by their concerns. Without being overly pessimistic or naive about the likelihood of achieving significant results, scientific knowledge about these issues could not only increase methodological understanding of such specific issues but as well enhance their credibility in regional democratic venues but also contribute to stabilizing power imbalances (Wyborn et al., 2019). The relationship between interactive scientific activity to vital issues and overt or covert political conflicts will serve as a significant source of inspiration for locals to get involved in the process of generating scientific knowledge (Brown & Williams, 2019a).

23.6.2 Reliability of the insights generated

Ensuring that there is a firm base of legitimacy and trust among the participating individuals and paying attention to how those get successfully attributed to distinct information are crucial if knowledge created by citizen science is to be utilized to assist decision-making (Santos-Fernandez & Mengersen, 2021). As the development of real proof of “professional expertise” could rapidly decontextualize the inputs for the formation of particular institutional and policy logics shaped by rural authorities, this also indicates the requirement to emphasize ideological conflicts inside local decision-making forums (Balázs et al., 2021). Regardless of whether that information is being gathered through an organized method, it may be challenging for citizen science narratives to flow into decision-making in water resources-related organizations in developing countries (Koch & Stisen, 2017a). This seems to be partially due to not being able to comply with the exact assessment and optimization that knowledge based on water science should indeed abide by, or because there may be inconsistencies and disagreements between what citizen science knowledge is suggesting and what the relevant scientific knowledge is proposing (Koch & Stisen, 2017b). This conflict between citizen science as well as traditional scientific understanding emphasizes the fact that issues related to the formation as well as dissemination of knowledge within an institutional setting are at least as substantial as both the preliminary planning and execution of collecting evidence from community members (Steinke et al., 2017). It might be difficult to address the authenticity and representation of knowledge.

23.6.3 Citizen science and decision making

For knowledge-based citizen science to be effective in decision-making, it must first be locally valid and pertinent (Njue et al., 2019). The relationship between citizen sciences with decision-making, however, needs to be obvious and explicit to guarantee information. This relationship, which is better comprehended from the perspective of feedback mechanisms at several levels, is most likely to be effective when it serves multiple purposes at various levels (Pateman et al., 2021; San Llorente Capdevila et al., 2020). The utility and relevancy of the data gathered either by citizen scientists for individuals’ decision-making are just what determines whether an instantaneous feedback mechanism occurs at the individual level. Additionally, this is reliant upon technological capabilities and otherwise, design elements that allow the specific citizen scientist to read, comprehend, or document the data instead of merely transmitting inaccessible or nonsensical data (Carlson & Cohen, 2018). A similar feedback mechanism is conceivable at the local, regional, or national level of democratic decision, for example, when a water management association depends on data gathered from one or more of its representatives to make choices concerning agricultural water distribution (Pocock et al., 2019). Finally, scientists engage in the system of generating knowledge, in which they incorporate regionally gathered data from citizen scientists with some other data configurations to imply significance to the information, they can create another feedback mechanism that makes their findings available for both individuals and group decision-making domains (Paul & Buytaert, 2018).

23.6.4 Promoting consistent citizen participation

The chances that the information produced will be specific and sustainable may be increased by including individuals early on, particularly if the system is integrated inside preexisting policy structures and if there is a link to a rural social benefit (Chen et al., 2015). The optimal solution could be for the most marginalized people in society to feel a perspective of responsibility over the system getting jointly established and to be able to shape it to address issues that matter to them (Pradhananga et al., 2015a). Even though citizen science-based knowledge and experiences are sought independently, every knowledge and valuing system needs to be acknowledged as valid within its respective right before this could be accomplished in reality (Hutchings et al., 2015). When abbreviating knowledge networks for managing water resources, it’s important to pay attention to the social dynamics that affect communication and mutual understanding among various knowledge networks (Sam & Todd, 2020). To do this, it is critical to accept power imbalances when merging various areas of research and knowledge collected from the public. Over this, it is crucial to remember that despite the possibilities that are available in water management for defining areas of substitutability between various knowledge structures, there invariably be facets of knowledge that cannot be completely interpreted by one another (Chen et al., 2015; Pradhananga et al., 2015b). This is partially due to the various strategies which subsist to create, justify, or grant credibility to expertise.

To promote knowledge-based conversation across various knowledge viewpoints, a new form of support and funding is required. This may suggest, for example, that financial support encourages the emergence of excellent social ties in more public knowledge spaces (Jones, 2011). The existing scientific fields, epistemic societies, and norms towards the authentication of information in scientific studies tend to look skewed or fragmented in any attempt to engage the significant viewpoints of individuals without such links.

23.7 Case studies

In this section, we discuss some rural case studies with active citizen science or local initiatives in setting up previously mentioned activities. These demonstrate the significance and feasibility of the ideas discussed previously. The instances are situated in remote rural areas, which are often places that mix marginalized communities that are heavily dependent on ecological systems with brittle and underrated ecological systems.

