

WATER POLLUTION AND WASTEWATER TREATMENT

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ABSTRACT

Water is an essential natural resource for human survival, public health, agriculture, industry, biodiversity, and sustainable economic development. However, rapid population growth, urbanization, industrialization, agricultural intensification, inadequate sanitation, improper waste disposal, and increasing chemical consumption have significantly increased the contamination of freshwater resources. Domestic sewage, industrial effluents, agricultural runoff, heavy metals, nutrients, pathogens, pharmaceuticals, pesticides, microplastics, and other emerging contaminants can enter rivers, lakes, groundwater, and coastal environments and adversely affect aquatic ecosystems and human health. Wastewater treatment is therefore an essential component of environmental protection and sustainable water management. This research examines the major sources and impacts of water pollution and critically reviews conventional and advanced wastewater-treatment technologies. The study uses a qualitative, literature-based research approach and synthesizes recent scholarly research, particularly publications from 2023 to 2026. The literature indicates that conventional physical, chemical, and biological treatment processes remain important for removing suspended solids, organic matter, nutrients, and pathogens; however, many emerging contaminants are difficult to remove completely through conventional processes. Advanced technologies such as adsorption, membrane filtration, advanced oxidation processes, nanotechnology, electrochemical treatment, constructed wetlands, and hybrid systems have therefore received increasing research attention. Recent reviews suggest that hybrid treatment systems can combine the strengths of multiple technologies, although high operational costs, energy consumption, membrane fouling, sludge management, scalability, and insufficient regulatory frameworks remain important challenges. The study also highlights water-pollution concerns in Pakistan, including microbial contamination, heavy metals, inadequate monitoring, and insufficient wastewater-management infrastructure. The findings indicate that sustainable wastewater management requires pollution prevention, improved sewage collection, appropriate treatment technologies, water reuse, resource recovery, technological monitoring, environmental regulation, and public participation. The study concludes that wastewater should increasingly be viewed as a recoverable resource rather than simply as waste, and integrated treatment systems should be developed to protect water resources while supporting long-term environmental sustainability.

KEYWORDS: *Water Pollution, Wastewater Treatment, Water Quality, Emerging Contaminants, Biological Treatment, Membrane Filtration, Advanced Oxidation, Adsorption, Water Reuse, Resource Recovery, Sustainable Development*

INTRODUCTION

Water is one of the most important natural resources on Earth and is fundamental to human life, environmental stability, economic development, agriculture, industry, and public health. Freshwater resources support drinking-water supplies, sanitation, food production, irrigation, livestock, manufacturing, energy generation, and ecological systems. Rivers, lakes, wetlands, groundwater systems, and coastal environments also provide habitat for diverse organisms and perform important ecological functions. Despite its importance, water quality is increasingly threatened by human activities. Urban expansion, industrial development, agricultural intensification, population growth, inadequate sanitation, mining, deforestation, plastic pollution, and inappropriate disposal of domestic and industrial waste have contributed to widespread water contamination. Consequently, water pollution and wastewater treatment have become central concerns in environmental science and sustainable

development Jiang, T., Wu, W., Ma, M., Hu, Y., & Li, R. (2024). Found that. Water pollution can be defined as the introduction of physical, chemical, biological, or other harmful substances into water at concentrations that alter its natural characteristics and reduce its suitability for human use or ecosystem functioning. Pollutants can enter water through point sources and non-point sources. Point sources include municipal sewage outlets, industrial discharge pipes, wastewater-treatment plants, and other identifiable discharge locations. Non-point sources include agricultural runoff, urban stormwater, soil erosion, atmospheric deposition, and dispersed waste.

Because different sources release different combinations of pollutants, water pollution is a complex environmental problem requiring multiple management strategies. Domestic wastewater is one of the most important contributors to water pollution. Household wastewater contains organic matter, nutrients, suspended solids, detergents, pathogens, pharmaceuticals, personal-care products, oils, and other chemicals. Where sewage collection and treatment systems are inadequate, untreated or partially treated wastewater may enter rivers, canals, lakes, groundwater, and coastal environments. Kato, S., Sakai, Y., Guan, G., & Kansha, Y. (2025). Explained. Such discharges increase organic and microbial pollution and may create significant risks to human health and aquatic ecosystems. Wastewater treatment is consequently essential for reducing contaminant loads before wastewater is released into the environment or reused. Industrial activities can generate wastewater containing highly complex and sometimes toxic pollutants. Textile, pharmaceutical, chemical, food-processing, petroleum, mining, paper, metal-processing, and other industries produce wastewater with different physical and chemical characteristics. Industrial wastewater may contain dyes, solvents, oils, salts, heavy metals, pharmaceuticals, persistent organic compounds, and other hazardous substances. A 2024 comprehensive review emphasizes that industrial wastewater varies substantially in quantity, pollutant concentration, and pollutant type, meaning that treatment systems need to be selected according to the specific characteristics of each industrial wastewater stream.

