Chapter 17
Legislative Policies and Industrial Responsibilities for Discharge of Wastewater in the Environment

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Abstract With the alarming water deficit around the globe, it is imperative to have policies that protect freshwater sources. Thus, removal of toxicants before discharge is of vital importance which may otherwise pose a threat to aquatic life and the surrounding environment. The growing demand for natural water supplies, as indicated by the effects of global climate change and shifting weather patterns, has sparked interest in reusing wastewater in recent years. Water resources management is the responsibility of government agencies, autonomous entities, industry, local government institutions, municipalities, and city corporations. The paradigm changed from seeing enormous amounts of wastewater as an expensive issue to seeing them as a useful resource. This has marked the beginning of building sustainable and resilient water management systems and fostering awareness, engagement, demand, and applying appropriate technologies among policymakers, local authorities, community stakeholders. The chapter describes the present-day scenario of water resources in the world and Asian countries and the prevailing problems and critical issues in wastewater management. Furthermore, a comparative account of policies and initiatives by Governments of the Asian countries is detailed. Consequently, advanced techniques for wastewater treatment and prospects of reuse and recycling of wastewater adopted by industries have been addressed.

Keywords Pollutant discharge pattern · Policies · Sustainable water use · Industrial wastewater discharge · Circular economy

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17.1 Introduction

Asia ranks top in population among the global continents. Many rivers in South Asia, such as the Ganges, Brahmaputra, and Indus, have a substantial impact on economic growth, food production, ecological stability, and long-term development. Several Asian economies have shifted from relying mainly on agricultural income to relying substantially on industrial income. Mushrooming industries include food and beverages, textiles, cement, rubber products, and electrical with production increasing by 20 to 45%. Industrial activity accounts for more than 20% of total GDP of more than 30 countries in Asia (ESCAP 2005). Droughts and floods have been caused by both man-made and natural tragedies, such as poor wastewater management systems and increased pollution in water bodies (UNESCAP 2018). Domestic, industrial, and agricultural waste have contaminated the majority of water resources in Asian countries, harming human health and water quality. Most of these countries have recently experienced weed infestation and eutrophication issues, which have harmed the normal biological functioning of these freshwater bodies. The loss of aquatic biodiversity due to eutrophication is estimated to be around one-third worldwide, with the most substantial losses occurring in South Asia, Europe, China, Japan, South Asia, and Southern Africa (OECD 2012). Surface runoff and poor wastewater treatment facilities outside OECD countries pose algal blooms which are expected to rise by 20% by 2050 (OECD 2012).

Scarcity of water and pollution affect both developed and developing countries (OECD Environmental Outlook to 2050, OECD 2012). To prevent contamination in receiving water bodies, tougher measures or legislation are urgently needed. In addition, to address the current water scarcity, more advanced and effective wastewater treatment procedures are required. The current study examines the current state of wastewater treatment procedures in Asian countries as well as their future prospects. Legislative strategies in Asian countries to conserve and effectively utilise water resources must be established. The water issue in developing countries has worsened as a result of unsustainable water consumption and poor management. The water situation is becoming more complex as a result of excessive water consumption and poor management in emerging countries (Shan et al. 2020). Asian countries are initiating sustainable methods of water management with emphasis on environmental legislation (Alexandra et al. 2012).

17.2 Present-Day Scenario of Wastewater Management in the World and Asian Countries

Due to urbanisation, most industrial sectors have expanded their production up to 20–45%. This increase in production has led to vast volumes of wastewater discharged untreated into the water bodies.

Asian countries in the north and south such as Mongolia, Kyrgyzstan, and Azerbaijan have high BOD/GDP rates (10 kg BOD/US$1000 GDP) exhibiting the greatest levels of industrial pollution. BOD emissions per US$1000 GDP are lesser in Bangladesh and Nepal (8 kg) and Sri Lanka and Cambodia (7 kg) (5 kg). BOD/GDP rates in other Southeast Asian countries are less than 4 kg/US$1000 GDP (ESCAP 2005). Southeast Asia's water bodies are said to be the most heavily polluted with heavy metals and harmful compounds in the region (ADB 1997). Mining is a major source of anthropogenic atmospheric mercury, with Asia being the largest producer. It accounts for over half of all world emissions (Li et al. 2009). Pakistan's industrialisation is putting a strain on the country's water supplies (ADB 2008).

In India, wastewater treatment remains a major concern, particularly in rapidly growing metropolitan areas. Only 36% of total wastewater has been efficiently treated in cities of grades one and two, according to CPCB reports (2013, 2017) Furthermore, just 13.5% of sewage is successfully processed, compared to 18.6% of total capacity in 2017 (CPCB 2013, 2017; Schellenberg et al. 2020).

Strokal et al. 2021 investigated the effects of urbanisation on future river pollution using a multi-pollutant method for the years 2020, 2050, and 2100. They used a multi-pollutant methodology to correlate population densities, wastewater treatment levels, and a multi-pollutant methodology to assess the effects of rising urbanisation on future global river quality. Correlation between microplastics, pathogens, and point source nutrients of 10,226 rivers was studied. River pollution is at an all-time high in Europe, Southeast Asia, and North America, according to them. More than 80% of the global population is predicted to live in sub-basins with multi-pollutant problems in the future, according to high urbanisation scenarios. River pollution in Africa is anticipated to be 11–18 times worse in the future than it was in 2010, making it harder to accomplish the Sustainable Development Goals. Improved wastewater treatment makes it theoretically possible to avoid future contamination in many regions.

Heavy metal concentrations in rivers are also creating a serious hazard because they are not treated like wastewater. Asia, Africa, and South America projected high metal concentration than European and North American counterparts exhibiting different sources across all continents with Africa dominating fertiliser and pesticide use, as well as rock weathering. In Asia and Europe, manufacturing industries and mining were dominating (AWDO 2020, Environmental Water Security).

According to the 2010 UNEP/UN-HABITAT Sick Water Report, densely populated coastal areas create up to 90% of untreated wastewater flows, polluting rivers, lakes, groundwater, and coastal waterways. Water produced by agriculture and animal operations poses a significant issue for downstream consumers since it contains organic and inorganic contaminants originating from fertilisers, pesticides, human waste, livestock dung, and minerals. Similarly, heavy metal pollution, man-made organic pollutants, and micropollutants like pharmaceuticals cause problems in wastewater generated by mining and industry.