23.7.1 Lake Tana, Ethiopia

Security of living is heavily reliant on regional environmental services provided by the local land and its cover in Ethiopia's rural Lake Tana region (Karlberg et al., 2015). Quick population growth has resulted in accelerated changes in land use, making the existing maintenance of the land untenable for supplying services like food, fodder, and power to the present generation. Area degradation, particularly the development of hardpans and a reduction in the subsoil is brought on by an expansion in farmed land paired with conventional farming methods such as ploughing. The land's capacity to deliver other crucial services, like carbon fixation and groundwater restoration, is hampered by declining resources. A variety of natural capital management solutions were created by the national government and put into practice regionally under governmental instruction to reduce such deterioration and retain the land's capability for production. These approaches frequently fail to increase both long-term and short-term benefits, and in certain cases, they hasten the decline of ecological services that eradicate poverty. The gap between what farmers are capable of keeping freely without government aid and what is advised by donors or the government is a major concern. For instance, to retain extra rainwater and enable it to seep into the subsoil, government organizations advise installing 60 cm wide and 30–40 cm broad ditches on the contours. The indigenous method of conserving soil, in contrast, is making tiny, 10–15 cm furrows slightly off the contours to carry any extra rainwater that may otherwise temporarily pool over a progressively porous layer.

However, a project throughout the upper Birr watershed has shown potential in resolving the issue that goes unaddressed in the governmental sector (Bastiaensen et al., 2005). The research started with local cooperation by first talking about various suggestions for repairing gullies with religious leaders and elders in the area, and afterward with local farmers. Since they thought these gullies were God's retribution for their transgressions, the religious authorities, farmers, and elders were initially suspicious and wary. The decision to begin a trial in one site was not made until they were provided images of other restored gullies while two farmers were invited to view one. 20 local farmers in and from the nearby region consented to provide labor plus wood for a barrier to preserve the gully and to fairly divide the harvested hay after the annual rainfall. Additionally, they established a monetary fine for anybody who let their animal enter the fence. Despite this understanding, a conference was called with the village master, administrators, development workers, members of the rural community, and religious leaders to divide duties. However, after the closures during the rainy seasons, the gully's vegetation flourished, but a dispute developed when the farmers whose land bordered the gully declined to split the rewards, such as the grasses grown in the conservation area. The dispute was settled by the local leaders by making the farmers apologize and sign a commitment to provide labor and wood during the upcoming program to restore the second community's gully.

Utilizing the casual decision-making procedure was key to the project's accomplishment. An alternative unofficial judgment system exists, that is focused on the seniors and priests whose influence is highly recognized, even if the official decision-making system is tightly centralized just after judgment from federal and regional authorities. As a result, when it's communicated by or via such individuals, certain new information developed among locals, especially among the major community members like local leaders and elders, can be fairly received. Another argument for such farmers' desire to join is that they believe there is something to gain since they have faith in their elders.

This case exemplifies a collaboration of citizen science project which was successfully achieved by the Ethiopian farmers and how the engagement changed efficiently the dynamics of environment management.

23.7.2 Naryn region, Kyrgyzstan

The Naryn of Kyrgyzstan area encompasses an isolated Himalayan catchment throughout the Central Tien Shan range. Although Kyrgyz herdsmen dominated the population for several generations and maintained the region's indigenous resource usage practices, collectivized government estates were constructed during the Soviet period. The agricultural land on all these estates, which was focused on raising livestock, was utilized to grow fodder to feed a range of animals, primarily sheep, cattle, and goats. Skilled workers were trained by knowledgeable cropland, pasture, and water management professionals from research institutions inside the communal farms, and they were aided by an advanced system to evaluate the climate change, runoff, and grassland area conditions (Kerven et al., 2012).

Following the fall of the Soviet Union, Kyrgyzstan underwent yet major realignment, which had a significant impact on both the social and political landscape. During the 1990s transition out of a planned economy to privatization, and land reforms resulted in a sizable transfer of resources like farmland, cattle, and government agricultural machinery. Post-independence, a concurrent, sharp rise in destitution brought on by economic forces and alterations in means of subsistence. In addition, most households developed a strong reliance on sustenance cultivation, with cattle serving as the main means of generating income (US EPA, 2012). The irrigation, transport, and pollution monitoring facilities all suffered throughout this substantial economic change, and organizations now engaged in further decentralized decision-making lacked proper information communication and interaction. Even though the trends and causes of deterioration have altered throughout time, this tendency has persisted to the current. The aforementioned issues are being made worse by global environmental change, which is also having an effect on environmental assets and increasing the frequency of catastrophic disasters. Among the primary issues in Naryn concerning water supply and administration are low government expenditure, intense inter-sectoral rivalry, shortages owing to waste and scarcity, or an increase in up/downstream conflicts. This double strategy approach is typically used concerning both scarcity and operational planning: boosting agricultural water supply through infrastructure building and renovation and reinforcing and upgrading water sector organizations. The majority of current initiatives in the area focus on the organization of water management, such as the encouragement and organizational growth of Water Users Associations (WUAs), the advancement of water resource systems among villages' WUAs and farmers, and the encouragement of advanced technologies for quite effective water usages.