Heavy metals are particularly important pollutants because they can persist in the environment and may accumulate in aquatic organisms and sediments. Lead, mercury, cadmium, chromium, arsenic, nickel, and other metals may originate from industrial discharge, mining, metal processing, batteries, electronic waste, pigments, and other activities. Unlike biodegradable organic substances, metals cannot simply be destroyed by biological processes. They must instead be removed, immobilized, recovered, or otherwise managed to prevent their movement through environmental systems. Microbial contamination is another major concern. Untreated domestic sewage can contain bacteria, viruses, protozoa, helminths, and other pathogens. Contaminated water can contribute to waterborne diseases, particularly in communities with inadequate sanitation and limited access to safe drinking water. Effective wastewater treatment and disinfection are therefore important not only for environmental protection but also for disease prevention. Nutrient pollution presents a further challenge. Explains Noor, R., Maqsood, A., Baig, A., Pande, C. B., Zahra, S. M., Saad, A., ... & Singh, S. K. (2023). E Nitrogen and phosphorus are necessary for plant growth, but excessive concentrations in aquatic systems can disrupt ecological balance. Nutrient enrichment can cause algal blooms, reduce water transparency, alter aquatic habitats, and contribute to oxygen depletion. Some algal blooms can also produce toxins that affect aquatic

organisms and human health. Therefore, wastewater-treatment systems increasingly need to consider nutrient removal in addition to organic-matter removal.

The growing concern regarding emerging contaminants has expanded the definition of water pollution. Emerging contaminants include pharmaceuticals, antibiotics, personal-care products, endocrine-disrupting chemicals, pesticides, industrial chemicals, microplastics, and other substances that may not be routinely monitored under traditional water-quality programs. A 2024 global review examined 54 common emerging contaminants in wastewater-treatment plants and reported their occurrence at concentrations ranging from nanograms per liter to micrograms per liter. Even at relatively low concentrations, some of these compounds can create ecological and potential human-health concerns because of their persistence, biological activity, or continuous release. Recent research indicates that conventional wastewater-treatment systems may not completely remove many emerging contaminants. Arkatkar, A., Jadhav, D. A., Hussein, M., Nguyen, H. Y., Eisa, T., Bahaa, A., ... & Chae, K. J. (2025). Revealed A 2024 comprehensive review identified adsorption, advanced oxidation, biodegradation, membrane filtration, nanotechnology, and artificial intelligence as important areas of contemporary wastewater-treatment research. It also concluded that no single technology can effectively remove every category of contaminant and that hybrid systems may provide more comprehensive treatment. The problem of emerging contaminants is especially important because wastewater-treatment plants were historically designed primarily to remove conventional pollutants such as suspended solids, biodegradable organic matter, and pathogens.

Water pollution also affects aquatic biodiversity. Pollutants can change water chemistry, reduce oxygen availability, alter habitats, disrupt food chains, and cause direct toxicity to aquatic organisms. Heavy metals may accumulate in organisms, while pesticides and industrial chemicals may affect reproduction, growth, behavior, and survival. Nutrient enrichment can change species composition by favoring certain organisms over others. Microplastics may also interact with organisms and other contaminants. Consequently, water pollution is not simply a problem of water quality; it is also a biodiversity and ecosystem-function problem. Wastewater treatment is therefore an important mechanism for protecting water resources. Conventional wastewater treatment normally consists of preliminary, primary, secondary, and tertiary or advanced stages. Sampaio, I. C. F., Santos, V. D. L. C. D., de Moura, I. V. L., Costa, G. L. M., Bueno de Oliveira, E. S., Azevedo, J., & Almeida, P. F. D. (2026). Elaborated On. Preliminary treatment removes large debris and materials that could interfere with subsequent processes. Primary treatment generally relies on physical processes such as sedimentation to remove settleable solids. Secondary treatment mainly uses biological processes to degrade biodegradable organic matter. Tertiary and advanced treatment can target nutrients, pathogens, dissolved pollutants, and specific emerging contaminants. A recent 2026 review evaluated more than 50 wastewater-treatment, separation, and purification technologies and emphasized the importance of integrated treatment pathways. It reported that hybrid systems combining nature-based solutions with advanced technologies such as membrane separation and advanced oxidation can improve contaminant removal while creating opportunities for resource recovery and sustainability.