In addition to these multiple obstacles, particularly in developing nations, financing, running, and maintaining wastewater treatment infrastructure is a substantial impediment. The cost of installing centralised wastewater treatment plants is often high. Investments in modern water and sewer systems are expected to cost roughly $30 billion per year by 2025, with prices rising to $75 billion (excluding operation and maintenance costs).

In centralised systems, wastewater transport and treatment facilities must be constructed to accommodate these erratic high flows. Through 2015, it is anticipated that developing nations will require $103 billion in funding for water, sanitation, and wastewater treatment. Brazil, China, and India, for example, have already devoted enormous resources to infrastructure development (Privatization Law No. (25) of Jordan, enacted in 2000).

17.3 Policies and Initiatives by the Government of Asian Countries

Wastewater treatment is vital for protecting human health from viruses and dangerous contaminants. International conventions like the Basel Convention on Hazardous Waste, the Rotterdam Convention on hazardous Chemicals and Pesticides, and the Stockholm Convention on POPs (Persistent Organic Pollutants) provide governments with the legal and monitoring tools they need to regulate substances entering waterways and protect public health and the environment (UNEP 2015). Municipalities must collect wastewater and decide whether to treat it intensively (mechanically) or broadly (chemically) (using wetlands, for example). Local environmental conditions like temperature, rainfall, resources availability (human, capital, geographical extent, raw material), cultural differences must be taken into consideration while adopting centralised or decentralised wastewater management system (UNEP 2015). The rising expenses of wastewater management should be altered to offset the operating and maintenance costs. For each geographical area, appropriate criteria for applying the ‘polluter pays’ principle must be defined based on end uses and effluent quality, as well as economic and social variables. The cost of treating and selling treated wastewater to end-users must cover the cost of delivery and maintenance at the very least (UNEP 2015).

Recently treated wastewater has been used for agriculture purpose. According to estimates of Sato et al. (2013), lower-middle-income countries (LMIC) and least developed countries (LDC) treat 28 and 8% of their generated wastewater, respectively. Some wealthy countries, on the other hand, have made headway toward treating all water. The limited treatment capacity of countries is due to two key factors. To begin with, the costs of treating wastewater are extremely expensive. For example, the total expenditure planned for tertiary and secondary treatment plants is EUR 14,800 million and EUR 2091 million, respectively (Kumar and Tortajada 2020). Second, in these countries, solid waste management takes precedence over wastewater treatment, with different degrees of treatment. Recycled water as an alternative source can help close the gap between supply and demand for water. Previously, wastewater was primarily used for irrigation and other agricultural reasons, with narrow attention on recycled water for various purposes within cities. Despite advancements in technology and legal frameworks, little progress has been accomplished in these economically backward nations. Below is a discussion of several Asian countries wastewater regulations and initiatives summarised in Table 17.1.

Table 17.1 Policies of Asian countries for wastewater management

Sr no	Country	Policies/initiatives	References
1	Russia	(a) Water technology transfer from developed countries (b) Use of non-conventional resources—desalination (c) The federal government motivated large business owners to establish PPPs (public–private partnerships)	Wei (2015)
2	China	(a) Comprehensive reform to convert resource fees to resource taxes	Guo et al. (2018a)
3	India	(a) National Water Policy (NWP) 2012 (b) Recycling of treated wastewater (2018)	Vij et al. (2021)
4	Saudi Arabia	(a) Inadequate infrastructure limits the recycling of partially treated wastewater (b) Use of non-conventional resources—desalination	Alkhudhiri et al. (2019)
5	Turkey	(a) Ministry of Environment and Urban development, Turkey has prepared an action plan for wastewater treatment for the years 2015–2023 (b) MoEU initiated the project, 'Reuse of Treated Wastewater in Turkey'	Maryam (2017) and Nas et al. (2020)
6	Indonesia	(a) National Policy of Wastewater Management in Indonesia encourages efforts to reuse/recycle domestic wastewater treatment products (b) Wastewater resource recovery (WRR)	Yudo and Said (2017) Marleni and Raspati (2020)
7	Korea	(a) Any building with more than 60,000 m2 of total floor space is required to install a water reuse system by law. However, only less than 0.5% of the total buildings have more than 10,000 m2. Therefore, the regulation is ineffective and merely nominal. (b) Inexpensive service water discourages the use of recycled water	Noh et al. (2004)
8	Japan	(a) Direct penalty system (b) Low carbon footprint	Hosomi (2016)
9	Pakistan	Lack of national policy and economic incentives	Batool and Shahzad (2021)
10	Thailand	Enhancement and Conservation of National Environmental Quality Act, (1992)—service fees shall be used as expenditures for operation and maintenance of the central wastewater treatment plan	Chevakidagarn (2006)

17.3.1 India

Over the years India has realised the potential of water as a necessary resource for economic development and basic human need. According to the Ministry of Environment, Forestry, and Climate Change only 37% of wastewater is treated out of 62 MLD generated from towns and cities (Vij et al. 2021).

India's first National Water Policy adopted in 1987 merely established the pollution control boards at central and state level. Later in 1974 and 1977 the Water pollution act and Water Cess act helped in preventing water pollution and maintaining the water quality. Later in 2002 the policy was revised with discharge limits defined in line with the principle of polluter pays.

Later in 2008 the focus shifted to sanitation and potable drinking water for all which led to adopting the National Urban Sanitation Policy (NUSP). Insufficient funds hindered the goals of the policy. This led to introduction of various finance schemes by government in later years. The Urban Infrastructure Development Scheme for Small and Medium Towns (UIDSSMT), Jawaharlal Nehru National Urban Renewal Mission (JNNURM) were some of the notable attempts. Although the lack of participation methods utilised in the construction of projects under these schemes has been criticised, these programs boosted the participatory and democratic government concepts (Kundu 2014).

Later in 2011 the Clean Ganga mission was established to treat sewage across the Ganga basin. Furthermore, the new policy of 2012 addressed climate change issues, water scarcity, and the economic value of water. Reuse and recycle of treated water being the primary goals of the policy. In 2016 bilateral Collaborations of Central Public Health and Environmental Engineering Organisation (CPHEEO) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) resulted in awareness of cities towards sustainable water management (3R, 2016 CPHEEO).

