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Water Pollution and Environmental Sustainability Interlinkages, Risks, and Sustainable Solutions

Wafaa A Alobaidi
Assistant Lecturer, Department of Biology, University of Baghdad, Baghdad, IRAQ

Corresponding Author: wafaa.a@sc.uobaghdad.edu.iq

ORCiD

https://orcid.org/0009-0001-5784-4824

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ABSTRACT

Water pollution is a severe worldwide issue threatening ecosystem quality, human health, and the sustainability of the environment in the long term. Some of the major contaminants affecting freshwater bodies are industrial effluents, agricultural effluents, domestic effluents and novel contaminants like pharmaceuticals and micro plastics among others. The effects of these stressors on the quality of water, biodiversity, ecosystem services and quality-added water scarcity. Climate change, population increase, and socioeconomic differences in access to clean water further increase the impact of water pollution on environmental sustainability. Sustainable solutions involve a combined and preventative solution, such as nature-based solutions, high-technology wastewater treatment systems, clean production, and efficient environmental governance. Water quality indices, heavy-metal pollution indices, biological indicators, and remote sensing are the environmental indicators and monitoring tools that are essential to evaluate the dynamics of pollution and make policy decisions. Nevertheless, gaps in research have remained, especially on the emergent contaminants and the lack of capacity to monitor in the developing areas. This review identifies the major sources of pollution, its effects and sustainable solutions to help in the protection of water resources in the long term.

Keywords- Water pollution; Environmental sustainability; Ecosystem services; Wastewater treatment; Nature-based solutions.

I. INTRODUCTION

Water pollution is a serious international problem that poses a threat to the stability of the ecological condition, human health, and sustainable development (Nti et al., 2023). The high rate of industrialization, agricultural intensification, urbanization, and population growth have all added to the emission of contaminants into freshwater sources leading to the extensive degradation of water quality (UNEP, 2022). Heavy metals, pesticides, nutrients, pharmaceuticals, microplastics, and pathogenic microorganisms are still found in rivers, lakes, and groundwater systems, as they exceed the natural self-purification ability of these systems and transform the work of these ecosystems (Nasr, 2022). Environmental sustainability seeks to focus on safeguarding the natural ecosystems, sound management of resources and equity across generations. The main element in the achievement of sustainability is clean and accessible freshwater which helps to sustain biodiversity, agricultural productivity, energy production, and the health of people (Khan & Srivastava, 2025)

Nevertheless, rising water pollution levels compromise numerous environmental sustainability pillars as they diminish the quality of ecosystem services, decrease freshwater supply, promote eutrophication, and elevate the concentration of toxic substances in food webs (Batuwita et al.,2022).

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Effects of water pollution are not limited to the ecological systems but also to serious health hazards to humans (Lin et al., 2022). Millions of cases of gastrointestinal infections, heavy-metal toxicity, and chronic illnesses are caused by polluted water, particularly in countries with low and middle incomes because the sanitation infrastructure is inadequate (WHO, 2023). In response to these issues, the latest scientific documents focus on the use of integrated and sustainable practices, including integrated water resources management (IWRM), nature-based solutions (NBS), green infrastructure, and applying the principles of a circular economy to the treatment of wastewater and reuse of it (Bunclark & De La Vega Hernández, 2022).Innovations in environmental monitoring, including water quality indicators, heavy-metal indicators, remote sensing, GIS-based evaluations, etc, are instrumental in locating the hotspots with pollution, and aligning it with policy-making (Sustain, 2026).

Thus, it would be necessary to comprehend the intricate interconnection between water pollution and environmental sustainability in order to develop effective management approaches, enhance environmental policies, and provide long-term security of water resources in a sustainability context.

II. CONCEPT OF ENVIRONMENTAL SUSTAINABILITY

Environmental sustainability is described as the responsible use and conservation of natural resources to guarantee long term wholeness, strength and viability of ecosystems to current and upcoming generations (Ziaul & Shuwei, 2023). It is one of the fundamental principles of sustainable development, together with economic and social sustainability, and insists on ensuring ecological balance and promoting human well-being (Mezentseva et al., 2024). One of the main principles of environmental sustainability is ecosystem services preservation of which are water purification, nutrient cycling, climate regulation, provision of habitats, and maintenance of biodiversity (Ali & Kamraju, 2023). Freshwater systems are also especially important to support such services, including rivers and lakes, wetlands and groundwater. Once the water quality has been affected by pollution, the ability of such systems to provide the necessary services is reduced and causes the ecological instability and decreased resistance to environmental factors (Bănăduc et al., 2022).

Sustainability of the environment is also generally understood within systems-based theories that interconnect human pressures to environmental change (Rabbi, 2025). The pressure-state-response (PSR) framework is one of the most used methods, and it can be viewed as having an impact on the environment by depicting that the anthropogenic pressures of industrial discharge, agricultural runoff, and urban wastewater change the environment and lead to a degradation of water quality and disruption of the ecosystem (An et al., 2025). The responses of the society, such as environmental policies, pollution control efforts, and monitoring initiatives, are then needed to decrease these impacts and reinstate sustainability (OECD, 2021). Environmental sustainability and water sustainability cannot be separated because the availability and quality of freshwater have a direct impact on the ecological health, food security, energy production, and human health. Sustainable water management entails ensuring that the amount and quality of water resources are sustained within ecological boundaries (Khondoker et al., 2023). Nonetheless, the increased pollution loads have jeopardized the sustainability of water by increasing the rate of eutrophication, encouraging toxic pollution, and disturbing aquatic food webs (Tiwari & Pal, 2022). Environmental sustainability has in the past few years extended its meaning to incorporate resilience and adaptive capacity in global change. The growth in population, climate change, and new types of contaminants are putting more strain on freshwater systems, which require an adaptive and integrated way of management. Solutions to the problems should therefore be both sustainable, incorporating environmental monitoring, technological innovation, policy implementation, and stakeholder involvement to mitigate the risk of pollution and increase the resilience of the ecosystem (Moore & Schindler, 2022)