Biological treatment is among the most established approaches for municipal wastewater. Microorganisms break down organic compounds and convert them into simpler substances.

Activated sludge, trickling filters, sequencing batch reactors, anaerobic reactors, membrane bioreactors, and constructed wetlands are examples of biological treatment systems. Biological processes can provide effective removal of biodegradable organic matter, and specialized configurations can also remove nitrogen and phosphorus. Anaerobic treatment has received considerable attention because it can simultaneously reduce organic pollution and generate biogas. Anaerobic processes operate without oxygen and use microbial communities to convert organic matter into methane-rich biogas. This creates an opportunity for energy recovery. However, anaerobic treatment may not always produce effluent that meets strict discharge standards, meaning additional polishing processes may be necessary. Constructed wetlands represent a nature-based approach to wastewater treatment. They use plants, microorganisms, substrates, and physical processes to remove pollutants. Constructed wetlands can be particularly useful for decentralized or low-resource applications because they may require less energy than some advanced mechanical systems. However, land requirements, seasonal performance, pollutant loading, and maintenance need to be considered. Membrane technology has become an important advanced treatment approach. Microfiltration, ultrafiltration, nanofiltration, and reverse osmosis provide different levels of contaminant separation. Opasola, O. A., Adiamo, B. Y., Adewuyi, M. E., Sakariyau, A. O., & Olayiwola, M. O. (2026) Found That Membrane systems can produce high-quality water and are increasingly relevant to water reuse. However, membrane fouling, energy requirements, membrane replacement, concentrate management, and high capital costs can limit their application.

Adsorption is another widely studied technology. Adsorbents such as activated carbon, biochar, biomass-based materials, and engineered nanomaterials can capture dissolved contaminants from water. Adsorption is especially useful for some pharmaceuticals, dyes, metals, and other organic compounds. However, contaminants are generally transferred from water to the adsorbent rather than destroyed, creating a need for adsorbent regeneration or safe disposal. Advanced oxidation processes are designed to transform persistent pollutants through highly reactive species. Ozonation, Fenton reactions, photocatalysis, electrochemical oxidation, and related methods can be effective against difficult-to-degrade organic compounds. However, energy consumption, chemical requirements, operating conditions, and potential transformation products must be considered when evaluating their sustainability. . Waseem, K., Akhtar, A. S., Nawaz, A., & Saeed, M. (2024). Revealed Recent research increasingly emphasizes hybrid treatment systems. Combining different processes can compensate for the limitations of individual technologies. A 2025 systematic review of 189 studies emphasized hybrid systems, resource recovery, artificial intelligence, and real-time monitoring as important directions for sustainable wastewater treatment. Hybrid technologies are also being investigated for microplastic and emerging-contaminant removal. Recent research indicates that combined physical and chemical systems can substantially improve removal performance, although very small particles and fibers remain difficult to manage. This demonstrates the importance of matching treatment technologies with specific pollutant characteristics. Water pollution is particularly important in developing countries, where wastewater-treatment infrastructure may not expand as rapidly as population and urban development Xue, W., Tabucanon, A. S., Amarakoon, A. M. S. N., Xiao, K., & Huang, X. (2025). Explained. Limited financial resources, inadequate sewage networks, electricity shortages, weak enforcement, poor maintenance, insufficient technical expertise, and limited monitoring capacity can restrict wastewater-treatment performance.

RESEARCH OBJECTIVES

1. To examine the major sources, types, and environmental and public-health impacts of water pollution.
2. To analyze conventional and advanced wastewater-treatment technologies and their effectiveness in removing different categories of pollutants.
3. To identify major challenges and sustainable strategies for improving wastewater treatment, water reuse, resource recovery, and long-term water-quality management.