Despite the fact that the Central/State Pollution control board (CPCB/SPCB) develops wastewater guidelines and manuals to ensure that water quality standards are met in India, policy implementation has been weak. According to one respondent, this is mostly due to a lack of human resources, inadequate state laboratories for evaluating pollutants and weak legislations (Starkl et al. 2013). The Gujarat state government stated in May 2018 that it has adopted the Reuse of Treated Waste Water Policy, which requires all power plants and significant enterprises within 50 kilometres of a sewage treatment plant to use recycled wastewater to reduce the pressure on groundwater and surface water. In Gujarat, industrial associations have successfully implemented PPP models using treated recycled wastewater. In this context, other states such as Punjab, Jharkhand, and Karnataka have altered their state water policy.

Currently Ministry of Environment, Forest and Climate change (MoEFCC) and CPCB are the nodal agencies for developing policies and regulating standards along with the newly formed Ministry of Jal Shakti (Schellenberg et al. 2020).

17.3.2 Russia

Russia's total freshwater consumption from water bodies is substantial, at around 70 billion m^3 per year. Southern Russia is major consumer of water for nuclear power plants, various heat supply and manufacturing industries along with agriculture. Following the 1998 economic crisis, the Russian government 'froze' utility service pricing for 1999–2000. After 2003, however, the federal government urged significant business owners to create public–private partnerships by sharing risks of disasters and ultimately reviving the treatment scenario in their municipality. The discharged water contained nitrates, phenols, mercury, and some untreated wastewater. Only 61% of the entire volume was remediated that met the guidelines (Russian Federal State Statistics Service 2017). On an average the utility and agricultural sector discharged over 90% of hazardous compounds due to inefficient treatment facilities (Gazeta 2010).

Water technology transfer (WTT) from developed nations may be expedited as a result of green economy aims, while WTT from underdeveloped countries may be accelerated as a result of increased foreign investor like China (Wei 2015). The conversion from chlorine-based treatment to UV and membrane treatment spread across entire Russia, as it has been in several other nations (for example, Saudi Arabia). About 30% seaports utilised treated sewage for domestic purpose.

17.3.3 China

Prior to 2015, China's Wastewater Discharge Fees were based on treatment costs. Low discharge costs resulted in excessive wastewater contamination and minimal water prices did not encourage businesses to recycle water, alleviate consumption, and reduce wastewater outflow. From 41.5 billion tonnes in 2000 to 73.5 billion tonnes in 2015, China's total wastewater output has gradually increased (Ao et al. 2020). With the prevailing issues China reconsidered its environmental laws pertaining to wastewater discharge.

The Chinese government has recently emphasised the role of markets in resource allocation and reformed the tax system by launching a comprehensive scheme, with Hebei serving as the pilot province (Cao et al. 2016). The Water Resource Taxes were reformed by concerned ministries. Later in 2018, the water tax (Environmental Protection Tax Law) came into effect. The state administration distinguished taxes and fees on three contexts. First, the tax authorities, customs, and fiscal authorities are the main tax-collection bodies representing the state, while fees are collected by sector administrations. Second, tax rates are fixed, whereas fee payments are determined by treatment costs. Lastly, fee earnings are used to conserve water, whereas tax revenue can be used for any purpose by the state. China used to regulate water resource levies that were expressly utilised for water conservation prior to the transition. However, there are certain issues with payment, such as a lack of understanding of the need to pay fees and the lack of necessary collection mechanisms, to name a few (Guo et al. 2018b).

China had issued over 60 sound and enhanced pollutant discharge guidelines for industrial wastewater by 2018. Based on previous achievements and foundations, China is entering a new era of wastewater treatment, with water recycling and resource recovery options from sludge becoming the primary objectives.

17.3.4 Pakistan

Pakistan's challenges include a lack of policies and adequate economic incentives from the government responsible for infrastructure and institutional failures, fixed water prices, and a scarcity of resources. In Pakistan, water is plentiful, and there appears to be no effluent discharge policy or industrial treatment incentives (Batool and Shahzad 2021).

17.3.5 Japan

The Water Pollution Control Law in Japan establishes effluent standards (Uniform National Effluent Standards) for defined enterprises across the country that are uniform across all industries. The control is done through a method known as the 'direct penalty system', which allows for penalties to be imposed solely because of excessive concentrations.

Almost three quarters of domestic sewage in urban areas of Japan is being treated in centralised STPs. It is estimated in one of the Central government report that the annual power requirement for operating the treatment plants requires seven billion kWh which is approximately equivalent to the output of nuclear power plant of capacity of one million kWh. This quantity of electricity usage accounts for 0.7% of Japan's total electric power consumption.

In addition to energy savings, greenhouse gas (GHG) emission reduction is critical in a wastewater treatment facility. In Japan, sewerage utilities release seven million tonnes of CO_2 per year, accounting for 0.5% of total CO_2 emissions. Regulatory controls on GHG emissions and nitrous oxide should be considered as potential targets in coming future. Paradigm shifts towards low ecological footprints with cost-effectiveness and better operating performance shall be included in the present strategy for wastewater management (Hosomi 2016).

17.3.6 Korea

It is predicted that with high water resources demand of 38 billion tonnes by 2020 shall be impossible to be met by Korea's present resource capacity. The obvious solutions to cope with the present scenario are reduced water consumption and optimum recycling of wastewater. In total, the country has 99 on-site water-recycling systems. The 99 systems have a total capacity of 429 thousand tonnes per day. In comparison to the remaining industrialised countries, Korea has a small number of water-recycling systems. The following are the key causes for this. To begin, every building in Korea that has a total floor area of more than 60,000 m^2 is obliged by law to incorporate a water recycle system. However, only about 0.5% of all structures are larger than 10,000 m^2. As a result, the regulation does not serve any purpose. Next, water is provided at a nominal cost (0.20 US dollars per cubic metre of water). People are typically discouraged from recycling treated wastewater because of the low cost of service water. Third, some individuals believe that recycled water is not clean enough and can lead to disease. As a result, people should be convinced of use of reusable grade of treated water that is generated by a properly managed recycling system (Noh et al. 2004).