III. SOURCES AND TYPES OF WATER POLLUTION

There are many diverse anthropogenic and natural sources of water pollution which cause the introduction of physical, chemical and biological pollutants into freshwater systems. The growing complexity and high volume of sources of pollution is an indicator of the growing demands of industrialization, agriculture, urbanization and population (Sharma et al., 2023). To determine the environmental effects of the water pollutants and design strategies of managing water pollution sustainably, it is important to know how they were contaminated and their classifications.

3.1 *Industrial Sources*

One of the greatest contributors of water pollution in the world is industrial activities. The effluents released by manufacturing plants, mining activities, oil refineries, and power stations usually have a high level of heavy metal, organic chemicals, acids and thermal contaminant (Morin-Crini et al., 2022). Different metals, including cadmium (Cd), lead (Pb), mercury (Hg), nickel (Ni), and chromium (Cr), are of particular concern since they are persistent, toxic, and can bioaccumulate in aquatic organisms (Edo et al., 2024). Poor treatment of industrial wastewater in most developing areas results in direct discharge of such contaminants into rivers and groundwater, which ultimately causes ecological degradation on a long-term basis (Singh et al., 2024).

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3.2 *Agricultural Sources*

Agricultural runoff represents a major non-point source of water pollution, particularly in intensively farmed regions. Overuse of fertilizers, pesticides and animal manure brings about nitrogen and phosphorus and agrochemicals to the system of surface and groundwater (Hussain et al., 2025). Enrichment of nutrients hastens the eutrophication process and leads to the appearance of algal blooms, which depletes the dissolved oxygen and disturbs the aquatic life cycles (Lan et al., 2024). The pesticide residues, such as herbicides and insecticides, are also dangerous because they are toxic to non-target organisms and may cause health problems to humans as a result of drinking contaminated drinking water (Ali, 2023).

3.3 *Domestic and Urban Wastewater*

The sources of organic matter, nutrients, pathogens, and emerging contaminants are found in domestic sewage and urban runoff in large amounts. Poorly treated or untreated municipal wastewater exposes bacteria, viruses, parasites, pharmaceuticals, personal care products, and household chemicals into the water bodies. UNESCO (2021) suggests that over 80 percent of all wastewater in the world is not adequately treated and released into the environment, especially in the low- and middle-income countries. Urban stormwater runoff also adds to the pollutants of the surface oils, heavy metals, plastics and sediments, which are predominantly found in densely populated zones with surfaces that are impermeable (Wang et al., 2022).

3.4 *Emerging Pollutants*

Over the past few years, emerging pollutants, such as pharmaceuticals, endocrine-disrupting compounds, microplastics, and nanomaterials have been gaining more and more attention (Imparato et al., 2022). These pollutants cannot be entirely eliminated using standard wastewater treatment mechanisms and can continue to exist in water bodies in low levels with long-term ecological consequences (Koul et al., 2022In particular, microplastics have been widely detected in freshwater systems, where they play a role of waterborne vectors of chemical and microorganisms toxicants and may pose a risk to aquatic life and food security (Li et al., 2018).

3.5 *Biological Contamination*

Biological pollution refers to intrusion of harmful micro-organisms like bacteria, viruses, protozoa and helminths into the waters. Poor sanitation, discharge of sewage and livestock rearing are directly associated with such form of pollution (Ali et al., 2025). Contaminated water is one of the causes of the leading causes of death among the population through waterborne diseases such as cholera, dysentery, and hepatitis and it is a serious matter of concern in the regions where individuals lack access to clean drinking water (WHO, 2023). In general, the issue of water pollution could be defined as the combination of different sources and types of contaminants, which in most cases, occur in the same water body (Ghosh et al., 2023). The cumulative and synergistic influences of the chemical, physical and biological pollutants make it difficult to manage the quality of water and this leads to more risk of degrading the environment in the long run. These various sources of pollution need combination and sustainable solutions, which encompass prevention of pollution, use of efficient treatment methods and sound regulatory controls (Zhang et al., 2023).

Table 1. Major Sources and Types of Water Pollution

Source Category	Key Pollutants	Main Activities	Environmental Impact
Industrial	Heavy metals, chemicals, dyes	Factories, mining	Toxicity, sediment contamination
Agricultural	Nitrates, phosphates, pesticides	Farming, livestock	Eutrophication, groundwater pollution
Domestic	Wastewater, detergents, pathogens	Households, sewage	Oxygen depletion, disease risks
Emerging Contaminants	Pharmaceuticals, microplastics	Hospitals, households	Unknown long-term effects

IV. ENVIRONMENTAL AND HUMAN HEALTH RISKS

Water pollution poses devastating effects to the health and the integrity of the environment due to the fact that the polluted water bodies serve as channels through which the toxic substances, pathogens and nutrients are conveyed through the food chain and ecosystems (Babuji et al., 2023). What makes these risks complex is that the pollutants are here to stay and the impact has been built over time and even further enhanced by the interaction of the pollutants with other biological systems. Such effects are essential in taking into account the macro-level impacts of the water contamination on the sustainability of environment (Singh et al., 2024).