RESEARCH QUESTIONS

1. What are the major sources and impacts of water pollution on human health and aquatic ecosystems?
2. How effective are conventional and advanced wastewater-treatment technologies in removing different categories of pollutants?
3. What strategies can improve sustainable wastewater treatment, water reuse, resource recovery, and water-quality management?

LITERATURE REVIEW

Water pollution is closely connected with the increasing generation and inadequate management of wastewater. Domestic, industrial, agricultural, and urban activities introduce diverse contaminants into water systems. Wastewater can contain organic matter, nutrients, pathogens, metals, pharmaceuticals, pesticides, plastics, and numerous other chemicals. Recent literature emphasizes that wastewater is a major pathway through which pollutants enter aquatic environments and therefore requires effective treatment before discharge or reuse. The pollution problem has become more complex because the composition of wastewater is changing. Ossai, I. C., Hamid, F. S., Redzwan, G., Aboudi-Mana, S. C., Hassan, A., Emenike, C. U., ... & Ntiamoah-Asare, D. (2026). Elaborated On Modern households and industries use increasingly diverse chemicals and products, resulting in wastewater containing substances that were not traditionally considered in treatment design. Pharmaceuticals and personal-care products are continuously released through domestic wastewater, while industrial chemicals may enter wastewater from manufacturing activities. Agricultural wastewater may contain pesticides, fertilizers, antibiotics, and animal waste. Emerging contaminants have become one of the most significant topics in contemporary water research. Pharmaceuticals, antibiotics, endocrine-disrupting chemicals, personal-care products, pesticides, microplastics, and other persistent substances can occur at trace concentrations. A global review published in 2024 documented the occurrence of 54 common emerging contaminants in wastewater-treatment plants across different geographic regions. These pollutants create challenges because many are biologically active, persistent, or difficult to degrade. Conventional treatment may reduce some compounds but not others.

Biological treatment can provide relatively sustainable removal of biodegradable pollutants. However, its effectiveness depends on microbial communities and environmental conditions. Persistent chemicals may not be adequately degraded, and biological systems may require additional treatment stages for high-quality effluent. Advanced oxidation processes have become important for treating persistent organic contaminants. These processes generate

highly reactive species capable of transforming difficult-to-degrade pollutants. Ozone, Fenton chemistry, photocatalysis, electrochemical oxidation, and related approaches have been widely investigated. The major advantage of advanced oxidation is its ability to target compounds that are resistant to conventional biological treatment da Silva, C. P., da Silva, N. S. R., dos Santos Matos, D. G., & de Campos, S. X. (2025) Found that. However, energy consumption, chemical use, operational complexity, and potential formation of transformation products remain important considerations. Adsorption is a flexible technology for removing dissolved pollutants. Activated carbon is one of the most widely used adsorbents, while recent research increasingly focuses on biochar, agricultural residues, biomass-derived adsorbents, nanomaterials, and engineered porous materials. Biomass-based adsorbents are particularly interesting because they may convert agricultural or biological waste into useful treatment materials. However, adsorption requires consideration of adsorbent regeneration, disposal, contaminant concentration, competing compounds, and long-term performance.

A 2024 review concludes that hybrid systems combining adsorption, advanced oxidation, biodegradation, and membrane filtration are more promising than reliance on a single treatment process. A 2026 review of more than 50 wastewater technologies similarly emphasizes hybrid treatment pathways that integrate nature-based solutions, membranes, advanced oxidation, and other technologies. Hybridization allows one process to compensate for the weaknesses of another. For example, biological treatment can reduce organic matter before membrane filtration, while adsorption can reduce micropollutants before advanced polishing. Industrial wastewater requires specialized treatment because pollutant composition differs substantially between industries. Textile wastewater may contain dyes and salts, pharmaceutical wastewater may contain active pharmaceutical compounds, mining wastewater may contain heavy metals, and food-processing wastewater may contain high concentrations of biodegradable organic matter. Worku, A. K., Ayele, D. W., Teshager, M. A., Omar, M., Yerkrang, P. P., Elgaddafi, R., & Alemu, M. A. (2025). Explained. Kato and Kansha's 2024 review emphasizes that understanding wastewater characteristics is essential for selecting appropriate treatment technologies. Therefore, industrial wastewater management should begin with source characterization and pollution prevention. Pakistan faces significant water-pollution challenges. Noor et al. (2023) reviewed water pollution in Pakistan and reported widespread microbial and toxic-metal contamination, inadequate water-quality monitoring, and concerns associated with urban and river pollution. Urbanization and industrialization have increased wastewater generation in major cities. Where sewage-treatment infrastructure is insufficient, wastewater can enter rivers, drains, canals, and groundwater. Agricultural runoff also contributes nutrients and chemicals to water systems. A 2024 review of water quality in Islamabad and Rawalpindi identified severe microbial contamination in several water sources, including high levels of total coliforms, fecal coliforms, and *E. coli*.