17.3.7 Indonesia

Indonesia confronts issues as a result of its population expansion, which reached 280 million in 2017 and is growing at a rate of 2% per year. Two-thirds of Indonesia's population will reside in cities, according to estimates (Indonesia and Statistik 2012–2013). The alarming population growth and congested locations threaten the availability of sufficient food resources and water resources that sustain life. Furthermore, a dense population has an adverse effect on the environment due to the excessive outflow of both treated and untreated effluent (Cordell et al. 2011; Gerbens-Leenes et al. 2010; Thornton 2010).

Untreated sewage has accelerated environmental degradation; however, some reports indicate stabilisation or even slight gains in only a few sites. Yudo and Said (2017) quoted a report submitted by the Ministry of Environment and Forestry that almost 75.2% of rivers are extremely contaminated. However, the government is still banking on the valuable resources in form of precious elements, electricity, nutrients, recycled water that can be recovered for the benefit of the society. The government policies in Indonesia support efforts to reuse/recycle residential wastewater treatment products along with regulatory disposals of the same (Yudo and Said 2017). The Wastewater Recovery (WWR) technique is being promoted by the government. The wastewater treatment fee is modest, which may encourage people to discharge rather than collect their effluent (Marleni and Raspati 2020).

17.3.8 Saudi Arabia

Saudi Arabia relies solely on desalinated water, surface water, and groundwater as there are no permanent water resources such as rivers or water bodies. Water scarcity is a serious issue in an arid region with limited water resources. The population rose by 3% in 11 years from 25 million to almost 33 million by 2018. In addition, freshwater consumption has risen considerably in the last 20 years. As a result, recovered wastewater and water conservation are viewed as strategic alternatives. The total sewage output is expected to reach 830 million m^3 per day by the end of 2019. Several more wastewater treatment plants will be built by 2019, bringing the overall number to around 95. These treatment plants will be capable of treating 2.8 billion m^3 of sewage per year. Because of a lack of incentives and inadequate treatment, wastewater could not be used as a substitute for natural water in the 1990s. In addition, the wastewater treatment infrastructure was insufficient to meet all demands. As a result, in Saudi Arabia, the reuse of cleaned wastewater was a controversial topic. According to Chowdhury and Al-Zahrani (2015), around 40% of wastewater is discharged untreated. Furthermore, in Saudi Arabia at the time, secondary treatment technique was the most often employed (Ouda 2015). With government approval, tertiary treatment is now used for all forms of wastewater, including domestic, industrial, and agricultural.

Desalination is viewed as a strategic solution to Saudi Arabia's water problem. Although the Saline Water Conversion Corporation (SWCC) ranks first in the production of desalinated water, the desalination industry confronts challenges such as crude oil dependence and brine management (Alkhudhiri et al. 2019).

17.3.9 Turkey

In terms of present water potential, Turkey is not a water-rich country. Its major water resource comes from rivers (86% of 112 billion m^3) and remaining 14% comes from groundwater resources.

The government has set up limited discharge criteria and levied taxes and fines for managing the wastewater. The Turkish Ministry of Environment and Urbanisation (MoEU) created a Strategy for Wastewater management for the years 2015–2023, which included monitoring of water quality and estimating quantity in Turkey's river basins, modelling approaches, and certain critical physicochemical characteristics. In 2016, the Ministry of the Environment undertook a survey to assess the state of wastewater treatment in Turkey across households of the country. According to the initiative, municipalities create 82.9% of treated wastewater, which grew to 85% in 2018. In the year 2023, Turkey's optimum rate for municipal wastewater treatment will be 100%. The second major initiative, 'Reuse of Treated Wastewater in Turkey,' was launched by the MoEU in 2017. The goal of this project is to evaluate the present standards and practices of the wastewater treatment as compared to global methods as well as formulate legislative policies for the reuse of treated wastewater in Turkey. As part of this research, all WWTPs were examined for the first time for wastewater reclamation and reuse reasons (MoEU and SU 2016; Nas et al. 2020).

17.3.10 Thailand

Thailand follows the Enhancement and Conservation of National Environmental Quality Act of 1992, which states that the Pollution Control Department (PCD) of the Ministry of Natural Resources and Environment (MONRE), which looks after the functioning of public wastewater treatment plant, has the authority and responsibility to collect penalties and fines. The service fees will be utilised to pay for the central wastewater treatment plant's operation and upkeep (Chevakidagarn 2006). Currently, wastewater from 66 million people pollutes 9.9 million m^3 of water per day, of which only 33% is being treated by about 100 WWTPs. According to inspection and law enforcement with pollution sources merely 48% comply to the standards.

17.4 Prevailing Problems and Critical Issues in the Wastewater Management

Inadequate institutional capacity to keep pace with industrial revolution has resulted in stringent water quality regulations in emerging economies. (Kathuria and Sterner 2006) and economic measures like taxes and the removal of fertiliser grants conflict with other development aims. Voluntary compliance is seldom achieved when monitoring is an expensive affair (Evans et al. 2012). The significant issues in wastewater treatment are divided into three broad categories: Inefficient treatment technologies, chemicals that escape treatment, and management flaws. A summary of the above issues is given in Table 17.2.

17.4.1 Inefficient Treatment Technologies

Operational efficiency is becoming increasingly important in many industries, but particularly in water treatment operations. There are numerous advantages to improving efficiencies within wastewater treatment plants in order to control costs and comply with increasingly stringent regulations (Brentagg websource).

Current wastewater treatment procedures are inefficient due to a heavy reliance on biological treatment systems that cannot withstand shock loads (Brentagg

Table 17.2 Common problems of inefficient wastewater treatment

Sr no	Categories	Problems
1	Inefficient treatment technologies	(a) Wear and tear of plant structures (b) Variable flow (c) Variable turbidity (d) Scale build-up (e) High BOD (f) Pin floc (g) Sludge management
2	Chemicals that escape	(a) High nutrients (b) Excessive FOG (fats, oil, and grease) (c) Microplastics (d) Xenobiotics/recalcitrants (broad-spectrum antibiotics and PPCPs) (e) Heavy metals (f) PFAS (per/poly-flouroalkyl substances)
3	Management flaws	(a) Lack of advanced technologies in developing countries due to high capital investment (b) Centralised/decentralised systems (c) Lack of skilled supervisor/operators (d) Lack of maintenance (e) Inadequate monitoring system

websource). Energy consumption is one of the most pressing issues confronting wastewater treatment plants. The massive carbon footprint and maintenance costs of these systems render wastewater treatment unsustainable and expensive (Brentagg websource). Some of the major issues that contribute to treatment inefficiency are as follows:

17.4.1.1 Wear and Tear of Plant Structures

Higher turbidity and hardness of the water cause erosion of concrete surfaces which add to the maintenance cost, reduce operational efficiency and life of equipment. The use of more resistant to erosion materials and designs in plants has become unavoidable.