4.1 Ecological and Environmental risks.

Aquatic ecosystems are quite sensitive to water quality changes. These chemical pollutants can be heavy metals, pesticides, and other organic pollutants that can disrupt the normal physiological processes of aquatic organisms, and their reproduction and survival rates (Zhang et al., 2023). The non-biodegradable nature of the heavy metals, including cadmium, lead and mercury, and possible bioaccumulation of these metals in sediments and biota make them particularly dangerous, as in the long-term, these substances will contaminate the ecosystem (Sharma et al., 2024). These chemicals can last decades,

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despite the sources of pollution being minimized, thus restricting the recovery of the ecosystems (Gnanasekaran & Raj, 2023). The agricultural runoff and wastewater discharge enhance nutrient enrichment in freshwater systems, which in turn increases eutrophication. Overload of nitrogen and phosphorus encourages algal growths that lower the amount of light penetration and dissolved oxygen leading to hypoxia or anoxia (Tiwari & Pal, 2022). This may result in fish kills, the death of benthic organisms, and species changes, which ultimately leads to a decrease in biodiversity and ecosystem resilience (Lan et al., 2024). The frequent occurrence of eutrophication undermines the stability of the ecosystem and undermines the ability of aquatic ecosystems to deliver the necessary services to the ecosystem. New pollutants, such as microplastics and the residues of pharmaceuticals, carry even greater risks to the ecology because of the ubiquitous nature and lack of long-term effects knowledge (Updhyay et al., 2025). Aquatic organisms can consume microplastics at different troic levels, which lead to physical injury, oxidative stress, and feeding behavioral changes. In addition, they are capable of transporting harmful substances and pathogens, increasing the flow of pollutants along aquatic food chains (Li et al., 2018).

4.2 Human Health Risks

Water degradation directly impacts on human health by exposing them to polluted drinking water, recreational water and eating contaminated aquatic food products (Sharma et al., 2022). One of the greatest causes of waterborne diseases is the presence of pathogenic microorganisms contained in untreated wastewater or poorly treated wastewater that includes cholera, dysentery, typhoid fever, and hepatitis (Narania & Kaur.,2026). Such illnesses are still one of the major concerns of the population in most developing countries, especially in areas where there is a lack of safe drinking water and sanitation facilities (WHO, 2023). The chemical pollution of water resources can be both acute and chronic. When drunk through water, a longterm exposure to heavy metals may lead to a neurological disorder, kidney damage, cardiovascular disorders, and even cancer. E.g., the severe public health crisis in a number of regions in the world has been associated with arsenic and lead contamination of the ground water (Sharma & Kumar, 2025). Likewise, the hormonal imbalance, reproductive disorders, and developmental outcomes have been linked to exposure to pesticide residues and endocrine-disrupting compounds (Jain et al., 2023). Toxic substances that have been bioaccumulated and biomagnified in fish and other aquatic creatures can increase the levels of toxic substances in human diets (Ray & Shaju, 2023). Societies in which people mostly consume fish as a main source of protein are at a high risk of them in particular, which underscores the convergence of environmental degradation and food security (Cojocaru et al., 2022).

4.3 Socioeconomic and Long-Term Sustainability Implications

In addition to the direct health effects of water pollution, it has high socioeconomic costs (Schwarzenbach et al., 2010). Higher health care expenses, fisheries and agricultural productivity, and clean water supplies make a contribution to economic instability and social unequalities (Shahid et al., 2024). Low-income and marginalized communities are usually at a disproportionate risk of these effects, which confirms the connection between environmental sustainability and social justice (UNEP, 2022). In general, environmental and human health hazards of water contamination negatively impact the robustness of the ecosystem, the wellbeing of a population, and sustainability in the long term (Akhai & Taneja, 2025). These risks need to be addressed on an integrated basis, which incorporates prevention of pollution, efficient water treatment, environmental monitoring as well as health risk evaluation as part of the sustainability agenda (Lako & Çomo, 2024).

V. ENVIRONMENTAL SUSTAINABILITY AND WATER POLLUTION.

Environmental sustainability and water pollution are fundamentally interconnected, as the condition of freshwater resources directly shapes the long-term stability of ecological and human systems (Bănăduc et al., 2022). Sustainable settings require healthy fresh water environments that can support the delivery of vital services elicited by fresh water like clean water, biodiversity, nutrient control and climate control (Ogwu et al., 2025). Once the water bodies are polluted, these processes are reduced, and the natural systems that support the health of people and the overall sustainability goals are compromised (UNEP, 2022). Water pollution is also a cause of a certain sustainability issue, which is called quality-induced scarcity of water where only freshwater cannot be consumed or reused even though it may seem that there is enough of it. This type of scarcity further stresses already strained areas, namely, arid and semi-arid ones (Ribeiro and Rosa, 2024). The climate change further increases these pressures, changing the temperature, precipitation, and hydrological regimes and altering the distribution and behavior of the pollutants and making the ecology more ecologically sensitive (Saxena, 2025).

Moreover, tainted fresh water systems reduce the advancement towards global sustainability initiatives especially those stipulated under the United Nations Sustainable Development Goals (SDGs). Water pollution obstructs targets related to clean water and sanitation, good health, food security, climate resilience, and ecosystem protection, while disproportionately affecting low-income and marginalized communities (United Nations, 2023).