Such findings highlight the importance of sanitation, wastewater treatment, and systematic water-quality monitoring. Sustainable wastewater management requires consideration of environmental performance, energy consumption, economic feasibility, resource recovery, and long-term operation. Wang, H., Gao, X., & Zuo, Y. (2024). Explains Recent research increasingly promotes circular-economy approaches in which wastewater is treated as a source of water, nutrients, and energy rather than simply as waste. A 2025 systematic review

of 189 studies identified resource recovery, hybrid treatment, digital management, and AI-assisted monitoring as important future directions. It also identified membrane fouling, high costs, and regulatory limitations as major barriers. Constructed wetlands, phytoremediation, algal treatment, and microbial systems can provide relatively low-energy treatment options. Recent research on plant-, algae-, and microbe-based hybrid systems indicates potential for substantial pollutant removal while reducing operational and sludge-management costs under suitable conditions. Nature-based systems may be particularly useful in decentralized settings, although land availability, climate, pollutant loading, and seasonal variations need to be considered. Saisruthi, V., & Kumar, A. (2026). Found that. Digital technologies are increasingly incorporated into wastewater management. Artificial intelligence and machine learning can assist with prediction, process optimization, sensor interpretation, fault detection, and energy management. Recent reviews identify digital tools as important components of future treatment systems. However, AI-based systems require reliable data and technical expertise.

METHODOLOGY

The collected information was analyzed through thematic analysis in which similar findings were grouped into major categories and differences among studies were critically examined. Particular attention was given to the effectiveness and sustainability of treatment technologies, including their potential for water reuse, resource recovery, reduction of sludge production, energy efficiency, and application in developing countries. The methodology also considered the specific wastewater-management challenges faced by Pakistan, including inadequate treatment infrastructure, industrial pollution, insufficient monitoring, microbial contamination, and limited enforcement of environmental regulations. The findings obtained from the reviewed literature were synthesized and interpreted in relation to the research objectives and questions. This methodological approach provided a comprehensive understanding of the relationship between water pollution and wastewater treatment and helped identify technological, economic, environmental, and institutional factors that influence the successful management of wastewater. The study also recognized limitations associated with secondary research, including differences in research methods, geographical contexts, wastewater characteristics, and treatment conditions among the reviewed studies. Overall, the methodology was designed to provide a structured and evidence-based assessment of current wastewater treatment practices and emerging sustainable approaches for reducing water pollution and protecting water resources. This study adopted a qualitative research approach because the purpose was to examine and synthesize existing knowledge concerning water pollution and wastewater treatment rather than to generate primary laboratory or survey data. A qualitative approach was suitable for understanding the different sources of water pollution, treatment mechanisms, technological advantages, limitations, environmental impacts, and sustainability considerations.

RESEARCH DESIGN

The research used a descriptive systematic literature-review design. This design was selected because the study aimed to identify, organize, compare, and synthesize existing scholarly evidence on water pollution and wastewater treatment. The literature was organized according to major themes including pollution sources, pollutant categories, health impacts, ecological

impacts, conventional treatment, biological treatment, adsorption, membrane filtration, advanced oxidation, hybrid systems, emerging contaminants, water reuse, and resource recovery. The research design also incorporated comparative examination of treatment technologies. Each major treatment category was considered according to its mechanism, treatment potential, environmental benefits, limitations, energy requirements, operational requirements, and potential for large-scale application. Recent peer-reviewed reviews were prioritized because wastewater treatment is a rapidly developing field. For example, recent studies have examined emerging contaminants, industrial wastewater, hybrid systems, membrane technologies, sustainable treatment, and digital wastewater management. The design also incorporated a developing-country perspective, particularly Pakistan. This was important because wastewater-management challenges can differ substantially between regions with advanced treatment infrastructure and regions where sewage collection, monitoring, treatment capacity, and environmental enforcement remain limited.