17.4.1.2 Variable Flow

Inefficient solids removal is caused by hydraulic overloading. Wastewater treatment plants must deal with a constantly changing flow rate. Peak demands can be met with automated chemical feed systems and the installation of holding tanks, which would require additional capital investment.

17.4.1.3 Variable Turbidity

Another issue is turbidity, which refers to the cloudiness of water caused by the presence of particles. If not handled properly, turbidity variation can have a severe impact on process result in failure of meeting quality standards. It might also result in more sludge being created. Turbidity fluctuation can be accommodated by designing a treatment system that is slightly larger. Automated chemical feed systems and sludge handling system oversizing can also help accommodate turbidity changes.

17.4.1.4 Scale Builds Up

Scaling caused by impurities such as silica, magnesium, calcium, iron, aluminium, and others can hinder treatment operations (Brentagg websource). Scaling hinders flow of water through the system, thereby increasing power consumption and alleviating overall efficiency. Speciality chemicals such as scale inhibitors can efficiently prevent scale build-up, which saves time and money.

17.4.1.5 High BOD

To prevent oxygen depletion in waterways, regulations ensure that biochemical oxygen demand (BOD), a measure of the number of organics in water, remains at particular levels (Brentagg websource). Keeping up to the oxygen demands encountered during high BOD is a difficult task. Advances in diffuser installation to meet such demands require attention. Aeration of the waste stream, which increases biological oxidation, can help wastewater plants regulate BOD (Brentagg websource). Solids would be produced by this process, which might be removed by filtration or clarifying.

17.4.1.6 Pin Floc

Wastewater treatment plants employ flocculants to collect particle suspended materials into floc clusters, which can then be removed from the water (brentagg websource). The flocculation process is an important aspect of the wastewater treatment process. Poor settleable pin floc particles alleviate the sedimentation of the solids making it difficult to remove them (Brentagg websource). In cases of excessive underloading or the presence of poisonous compounds that could generate pin-flocs and lead to unsatisfactory treatment, settling aids will be required.

17.4.1.7 Sludge Management

A byproduct of the sedimentation process at the primary and secondary treatment stage contains nutrients and organic matter, making it sound like a fertiliser in the agriculture industry. Sludge often poses a disposal issue because of large quantities in generation and hazardous nature. Hence plants must discover long-term, safe, and sustainable sludge management solutions.

17.4.2 Chemicals That Escape Treatment

Many of the chemicals in wastewaters now originate in our houses and are leached from products or are directly added in the case of cleaning products and excreted drugs, according to research (UKWIR 2018). Concerns are developing about the existence of chemical mixes in the environment, dubbed the ‘cocktail effect’, which may be affecting aquatic life (EEA 2019). Antimicrobial resistance (AMR), which results from the use of antimicrobials such as antibiotics in human and veterinary treatment, is one example of potential new risk. Antimicrobial usage and excretion have resulted in the emergence of resistant bacteria, viruses, and microorganisms that can cause disease and are now resistant to therapy. During tertiary treatment, physical separation and membrane-based techniques are used to remove the remaining inorganic compounds (ammonium, sulphate, and phosphate) and other xenobiotics (Liu 2017).

17.4.2.1 High Nutrient Levels

The presence of nutrients in partially treated waters being discharged into rivers causes eutrophication. The water treatment systems need to implement nutrient reduction processes to safe levels in order to overcome this issue. This necessitates considerable process adjustments, such as anaerobic and/or anoxic treatment of a section of the aeration basin, which reduces aerobic volume and limits nitrification capabilities.

17.4.2.2 Excessive FOG

Water does not mix well with fats, oils, and grease (FOG). FOG levels in wastewater that are unusually high can cause serious complications. If discharged inappropriately it has the potential to choke pipelines and infrastructure, increase BOD, float to the top, etc. (brentagg websource). FOG levels that are unusually high may limit oxygen from reaching the water, resulting in septic conditions (brentagg websource). Excess FOG must be removed by chemical or mechanical means, which is both inconvenient and expensive.

17.4.2.3 Microplastics

Plastics end up in the environment as a result of either a single source of contamination or a widespread contamination. Vermeiren et al. (2016) reported various non-point sources of microplastics including agricultural runoff, industrial spills, and air depositions. Each year, oceans receive up to 2.41 million tonnes of microplastics from rivers (Lebreton et al. 2017). Microplastics, particularly fibres, have been recognised as a key source of microplastics at wastewater treatment plants (WWTP) (Browne et al. 2011). Cosmetics and personal care goods, plastic products such as textiles, and automobile tyres or road paints are among the sources of plastic debris that reach WWTP. Microplastics reach WWTPs via home wastewater or drainage systems, where they may be released into bodies of water or scattered with sludge (Ngo et al. 2019). According to several research, WWTPs have high rates of microplastic removal, frequently exceeding 95%. Despite the fact that sludge has absorbed the majority of the microplastics, the remaining fraction is still significant (Sun et al. 2019; Lv et al. 2019).

Furthermore, WWTP sludge is commonly used as a soil amendment in agriculture due to its high nutritional value (Gherghel et al. 2019). Recycling wastewater and sludge supports the circular economy concept; however, they reintroduce microplastics into the ecosystem, posing a significant environmental risk (Gatidou et al. 2019). Inadequate understanding of lifecycle of tiny plastic particles and fibres in the WWTPs warrants a debate about how much water discharges and sludge management contribute to microplastic buildup in environmental compartments (Carr et al. 2016).

17.4.2.4 Xenobiotics/Recalcitrants

Spongberg and Witter (2008), Palmer et al. (2008), Vieno et al. (2006), and Bendz et al. (2005) reported that majority of xenobiotics enter the aquatic environment via domestic sewage treated in conventional treatment plants. The inefficient traditional WWTPs discharge considerable quantities of many xenobiotics due to inadequate biological degradation and high levels of raw influences in secondary treatments. An important source of recalcitrant xenobiotics contains broad-spectrum antibiotics. Because many pesticides are poorly biodegradable and very hydrophilic, they are of special concern. The ability of convectional wastewater technology to process these impurities may be limited (Armah et al. 2020).