Table 2. Interlinkages Between Water Pollution and Environmental Sustainability

Sustainability Dimension	How Water Pollution Impacts It	Example
Environmental	Loss of biodiversity, habitat degradation	Fish mortality, ecosystem imbalance
Social	Health risks, unsafe drinking water	Cholera, heavy metal poisoning

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Economic	Reduced crop yield, higher treatment costs	Costly desalination and filtration
Climate Resilience	Lower adaptive capacity	Increased algal blooms under warming

VI. SUSTAINABLE SOLUTIONS AND MITIGATION APPROACHES

Environmental sustainability in the situation of water pollution needs to be achieved through integrated, preventative, and science-based solutions that would mitigate pollution on the source and enhance resilience of the ecosystems. Modern solutions are focused on the shift to the non-separated, end of pipeline treatment to the ecological, technological, and governance-based holistic frameworks (Kumar et al., 2025).

6.1 Integrated Water Resources Management (IWRM)

The concept of Integrated Water Resources Management (IWRM) is one concept that is believed to be among the pillars of sustainable water governance. It promotes a combination of control of the water, land among other associated resources in order to realize the greatest social and economic benefits without diminishing the ecosystems. Cumulative pollution pressures can be reduced with the help of IWRM, which includes water quality goals in a basin-level plan, and enables stakeholder participation (Shemer et al., 2023).

6.2 Nature-Based Solutions (NBS)

The Nature-Based Solutions are affordable, sustainable solutions that can be used to stop the pollution of water. Constructed wetlands, riparian buffers, floodplain restoration and green roofs enhance natural purification processes, reduce the nutrient and sediment loads, and enhance the ecological stability (Barman et al., 2024). The solutions also provide co-benefits such as biodiversity conservation and climate adaptation, thus making them more sustainable than conventional engineered systems (Kabisch et al., 2017).

6.3 Sustainable Wastewater Treatment and Reuse

The existing wastewater treatment systems are energy-oriented, resource-recycling based, and based on the principles of a circular economy. The methods that can be used to remove nutrients, pathogens and new contaminants are membrane bioreactor, advanced oxidation process and anaerobic digestion. The freshwater resources are reduced by using treated wastewater in agriculture and industries and are used to allocate water in a sustainable manner (van der Hoek et al., 2016).

6.4 Pollution Prevention and Cleaner Production

Pollution prevention is also geared towards minimizing the contaminant process creation through optimization of process, substitution of dangerous materials, and wastes. Such cleaner production practices will contribute significantly to the reduction of the number of pollutants in the water bodies, the reduction of the cost of cleaning, and the eventual high level of environmental protection particularly in the industrial and agricultural industries (UNIDO, 2019).

6.5 Policy, Governance, and Stakeholder Engagement

Sustainable water pollution can only be achieved through proper governance. Strong institutional capacity in water, cross sectoral coordination and involve stakeholders should go hand in hand with regulatory frameworks that achieve standards in water quality and prevent discharges. Compliance and long-term stewardship of water resources are also reinforced through community involvement and the creation of social awareness (OECD, 2015).

6.6 Technological Innovation and Monitoring

Emerging digital technologies including smart sensors, real-time monitoring systems, and data-driven decision-support tools enhance early detection of pollution events and improve regulatory compliance. The innovations can be used along with modeling and risk-assessment to adjust the adaptive water management to the changing environment (Hong et al., 2021).

VII. ENVIRONMENTAL INDICATORS AND MONITORING TOOLS

Sustainable water management requires environmental indicators and monitoring tools, as they present credible information on the status of water quality, the trend of pollution as well as the ecological condition. These tools facilitate evidence-based planning, finding the points of pollution hotspots, and measuring the efficiency of environmental policies and mitigation strategies through the combination of chemical, biological, and technological testing.

7.1 Water Quality Indices (WQI)

Water Quality Indices (WQI) is an oversimplification of the sophisticated pool of water quality parameters, which combines the parameters of pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), nutrient and turbidity in a single score. WQI enable a complete comprehension of the drinkability, irrigation, and aquatic life of water, and thus they are usually used in the international monitoring programs due to their simplicity and reliability (Sutadian et al., 2016).

7.2 Heavy Metal Pollution Indices

The contamination of heavy metals is usually determined by the following indices: Contamination Factor (CF), Pollution Load Index (PLI), Geo-accumulation Index (Igeo), Enrichment Factor (EF), Contamination Degree (CD), and

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Potential Ecological Risk Index (PERI). The indices measure the pollution rates, the origins of contamination, and the ecological threats, especially in industrial and mining-related areas (Nasir et al., 2023).

7.3 Biological Indicators (Bioindicators)

Biological indicators like algae, macroinvertebrates, fish and aquatic plants provide delicate information about the well-being of the ecosystem as they are susceptible to the pollution and changes in habitat in the long run. The examples of such tools are the Biological Monitoring Working Party (BMWP) score and Macroinvertebrate Community Index (MCI), which might be used to evaluate the ecological state and obtain the complex analysis that would be impossible with the help of chemical parameters only (Muñoz et al., 2022).

7.4 Remote Sensing and GIS Technologies

The remote sensing and Geographic Information Systems (GIS) have revolutionized water monitoring as it has made it possible to analyse the water quality and land-use impacts on a large scale and in real time. These sensors (Landsat, Sentinel-2, and MODIS) present the data regarding chlorophyll-a, turbidity, suspended solids and temperature of the surface When used together with GIS, they help to map pollution, model the watershed, and predict ecological risks (Gholizadeh et al., 2016).