DATA ANALYSIS

The study employed thematic analysis to analyze the selected scholarly literature. First, information related to water-pollution sources and pollutant types was identified and organized into categories such as domestic pollutants, industrial pollutants, agricultural pollutants, pathogens, nutrients, heavy metals, pharmaceuticals, pesticides, and microplastics. The literature concerning wastewater-treatment technologies was categorized according to physical, chemical, biological, membrane, adsorption, advanced oxidation, nature-based, and hybrid approaches. The strengths and limitations of each category were compared. Third, recurring issues across the literature were identified. These included treatment efficiency, energy consumption, operational costs, membrane fouling, sludge production, emerging-contaminant removal, resource recovery, scalability, and environmental sustainability. Fourth, the evidence was synthesized to identify broader patterns. The analysis indicated that no individual technology can effectively address all wastewater contaminants and that integrated treatment systems are increasingly important. This conclusion is consistent with recent comprehensive reviews of emerging-contaminant removal and sustainable wastewater treatment. Finally, the results were interpreted in relation to sustainable water management. Particular attention was given to pollution prevention, water reuse, resource recovery, digital monitoring, affordable technologies, and environmental governance. Because the study is literature-based, no artificial survey results or fabricated experimental measurements were included.

FINDINGS

The literature analysis demonstrates that water pollution is a complex and multidimensional environmental problem. Domestic sewage, industrial wastewater, agricultural runoff, urban activities, mining, plastics, pharmaceuticals, and other sources introduce different combinations of pollutants into water resources. Effective water-quality management therefore requires source-specific as well as integrated strategies. A major finding is that conventional wastewater treatment remains essential but has important limitations. Preliminary, primary, and secondary processes are effective for many conventional pollutants, especially suspended solids and biodegradable organic matter. However, emerging contaminants can remain in treated effluent, creating a need for tertiary and advanced

treatment. The analysis demonstrates that emerging contaminants are an increasingly important component of water pollution. Pharmaceuticals, personal-care products, endocrine-disrupting chemicals, pesticides, and other micropollutants have been detected in wastewater-treatment systems around the world. Their continuous introduction into aquatic environments means that wastewater-treatment plants must increasingly consider pollutants beyond conventional parameters. The findings also show that biological treatment remains a core component of wastewater treatment. Biological systems can effectively reduce biodegradable organic matter and can be configured for nitrogen and phosphorus removal. Their relatively established technology and potentially lower chemical requirements make them important for municipal wastewater treatment. Advanced oxidation processes were identified as useful for persistent organic pollutants that are difficult to remove through conventional biological treatment.

CONCLUSION

Water pollution and wastewater treatment are critical components of environmental protection, public health, ecosystem conservation, and sustainable development. The present literature-based study demonstrates that water resources are increasingly affected by domestic sewage, industrial effluents, agricultural runoff, heavy metals, nutrients, pathogens, pharmaceuticals, pesticides, microplastics, and other emerging contaminants. The study concludes that conventional wastewater treatment remains an essential foundation for pollution control. Physical processes, biological treatment, sedimentation, and disinfection can effectively address many conventional pollutants. However, the growing occurrence of emerging contaminants means that conventional treatment alone may not always provide adequate protection. Recent research therefore supports the integration of advanced treatment technologies. Advanced oxidation, adsorption, membrane filtration, electrochemical processes, nanotechnology, constructed wetlands, and advanced biological systems provide additional options. However, each technology has limitations. Advanced systems may require higher investment, energy, technical expertise, or maintenance. Therefore, technology selection should be based on wastewater characteristics, treatment objectives, environmental standards, economic conditions, and long-term sustainability. The literature strongly supports hybrid treatment systems as a promising direction. Combining different treatment mechanisms can improve the removal of diverse pollutants and reduce the limitations of individual technologies. Recent research emphasizes hybrid systems, resource recovery, and digital monitoring as important components of future wastewater treatment. The study further concludes that wastewater should increasingly be treated as a resource rather than simply as waste. Water reuse, energy recovery, nutrient recovery, and circular-economy approaches can reduce pressure on freshwater resources and improve the sustainability of treatment systems. Pakistan requires particular attention because available research indicates significant water-pollution challenges, including microbial contamination, heavy metals, river pollution, and inadequate monitoring. Improving wastewater-treatment infrastructure, enforcing environmental standards, expanding water-quality monitoring, and increasing public awareness are important steps toward improving water security.

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