Verlicchi et al. (2010) and Martin Ruel et al. (2010) reported the effectiveness of advanced techniques of nanofiltration (NF), ultraviolet (UV) or ozone and reverse osmosis (RO) in removal of more than 90% of xenobiotics that were previously poorly removed in WWTPs. However, these procedures are not ‘environmentally friendly’ (Wenzel et al. 2008; Høibye et al. 2008) and lack sustainability. Overcoming difficulties such as the treatment of RO concentrates and of hazardous metabolites during ozone oxidation need adequate research (Verlicchi et al. 2010).

Broad-spectrum antibiotics, pharmaceuticals, and personal care products (PPCPs) have inherent ability to cause physiological effects in low doses (Ebele et al. 2017). A growing number of studies have established the presence of numerous PPCPs in diverse environmental compartments, raising worries about possible negative consequences for humans and wildlife.

17.4.2.5 Heavy Metals

Heavy metals, usually referred to as trace metals, are among the most persistent contaminants found in wastewater (Akpor et al. 2014). Metals, primarily from the textile, mining, and manufacturing units are commonly found in wastewater. Baysal et al. (2013) reported the most common metals found in industrial wastewaters, namely arsenic, lead, sodium, aluminium, mercury, iron, chromium, nickel, copper, tin, potassium. Heavy metals are commonly found in wastewater from mining and foundries followed by microelectronics and textiles. High remediation costs pose a variety of environmental issues such as plant growth distortion, algal bloom, aquatic biota death, debris development, and sedimentation (Akpor et al. 2014). Burakov et al. (2018) reported cancer, skin disorders, multiple organ failures, respiratory illness, and nervous disorders as human health impact. Bioaccumulation of metals in wastewater even at trace concentrations (1–3 mg/L) is hazardous (Baysal et al. 2013; Al-Saydeh et al. 2017).

17.4.2.6 Per-/Poly-Fluoroalkyl Substances (PFAS)

These are a new class of environmental pollutants that are employed as additives to improve product thermo-chemical stability or alter surface qualities. PFAS are amphiphilic compounds made up of fluoroalkyl chains terminated by carboxylic, sulphonic, phosphate, sulphonamide, and betaine functional groups. It has surfactant-like properties, making it highly persistent and mobile in various types of environments. The complexity of the wastewater matrix coupled with low quantities renders inefficient removal of the PFAS. Trace exposure of PFAS can have serious impacts on the health of all living beings (Garg et al. 2021).

PFAS (perfluoroalkyl sulfonates) values of 124.95 g/day (PFAS: 49.81 g/day; PFCAs (perfluoroalkyl carboxylates): 75.14 g/day) have been observed from eight WWTPs in Japan and 55.04 g/day (PFASs: 12 g/day; PFCAs: 43.04 g/day) from five (Shivakoti et al. 2010). The Han and Nakdong Rivers received 89% of the total PFAS discharge from WWTPs in Korea, according to the projected total daily mass of emitted PFCs (Kwon et al. 2017).

17.5 Advanced Techniques for the Treatment of Wastewaters Adopted by Industries

Toxins, phosphorus, nitrogen, and heavy metals are not entirely removed from contaminated wastewater using conventional treatment processes. Despite the fact that all of these elements make them expensive and time-consuming, these processes help to reduce the levels of myriad pollutants to some extent and each has its own set of benefits and drawbacks (Jain et al. 2021). The next sections detail some of the advanced strategies used by industry to overcome the difficulties stated at the beginning of the chapter.

17.5.1 Techniques to Overcome Operational Difficulties

Installation of holding tanks and automated chemical feed systems can be used to manage peak demands which would prevent short-circuiting issues. Designing an oversized treatment system shall help accommodate turbidity variation. The use of scale inhibitors can save energy and maintenance costs by preventing build up in equipment. Overcome pin-flocs by use of appropriate coagulants and polyelectrocytes shall enhance the solid removal.

17.5.2 Techniques to Treat Persistent Chemicals and Microplastics

17.5.2.1 Advanced Oxidation Technologies

Some pollutants contained in wastewater are resistant to treatment using physical and chemical methods. Chemical oxidation techniques can supplement conventional treatment methods by introducing transformations that use oxidation and reduction reactions to eliminate stubborn substances.

In the wastewater treatment sector, the advanced oxidation method is gaining favour. The hydroxyl radical is the major focus of this mechanism, which, once created, destroys practically all organic molecules vigorously. To remove recalcitrant organic molecules, photocatalytic (TiO_2/UV) processes, ozonation, H_2O_2/UV processes, and Fenton's reactions have all been employed extensively (COD, TOC, dyes, and phenolic compounds). These processes are influenced by primary pollutant concentrations, oxidants, catalyst quantity, light intensity, irradiation period, and the makeup of the wastewater solution (pH, TDS, and other ions). It has been determined that doing pilot plant studies is required for estimating capital costs, overhead, and management prices since pilot plant studies are better equipped to provide closer circumstances for estimating correct costs. H_2O_2/O_3 and H_2O_2/UV appear to be the two most promising AOP systems based on the limited reviews and they are both economically viable (Krishnan et al. 2017).

17.5.2.2 Advance Anaerobic Sludge Digestion Processes

Because it takes up less space, produces less sludge, and produces renewable energy in the form of methane, anaerobic digestion has been lauded as the most environmentally friendly wastewater treatment technology. Anaerobic baffled reactors (ABR), sequencing batch reactors, and up-flow anaerobic sludge blanket (UASB) reactors are now used to treat oily wastewater (Kuyukina et al. 2020). However, anaerobic treatment is insufficient to meet water discharge criteria, necessitating further treatment, such as aerobic treatment (Wang et al. 2017). PAHs were removed from refinery wastewater using a laboratory treatment system that included UASB and aerobic packed-bed biofilm (PBB) reactors (COD of 435 mg/L; TPH of 1520 mg/L; PAH of 10.33 mg/L), yielding an overall COD removal efficiency of 81.07% and complete removal of three PAHs (naphthalene, phenanthrene, and pyrene) after 118 days (COD of 435 mg) (Nasirpour et al. 2015).

17.5.2.3 Membrane Bioreactors

Over the last century, membrane bioreactor (MBR) technology has surpassed the traditional activated sludge process (ASP) as the preferred wastewater treatment technology (Ramachandra et al. 2006).