7.5 Microbiological Monitoring

Microbiological monitoring detects pathogenic microorganisms using culture-based and molecular techniques. PCR, qPCR, and next-generation sequencing (NGS), PCR, and qPCR are new methods that can quickly identify microbial contaminants to improve the recognition of the possible risk of waterborne diseases in the early stages and tracking the efficacy of treatment (Paruch, 2022).

7.6 Big Data, IoT, and Smart Monitoring Systems

Digital technologies, including the Internet of Things (IoT), artificial intelligence (AI), and big data analytics, support smart monitoring systems that operate on the principle of real-time monitoring of the water parameters.Cloud-based platforms process sensor data to enable predictive modeling, anomaly detection, and adaptive environmental management, enhancing early-warning capabilities and sustainability outcomes (Zhang et al., 2023).

VIII. FUTURE CHALLENGES AND RESEARCH GAPS

Although the issue of water pollution and its consequences on environmental sustainability have advanced considerably, there have been numerous challenges and knowledge gaps that have restricted the use of the current management techniques. These issues are critical in the realization of sustainable water resource management in the context of growing environmental, climatic and socioeconomic demands.

8.1 Climate Change and Intensifying Pollution Pressures

Climate change shifts the hydrology and increases the extreme events, which mobilize pollutants during floods and concentrate the contaminations during droughts. Nevertheless, the majority of literature continues to consider climate change and pollution independently, which shows that combined models are required (Van Vliet et al., 2023).

8.2 Emerging Contaminants

Freshwater systems are increasingly contaminated with pharmaceuticals, personal care products, nanomaterials, and antibiotic-resistant microbes though their long-term effects are not well comprehended (Gomes, 2024). They can be difficult to eliminate by the current treatment technologies, and better risk assessment frameworks are required (aus der Beek et al., 2016).

8.3 Data Gaps in Developing Regions

Limited monitoring infrastructure, insufficient funding, and inconsistent datasets restrict accurate water quality assessment in developing regions. This geographic imbalance reduces global applicability of sustainability research and underscores the need for standardized monitoring and capacity-building (Lukhabi et al., 2023).

8.4 Lack of Interdisciplinary Integration

Numerous researches concentrate on the ecological or chemical components, and do not correlate pollution with social-economic or health outcomes of people. More successful sustainability policies require holistic and cross-disciplinary directions (Fuller et al., 2022).

8.5 Governance and Policy Implementation Gaps

The effectiveness of pollution control is decreased by weak enforcement, disjointed institutions and inadequate policy appraisal. The governance structure needs to be reinforced and the stakeholders involved in order to guarantee a long-term success (Steinebach, 2019).

8.6 Technological and Methodological Limitations

The modern monitoring tools offer potential new opportunities, yet they are too expensive, and demand that data are combined, which is not easily available in areas that have limited resources. The difficulty in the future would be concentrating on low cost and scalable technologies (Vasavi et al., 2025).

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IX. CONCLUSIONS

One of the biggest obstacles to environmental sustainability is water pollution which pollute the ecosystem, reduces biodiversity, and availability of safe freshwater. The industrial, agricultural, and domestic contaminants along with the emerging contaminants lead to the further worsening of the water scarcity and the population health and food security is threatened. Sustainable development preventive measures should be combined with solutions such as solutions in nature, improved treatment of wastewater, clean production and proper environmental governance. In order to improve the safety of the water resources and long-term ecology, the monitoring systems need to be improved, and the gaps in the research, in particular, in the developing regions, should be closed.

REFERENCES

[1] Ali, I. M. (2023). The harmful effects of pesticides on the environment and human health: A review. *Diyala Agricultural Sciences Journal, 15*(1), 114–126. https://doi.org/10.52951/dasj.23150112

[2] Ali, M. A., & Kamraju, M. (2023). Ecosystem services. In *Earth and environmental sciences library* (pp. 51–63). https://doi.org/10.1007/978-3-031-46720-2_4

[3] Ali, N. M., Khan, M. K., Mazhar, B., & Mustafa, M. (2025). Impact of water pollution on waterborne infections: Emphasizing microbial contamination and associated health hazards in humans. *Discover Water, 5*(1). https://doi.org/10.1007/s43832-025-00198-x

[4] An, R., Hu, X., & Sun, S. (2025). The nonlinear relationship between urbanization and ecological environment in China under the PSR (Pressure-State-Response) Model: Inflection point identification and policy pathways. *Sustainability, 17*(10), 4450. https://doi.org/10.3390/su17104450

[5] aus der Beek, T., et al. (2016). Pharmaceuticals in the environment—Global occurrences and perspectives. *Environmental Toxicology and Chemistry, 35*(4), 823–835. https://doi.org/10.1002/etc.3339

[6] Babuji, P., Thirumalaisamy, S., Duraisamy, K., & Periyasamy, G. (2023). Human health risks due to exposure to water pollution: A review. *Water, 15*(14), 2532. https://doi.org/10.3390/w15142532

[7] Bănăduc, D., Simić, V., Cianfaglione, K., Barinova, S., Afanasyev, S., Öktener, A., McCall, G., Simić, S., & Curtean-Bănăduc, A. (2022). Freshwater as a sustainable resource and generator of secondary resources in the 21st century: Stressors, threats, risks, management and protection strategies, and conservation approaches. *International Journal of Environmental Research and Public Health, 19*(24), 16570. https://doi.org/10.3390/ijerph192416570

[8] Barman, A., Rajak, F., & Jha, R. (2024). Integrating wetlands as nature-based solutions for sustainable built environments. *Engineering, Technology & Applied Science Research, 14*(6), 18670–18680. https://doi.org/10.48084/etasr.8923