In rural areas of Naryn, currently limited opportunities or community assets for monitoring water supplies. Over this data-scarce location, a proactive citizen science strategy, though, is intriguing and might be utilized advantageously to not only address information and data shortages but also to engage together with livestock populations to develop pertinent management-oriented expertise. If the right motivating elements were firmly demonstrated, citizen science can assist offer a mobilizing and motivating impact within society. Both researchers and residents could benefit from these collaborative tasks by creating lengthy alliances and jointly defining the most significant research problems or queries to confront. By doing this, they can jointly create stakeholder engagement for measuring water flow, gathering pertinent climate data, working sequence and analyzing data, creating new knowledge, and transparently investigating the situation. Combining extrinsic and intrinsic factors, such as personal growth, curiosity, and the expectation of future financial benefits, are likely to play a role in the local incentive for engagement in collaborative work. However, one key element for the affirmation and applicability of citizen science within the highest, expert-oriented judgment inheritance which still exists in Kyrgyzstan is likely to become the revelation of an encompassing research strategy that balances pre-Soviet and scientific understanding kinds. The efficient use of citizen science for acquiring knowledge is also likely to rely on finding and collaborating with distinctive, creators who are open to considering and trying novel joint management techniques. Several innovative transportable equipment and devices, such as those for measuring channel outflow or measuring precipitation, are now reasonably priced and simple to use, especially by unskilled local organizations or learners from neighboring institutions. This is from a technological standpoint. However, there are still considerable barriers preventing citizen science from being generally embraced. While citizen science does have the potential to overcome deeply ingrained legacies by empowering citizens to actively design their pertinent expertise, this collaborative approach to science experiences obstacles since many individuals in the transition phase post-Soviet circumstances even now tend to rely on external consultants instead of developing their potency.

Council conferences and the gathering of preliminary information have been ongoing as part of the Ecosystem Services for Poverty Alleviation (ESPA) project, which is funded by the United Kingdom (Fisher et al., 2014). These details will help the research group effectively understand the social framework in Naryn. Numerous environmental effects, such as the supply of grassland feed, fodder, animal commodities including irrigation water, wool, and milk, water management, soil erosion control, and diversity, including carbon capture, have been found through this approach. Essentially all of these environmental activities, including those that benefit either or have an influence on livestock lifestyles, are linked to the hydrological cycle. In light of this, the research group believes it to be a plausible theory that when additional local knowledge on water and associated environmental variables is produced with involved community members, its validity will be acknowledged more and its absorption within community judgment will rise. Subjects of mutual concern and particular queries regarded as being of local relevance are still being identified.

23.8 Conclusion and future perspectives

Even while citizen research is fundamental to the process of scientific advancement and innovation, the idea and its implications have only lately drawn more research interest. New technical advancements are enabling innovative and more effective approaches to data gathering, analysis, visualization, and interaction. Due to these possibilities, thinking about the difficulties and possibilities of citizen science is topical and important, particularly in the framework of regulating ecological assets and utilizing them for social health.

It is especially true for water management, which is frequently among the foremost essential ecological activities and a major barrier to environmental sustainability and the eradication of poverty. Due to the advent of low-cost, reliable, and heavily mechanized devices as well as the capacity to integrate them with dynamic environmental modeling to build rich and immersive visualization techniques, there is a significant capacity to increase public participation in information gathering. However, we recognize the foregoing as the main operational and research hurdles for leveraging citizen science for managing water resources and alleviating poverty.

Although embraced in certain areas, the phrase "citizen science" is still viewed with some skepticism by the majority of scientists. Any uncertainty does tend to harm scientists' reputations and, in the end, hinder development if the importance and legitimacy of citizen science remain to be inadequately conveyed. We contend that while it is critical to maintaining optimism regarding citizen science's ability, constraints must be acknowledged by establishing sensible objectives that lessen the impact of disillusionment when programs fall short of expectations. It is essential to comprehend more about how resource management concerns could be defined in a seamless and consultative method that favors the incorporation of historically marginalized and asset members, given the nature of decision-making and divergent ideas of handling limited natural resources. Regardless of the potential to divide the work among numerous actors, citizen science requires a significant amount of human capital, particularly in the cooperation between actors, the requirement for sufficient education and training, and the maintenance of a sensible stage of involvement in the project.

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WATER RESOURCES MANAGEMENT FOR RURAL DEVELOPMENT

Challenges and Mitigation

Edited by Sughosh Madhav, Arun Lal Srivastav, Sylvester Chibueze Izah, and Eric van Hullebusch

Water Resources Management for Rural Development: Challenges and Mitigation Measures provides a full overview of the current challenges of rural water and its management strategies. The content contains practical and theoretical aspects of the water crisis in rural areas in changing climate era, with an emphasis on the recent water crisis research and management strategies. The book structure contains fundamentals of water resources, pollution, remediation, supply, and management strategies. The case studies included provide different water-related issues around the globe.

Water Resources Management for Rural Development introduces the reader to the paths of reducing the burden on the groundwater and the alternative options for the supply of water in rural areas. Therefore, decision-makers and water supply authorities will also benefit from the students to supply safe water in the cities. This book will be unique in the specified area of rural water management as no comparable book has been available until now.

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