Over the last century, membrane bioreactor (MBR) technology has been a growing wastewater treatment method (Ramachandra et al. 2006). Ultrafiltration, reverse osmosis, and nanofiltration are examples of membrane filtration processes that have been widely used. Nanofiltration, photocatalysis, adsorption and biosorption, disinfection treatment and pathogenic control, sensing, and monitoring are all nanotechnology-based wastewater cleanup approaches. Membrane bioreactor (MBR) technology has lately gained popularity as a treatment method in wastewater treatment plants. It performs exceptionally well in the removal of microplastics (removal effectiveness of 99.9%) (Talvitie et al. 2017).

However, the use of nanotechnology in wastewater treatment is subjected to the systematic investigation of possible biological and ecotoxicity associated with their use. Membrane fouling is most common drawback of the membrane filtration which can be overcome by physical cleaning, using biocides, acid, and bases.

Advanced treatment technologies including as UV or ozone oxidation, nanofiltration (NF), and reverse osmosis (RO) have been shown to improve treatment for the majority of xenobiotics that are difficult to remove in typical WWTPs, with removal efficiencies of over 90% (Verlicchi et al. 2010; Martin Ruel et al. 2010). These procedures, however, are not ‘environmentally friendly’ (Wenzel et al. 2008; Høibye et al. 2008) and cannot be made sustainable unless a number of concerns, such as the treatment of concentrate by RO/NF processes or the generation of hazardous metabolites during ozone oxidation, are handled (Verlicchi et al. 2010).

Chemical precipitation, lime coagulation, ion exchange, reverse osmosis, and solvent extraction are all typical methods for extracting metal ions from aqueous streams (Rich and Cherry 1987). Biosorption is the process of removing chemical species from biological or natural materials as sorbents through extracellular and intracellular bonding, which is influenced by the nature of the organic compound, the structure of adsorptive materials, the microbial metabolism, and the transport process. Adsorption, absorption, ion exchange, precipitation, and surface complexation are some of the mechanisms involved in the biosorption process (Gorduza et al. 2002; Gadd 2009).

Biosorption is an economical and efficient alternative to traditional wastewater treatment plants, using living or dead biomass in static or dynamic conditions. Process efficiency has been shown to be effective in retaining both inorganic and organic compounds found at low quantities in various industrial wastewaters (Suteu et al. 2012). Microalgal biosorbents, Biochar, microbial biosorbents, etc. are being researched upon in recent times.

17.5.2.4 Phytoremediation

For the cleanup of diverse industrial effluents, phytoremediation is a potential green method. In their investigation on textile effluent from Surat CETP, Sidi and Mesania (2015) found that *Eichhornia crassipes* was the best probable bioremediator. Their investigations revealed that the plants might be utilised in the CETPs preliminary effluent treatment stage, reducing effluent treatment costs and increasing cleanup efficiency while using less dosing chemicals and generating less sludge.

A recent study looked at the phytoextraction potential of aquatic plants including *Pistia stratiotes L, Salvinia adnata Desv, and Hydrilla verticillata (L.f) Royle* for cotton textile dying unit in Tamil Nadu, India. The phytoremediation capacity of P. stratiotes L efficiently decreased pollutants from the dyeing effluent without changing the pH, according to the study. The changes in phytochemical content in aquatic plants before and after the phytoremediation procedure were validated by GC–MS analysis, particularly for ascorbic acid. The plant biomass and liquid generated during the treatment process were recovered and used for composting and watering of decorative plants, indicating that the dyeing business has a great zero-waste option (Ahila et al. 2021). These discoveries pave the path for an environmentally friendly and long-term wastewater treatment technology.

17.5.2.5 Heavy Metal Removal and Reuse Techniques

Technology has advanced to the point that metal ions can now be extracted and reused from metal-contaminated wastewater. For example, in the Community Bureau of Reference (BCR) sequential extraction system, diethylenetriaminepentaacetic acid (DTPA) can remove 99.6% of Cd^{2+} from wastewater (Fuentes et al. 2004). Cu^{2+} can be extracted from wastewater with 99% efficiency using silica-polyamine composite materials (Fischer et al. 1999). Electrospun titania nanofibers with surface-functionalised surfaces reduce Pd2+ levels in wastewater by up to 99.9%. (Dai et al. 2016).

17.5.3 Tecniques to Cope with Management Flaws

The lack of advanced technologies in developing countries is due to high capital investment. The differential investment requirements for centralised/decentralised systems pose a challenge for the countries to adopt. Lack of skilled supervisors/operators with very few local technicians skilled in operating the plants cannot cope well with the engineering and scientific problems. Additionally, a lack of maintenance and an inadequate monitoring system lead to inefficiency.

Unskilled operators coupled with complex treatment requirements warrant real-time monitoring systems that would ensure wastewater discharge standards. Most Asian countries have adopted SCADA-based water quality monitoring. A case from India has been elaborated below.

17.5.3.1 Online SCADA-Based Monitoring with IoT

For real-time water quality monitoring, a supervisory control and data acquisition (SCADA) system that connects with Internet of Things (IoT) technology is used. Using the Global System for Mobile Communication (GSM) module, it intends to assess water contamination, pipeline leakage, and an automatic measurement of parameters (such as temperature sensor, flow sensor, and colour sensor) in real-time. The system was used in the Tirunelveli Corporation (a metropolis in Tamil Nadu, India) to capture sensor data automatically (pressure, pH, level, and energy sensors). With the addition of additional sensors and a lower cost, the SCADA system has been fine-tuned.

The results reveal that the suggested system outperforms and generates better results than existing systems. Through GSM connectivity, SCADA obtains the real-time accurate sensor values of flow, temperature, colour, and turbidity (Saravanan et al. 2018).

The Jal Jeevan Mission is an Indian government flagship programme aimed at promoting holistic management of local water resources through the use of IoT-based sensors, flow metres, water-quality detection kits, and innovative mobile applications. It has been using innovative technology to find cost-effective ways to provide safe drinking water to every rural home in the country by 2024.