[9] Batuwita, S., Udugampala, S., & Edirisinghe, U. (2022). Factors affecting habitat selection of freshwater fishes of Sri Lanka: A review. *Apple Academic Press eBooks*, 215–276. https://doi.org/10.1201/9781003277125-11

[10] Bunclark, L., & De La Vega Hernández, I. M. (2022). Scientific mapping of research on nature-based solutions for sustainable water management. *Water Resources Management, 36*(12), 4499–4516. https://doi.org/10.1007/s11269-022-03242-w

[11] Cojocaru, A. L., Liu, Y., Smith, M. D., Akpalu, W., Chávez, C., Dey, M. M., Dresdner, J., Kahui, V., Pincinato, R. B. M., & Tran, N. (2022). The "Seafood" system: Aquatic foods, food security, and the Global South. *Review of Environmental Economics and Policy, 16*(2), 306–326. https://doi.org/10.1086/721032

[12] Edo, G. I., Samuel, P. O., Oloni, G. O., Ezekiel, G. O., Ikpekoro, V. O., Obasohan, P., Ongulu, J., Otunuya, C. F., Opiti, A. R., Ajakaye, R. S., Essaghah, A. E. A., & Agbo, J. J. (2024). Environmental persistence, bioaccumulation, and ecotoxicology of heavy metals. *Chemistry and Ecology, 40*(3), 322–349. https://doi.org/10.1080/02757540.2024.2306839

[13] Fuller, R., Landrigan, P. J., Balakrishnan, K., Bathan, G., Bose-O'Reilly, S., Brauer, M., Caravanos, J., Chiles, T., Cohen, A., Corra, L., Cropper, M., Ferraro, G., Hanna, J., Hanrahan, D., Hu, H., Hunter, D., Janata, G., Kupka, R., Lanphear, B., . . . Yan, C. (2022). Pollution and health: A progress update. *The Lancet Planetary Health, 6*(6), e535–e547. https://doi.org/10.1016/S2542-5196(22)00090-0

[14] Gholizadeh, M. H., Melesse, A. M., & Reddi, L. (2016). A comprehensive review on water quality parameters estimation using remote sensing techniques. *Sensors, 16*(8), 1298. https://doi.org/10.3390/s16081298

[15] Ghosh, D., Chaudhary, S., Sarkar, S., & Singh, P. (2023). Water pollution in rural areas: Primary sources, associated health issues, and remedies. In *Elsevier eBooks* (pp. 15–28). https://doi.org/10.1016/B978-0-443-18778-0.00017-9

[16] Gnanasekaran, S., & Raj, S. A. (2023). Heavy metal bioaccumulation in sediment and benthic biota. In *IntechOpen eBooks*. https://doi.org/10.5772/intechopen.110015

[17] Gomes, M. P. (2024). The convergence of antibiotic contamination, resistance, and climate dynamics in freshwater ecosystems. *Water, 16*(18), 2606. https://doi.org/10.3390/w16182606

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[18] Hong, J., Lee, S., Lee, G., Yang, D., Bae, J. H., Kim, J., Kim, K., & Lim, K. J. (2021). Comparison of machine learning algorithms for discharge prediction of multipurpose dam. *Water, 13*(23), 3369. https://doi.org/10.3390/w13233369

[19] Imparato, C., Bifulco, A., Silvestri, B., & Vitiello, G. (2022). Recent advances in endocrine disrupting compounds degradation through metal oxide-based nanomaterials. *Catalysts, 12*(3), 289. https://doi.org/10.3390/catal12030289

[20] Jain, D., Verma, R. K., Sharma, V., Kaur, A., Rai, A. R., Kumari, P., Nagar, V., Sankhla, M. S., & Parihar, K. (2023). Associations between high levels pesticide and adverse reproductive outcomes in females: A comprehensive review. *Materials Today Proceedings, 95*, 50–60. https://doi.org/10.1016/j.matpr.2023.06.449

[21] Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (2017). *Nature-based solutions to climate change adaptation in urban areas*. Springer. https://doi.org/10.1007/978-3-319-56091-5

[22] Khan, A. S., & Srivastava, P. (2025). Bridging the gap between environmental justice and ecosystem management: A comprehensive framework for equitable sustainability. In *Green energy and technology* (pp. 295–307). https://doi.org/10.1007/978-981-96-3993-9_14

[23] Khondoker, M., Mandal, S., Gurav, R., & Hwang, S. (2023). Freshwater shortage, salinity increase, and global food production: A need for sustainable irrigation water desalination—A scoping review. *Earth, 4*(2), 223–240. https://doi.org/10.3390/earth4020012

[24] Koul, B., Yadav, D., Singh, S., Kumar, M., & Song, M. (2022). Insights into the domestic wastewater treatment (DWWT) regimes: A review. *Water, 14*(21), 3542. https://doi.org/10.3390/w14213542

[25] Kumar, P., Singh, J., & Kaur, A. (2025). Ecosystem resilience and water resources: A synergistic approach. In *Climate change management* (pp. 99–116). https://doi.org/10.1007/978-3-031-77957-2_7

[26] Lako, A., & Çomo, E. (2024). Sustainable water management: An integrated approach to solving the problems of wastewater treatment. *Qubahan Academic Journal, 4*(1), 91–100. https://doi.org/10.58429/qaj.v4n1a267

[27] Lan, J., Liu, P., Hu, X., & Zhu, S. (2024). Harmful algal blooms in eutrophic marine environments: Causes, monitoring, and treatment. *Water, 16*(17), 2525. https://doi.org/10.3390/w16172525

[28] Li, J., Liu, H., & Chen, J. P. (2018). Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for detection. *Water Research, 209*, 117921. https://doi.org/10.1016/j.watres.2021.117921

[29] Lin, L., Yang, H., & Xu, X. (2022). Effects of water pollution on human health and disease heterogeneity: A review. *Frontiers in Environmental Science, 10*. https://doi.org/10.3389/fenvs.2022.880246

[30] Lukhabi, D. K., Mensah, P. K., Asare, N. K., Pulumuka-Kamanga, T., & Ouma, K. O. (2023). Adapted water quality indices: Limitations and potential for water quality monitoring in Africa. *Water, 15*(9), 1736. https://doi.org/10.3390/w15091736

[31] Mezentseva, E., Baysaeva, M., & Fayzullaev, N. (2024). The impact of sustainable development on economic growth: Balancing environmental, social and economic factors. *КиберЛенинка*. https://cyberleninka.ru/article/n/the-impact-of-sustainable-development-on-economic-growth-balancing-environmental-social-and-economic-factors

[32] Moore, J. W., & Schindler, D. E. (2022). Getting ahead of climate change for ecological adaptation and resilience. *Science, 376*(6600), 1421–1426. https://doi.org/10.1126/science.abo3608

[33] Morin-Crini, N., Lichtfouse, E., Liu, G., Balaram, V., Ribeiro, A. R. L., Lu, Z., Stock, F., Carmona, E., Teixeira, M. R., Picos-Corrales, L. A., Moreno-Piraján, J. C., Giraldo, L., Li, C., Pandey, A., Hocquet, D., Torri, G., & Crini, G. (2022). Worldwide cases of water pollution by emerging contaminants: A review. *Environmental Chemistry Letters, 20*(4), 2311–2338. https://doi.org/10.1007/s10311-022-01447-4

[34] Muñoz, A. H. S., Aguilar, A. G., Castrejón, U. E. R., Schüth, C., & Luna, B. N. (2022). Bioindicators and biomonitoring: Review of methodologies applied in water bodies and use during the COVID-19 pandemic. *Acta Universitaria, 32*. https://doi.org/10.15174/au.2022.3388

[35] Narania, P., & Kaur, T. (2026). Waterborne diseases. In *Biotechnology innovations for a sustainable future: Integrating clean energy, life on the planet, clean water, and climate action* (pp. 1569–1590). Springer Nature Singapore.

[36] Nasir, M. J., Wahab, A., Ayaz, T., Khan, S., Khan, A. Z., & Lei, M. (2023). Assessment of heavy metal pollution using contamination factor, pollution load index, and geoaccumulation index in Kalpani River sediments, Pakistan. *Arabian Journal of Geosciences, 16*(2). https://doi.org/10.1007/s12517-023-11231-5

[37] Nasir, M. J., Wahab, A., Ayaz, T., Khan, S., Khan, A. Z., & Lei, M. (2023). Assessment of heavy metal pollution using contamination factor, pollution load index, and geoaccumulation index in Kalpani River sediments, Pakistan. *Arabian Journal of Geosciences, 16*(2). https://doi.org/10.1007/s12517-023-11231-5

[38] Nasr, M. (2022). Aquatic pollution and wastewater treatment system. In *Elsevier eBooks* (pp. 23–37). https://doi.org/10.1016/B978-0-12-824270-4.00006-7

[39] Nti, E. K., Cobbina, S. J., Attafuah, E. E., Senanu, L. D., Amenyeku, G., Gyan, M. A., Forson, D., & Safo, A. (2023). Water pollution control and revitalization using advanced technologies: Uncovering artificial intelligence options towards environmental health protection, sustainability and water security. *Heliyon, 9*(7), e18170. https://doi.org/10.1016/j.heliyon.2023.e18170

Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)