17.6 Future Prospects of Reuse and Recycle of Wastewater

Recent advances in wastewater management, fortunately, offer enormous promise to assist alleviate some of the challenges of water supply, pollution control, waste recycling, water-borne disease health difficulties, and environmental protection. There are several contemporary developments in wastewater management that vary depending on climatic variables, development levels, and financial resources available for investment. These findings show that, far from being a nuisance, wastewater is increasingly being viewed as a resource, thanks to advances in technology that allow treated wastewater to be used in industrial operations, irrigation, and as drinkable water.

Decentralisation is an alternative to the traditional strategy of conveying reclaimed water from a central WWTP. Zero liquid discharge (ZLD) and wastewater resource recovery (WRR) are two developing solutions that must be researched and implemented in the circular economy. This emerging approach is illustrated in Fig. 17.1.

A circular economy aims to keep material value as long as possible inside the economic system (European Commission 2021). The term ‘zero liquid discharge’ (ZLD) refers to a treatment procedure in which the plant does not discharge any effluent, thereby preventing treatment-related contamination. Other profit is that a ZLD process makes efficient use of wastewater treatment, recycling, and reuse, helping to water savings by reducing the amount of freshwater used (Ahirrao 2014).

The zero liquid discharge concept was first successfully implemented in Gujarat, India, after which it declared a policy for the reuse of recycled. The cluster of textile

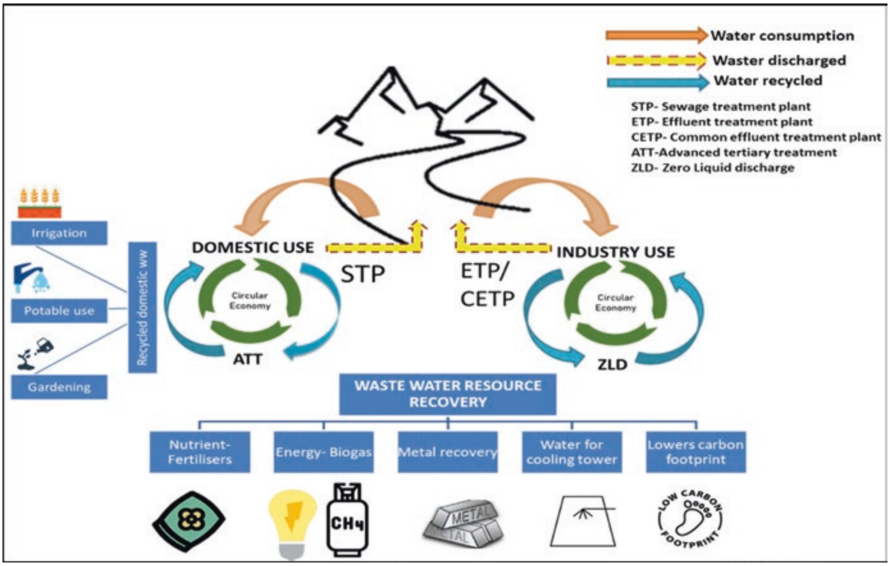

Fig. 17.1 Emerging sustainable approach of Circular economy and Wastewater resource recovery

and dyeing units in Pandesara and Bamroli came together to form an association (centralised system) to treat sewage water from the nearby areas and cater to the needs of the industries in the neighbouring GIDC. The revenue earned by member industries was utilised to maintain and operate the ETPs. CETPs later began advanced tertiary water treatment (using advanced filtration techniques) in order to recycle the water for reuse within the same industry (decentralised system). This ensures a long-term strategy for water resource management. This was a public–private cooperation (public–private partnerships). Community contractors, service contracts, management contracts, leases, concessions (build-operate-transfer), divestures, and public–private partnerships are all examples of public–private partnerships (Hutton and Wood 2013).

Due to its huge amounts, wastewater has been recognised as a resource, as it contains many valuable resources that may be transformed into valuable material. Recycling of wastewater and deriving benefits from its byproducts can reduce the impact on environment (Marleni and Raspati 2020).

Wastewater treatment plants (WWTPs) play an instrumental role within the water-energy nexus as they remove pollutants with large energy consumptions and overall reduced environmental impacts (Gu et al. 2016; Xu et al. 2017). Over the last few decades, wastewater treatment has aimed to improve sustainability through resource recovery and energy efficiency by providing flexibility and renewable energy production (heat recovery, biogas, incineration, micro-hydropower, power to methane) in the system (Logan et al. 2021).

Wastewater may be used to extract energy, clean water, fertilisers, and nutrients, which can all be used to assist accomplish the SDGs. Best available methods (BATs) can help accelerate the transition to a circular economy by encouraging resource reuse and recovery and assuring long-term wastewater management. Another use of wastewater is direct and indirect potable reuse.

There are 48 countries in Asia, of which 37 are coastal states. These coastal countries can get non-conventional water resource from the desalination of sea water. Desalination has been an important water resource but brine management is another hurdle to procuring water from the sea. Brine is a saline wastewater produced by a variety of businesses (e.g., desalination, energy, and oil production) and its disposal has the potential to harm the environment. To solve this problem, brine treatment appears to be a potential solution for recovering additional freshwater and valuable elements like salts.

Technology is also evolving, bringing new choices for rural areas and communities, such as the usage of wetlands and lagoons, as well as decentralised or small-scale wastewater systems. Local standards should reflect local reality and authorities should consider local conditions when deciding between these possibilities.

Standards and rules must be redesigned for this changing urban setting, which may necessitate becoming more nuanced, holistic, dynamic, transparent, participatory, and contextual. Step wise incorporation of enforcement strategies to achieve compliance for water reuse should be planned (Schellenberg et al. 2020).

17.7 Conclusion

"Wastewater treatment not only reduces the problems linked to pollution but also resolves issues of water supply, environmental protection, health issues associated to water-borne diseases as population increase, industry, and urbanization." Wastewater can be used as a source of energy as well as repurposed in agriculture and industry, reducing the need for freshwater abstraction. Recognising wastewater as a resource decreases water pollution by avoiding tainted wastewater from being dumped into bodies of water. Reusing wastewater has two main benefits: it improves the living standards of the local population by generating economic opportunities and it saves money.

Innovations and extensive opportunities to use wastewater will become a necessity in the coming years of economic development. Many wastewater management methods and concepts have been successfully implemented in the past, but they have yet to reach their full potential. Not only is a paradigm shift in water policies and wastewater management required to protect human health, biodiversity, and ecosystems, but it is also necessary to modify our perception of wastewater as a valuable resource that may contribute to future water security.

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