[40] OECD. (2015). *Stakeholder engagement for inclusive water governance*. Organisation for Economic Co-operation and Development.
[41] OECD. (2021). *OECD environmental performance reviews: Water and sustainability*. Organisation for Economic Co-operation and Development.
[42] Ogwu, M. C., Ojo, A. O., & Alaka, A. C. (2025). Biodiversity and human health: The interconnections of species loss and ecosystem services. In *Environmental science and engineering* (pp. 113–141). https://doi.org/10.1007/978-3-031-81966-7_5
[43] Paruch, L. (2022). Molecular diagnostic tools applied for assessing microbial water quality. *International Journal of Environmental Research and Public Health, 19*(9), 5128. https://doi.org/10.3390/ijerph19095128
[44] Rabbi, M. F. (2025). A dynamic systems approach to integrated sustainability: Synthesizing theory and modeling through the synergistic resilience framework. *Sustainability, 17*(11), 4878. https://doi.org/10.3390/su17114878
[45] Ray, S., & Shaju, S. T. (2023). Bioaccumulation of pesticides in fish resulting toxicities in humans through food chain and forensic aspects. *Environmental Analysis Health and Toxicology, 38*(3), e2023017. https://doi.org/10.5620/eaht.2023017
[46] Ribeiro, R., & Rosa, M. (2024). The role of scenario-building in risk assessment and decision-making on urban water reuse. *Water, 16*(18), 2674. https://doi.org/10.3390/w16182674
[47] Saxena, V. (2025). Water quality, air pollution, and climate change: Investigating the environmental impacts of industrialization and urbanization. *Water, Air, & Soil Pollution, 236*(2). https://doi.org/10.1007/s11270-024-07702-4
[48] Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., Von Gunten, U., & Wehrli, B. (2010). Global water pollution and human health. *Annual Review of Environment and Resources, 35*(1), 109–136. https://doi.org/10.1146/annurev-environ-100809-125342
[49] Shahid, T. A., Pinjaman, S. B., Amir, H., Bilal, K., & Rehman, A. U. (2024). Assessing the nexus between health expenditure, food production and water quality: Policymaking for achieving sustainable development goals. *The Critical Review of Social Sciences Studies, 2*(2), 1168–1197. https://doi.org/10.59075/daymca07
[50] Sharma, A., Grewal, A. S., Sharma, D., & Srivastav, A. L. (2022). Heavy metal contamination in water: Consequences on human health and environment. In *Elsevier eBooks* (pp. 39–52). https://doi.org/10.1016/B978-0-323-95919-3.00015-X
[51] Sharma, K., Rajan, S., & Nayak, S. K. (2023). Water pollution: Primary sources and associated human health hazards with special emphasis on rural areas. In *Elsevier eBooks* (pp. 3–14). https://doi.org/10.1016/B978-0-443-18778-0.00014-3
[52] Sharma, M., & Kumar, P. (2025). Environmental sources of heavy metals and their impacts on human health. In *Elsevier eBooks* (pp. 317–326). https://doi.org/10.1016/B978-0-443-36575-1.00030-3
[53] Sharma, M., Kant, R., Sharma, A. K., & Sharma, A. K. (2024). Exploring the impact of heavy metals toxicity in the aquatic ecosystem. *International Journal of Energy and Water Resources, 9*(1), 267–280. https://doi.org/10.1007/s42108-024-00284-1
[54] Singh, P. K., Kumar, U., Kumar, I., Dwivedi, A., Singh, P., Mishra, S., Seth, C. S., & Sharma, R. K. (2024). Critical review on toxic contaminants in surface water ecosystem: Sources, monitoring, and its impact on human health. *Environmental Science and Pollution Research, 31*(45), 56428–56462. https://doi.org/10.1007/s11356-024-34932-0
[55] Steinebach, Y. (2019). Instrument choice, implementation structures, and the effectiveness of environmental policies: A cross-national analysis. *Regulation & Governance, 16*(1), 225–242. https://doi.org/10.1111/rego.12297
[56] Sutadian, A. D., Muttil, N., Yilmaz, A. G., & Perera, B. (2016). Development of river water quality indices: A review. *Environmental Monitoring and Assessment, 188*, 1–26. https://doi.org/10.1007/s10661-015-5050-0
[57] Tiwari, A. K., & Pal, D. B. (2022). Nutrients contamination and eutrophication in the river ecosystem. In *Elsevier eBooks* (pp. 203–216). https://doi.org/10.1016/B978-0-323-85045-2.00001-7
[58] UNEP. (2022). *State of the world's waters 2022: Water quality and sustainability*. United Nations Environment Programme.
[59] UNESCO. (2021). *UN World Water Development Report 2021: Valuing water*. United Nations Educational, Scientific and Cultural Organization.
[60] UNIDO. (2019). *Industrial wastewater management and cleaner production*. United Nations Industrial Development Organization.
[61] United Nations. (2023). *The sustainable development goals report 2023*.
[62] Updhyay, D., Shukla, K., Mishra, A., & Shukla, S. (2025). Freshwater phytoplankton: The significant ecosystems services provider in aquatic environment. In *Green energy and technology* (pp. 179–196). https://doi.org/10.1007/978-981-96-3993-9_9
[63] Vahidi, E., Navarro, J., & Zhao, F. (2016). An initial life cycle assessment of rare earth oxides production from ion-adsorption clays. *Resources, Conservation and Recycling, 113*, 1–11. https://doi.org/10.1016/j.resconrec.2016.05.006
[64] Van Vliet, M. T. H., Thorslund, J., Strokal, M., Hofstra, N., Flörke, M., Macedo, H. E., Nkwasa, A., Tang, T., Kaushal, S. S., Kumar, R., Van Griensven, A., Bouwman, L., & Mosley, L. M. (2023). Global river water quality under climate

Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)

change and hydroclimatic extremes. *Nature Reviews Earth & Environment, 4*(10), 687–702. https://doi.org/10.1038/s43017-023-00472-3

[65] Vasavi, S., Anandaraja, N., Murugan, P., Latha, & Selvi, R. P. (2025). Challenges and strategies of resource poor farmers in adoption of innovative farming technologies: A comprehensive review. *Agricultural Systems, 227*, 104355. https://doi.org/10.1016/j.agsy.2025.104355

[66] Wang, Y., Yin, H., Liu, Z., & Wang, X. (2022). A systematic review of the scientific literature on pollutant removal from stormwater runoff from vacant urban lands. *Sustainability, 14*(19), 12906. https://doi.org/10.3390/su141912906

[67] WHO. (2023). *Global report on water, sanitation and hygiene*. World Health Organization.

[68] Zhang, P., Yang, M., Lan, J., Huang, Y., Zhang, J., Huang, S., Yang, Y., & Ru, J. (2023). Water quality degradation due to heavy metal contamination: Health impacts and eco-friendly approaches for heavy metal remediation. *Toxics, 11*(10), 828. https://doi.org/10.3390/toxics11100828

[69] Ziaul, I. M., & Shuwei, W. (2023). Environmental sustainability: A major component of sustainable development. *International Journal of Environmental Sustainability and Social Science, 4*(2), 620–627. https://doi.org/10.38142/ijesss.v4i2.296

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