

Research on the Current Status of Global Water Pollution and Corresponding Countermeasures

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Abstract. Water pollution is a pressing global issue that threatens ecosystems, human health, and economic stability. This paper aims to explore the current state of global water resources, highlighting their limited availability and uneven distribution. It identifies key causes of water pollution, including industrial waste, agricultural runoff, and untreated urban wastewater, alongside newer challenges posed by emerging pollutants like microplastics and pharmaceuticals. Case studies illustrate the severe pollution problems in Pakistan and the successes achieved in China through stricter regulations and improved treatment facilities. The consequences of water pollution include loss of biodiversity, habitat degradation, and significant economic costs, particularly in agriculture, fisheries, and water treatment. Addressing these issues will require a combination of advanced treatment technologies, stronger environmental regulations, and public awareness campaigns. Sustainable practices and international cooperation are critical to reducing pollution and safeguarding water resources. This paper highlights the importance of comprehensive strategies to manage and reduce water pollution.

Keywords: Water resources; water pollution; water management.

1. Introduction

Water, the cornerstone of life on Earth, plays a vital role in sustaining human civilization and natural ecosystems. It is integral to agriculture, industrial processes, and daily life, serving as the foundation for economic prosperity and societal advancement. However, the relentless pursuit of economic growth and technological advancement has led to the widespread contamination of water bodies, posing a significant threat to human health, biodiversity, and the environment. Therefore, the urgent need to address water pollution cannot be overstated; it is a matter of global significance that demands immediate and sustained action.

The current landscape of water pollution control efforts is marked by a complex interplay of technological advancements, regulatory frameworks, and public engagement. While advancements in water treatment technologies have made significant strides in removing contaminants from water, the challenge lies in their widespread implementation and accessibility. Similarly, the enforcement of environmental regulations is crucial in preventing pollution at its source, yet variations in legal frameworks and enforcement capabilities across countries can hinder effective pollution control. Furthermore, public awareness and participation are indispensable in fostering a culture of environmental stewardship and promoting sustainable water management practices.

This paper aims to underscore the paramount importance of addressing water pollution and to contribute to the ongoing discourse on water resource management. We commence by providing a comprehensive overview of the global status of water resources and the prevalence of water pollution. This foundation sets the stage for an in-depth exploration of the primary factors contributing to water pollution, including industrial discharge, agricultural runoff, and urban wastewater. Additionally, we analyze the water pollution control strategies employed by selected countries, examining their successes and challenges. By synthesizing these insights, we hope to illuminate pathways for effective water pollution mitigation and foster a deeper understanding of the multifaceted nature of this global challenge.

2. Global Water Resources and Current Situation of Water Pollution

2.1. Global Water Resources

Water is the most vital element among the natural resources, and is critical for the survival of all living organisms including human, food production, and economic development [1]. Current estimates suggest that Earth's hydrosphere contains approximately 1386 million cubic kilometers of water, with 97.5% being saline and only 2.5% being freshwater. The majority of this freshwater (68.7%) is in the form of ice and permanent snow cover in the Antarctic, the Arctic, and mountainous regions. Following that, 29.9% exists as freshwater groundwaters. A mere 0.26% of the total freshwater on Earth is concentrated in lakes, reservoirs, and river systems, which are most accessible for our economic needs and absolutely vital for water ecosystems [2].

The distribution of freshwater is highly uneven across the globe, creating disparities in access and availability. For instance, South America benefits from abundant water resources, primarily due to the Amazon basin, which holds one of the largest reserves of freshwater globally. This vast network of rivers and tributaries supports diverse ecosystems and provides a critical water source for the region's populations and industries. In contrast, arid regions such as the Middle East and parts of sub-Saharan Africa face chronic water shortages, where limited rainfall and high evaporation rates exacerbate the scarcity. These areas often depend heavily on groundwater, much of which is being depleted faster than it can be replenished, intensifying the challenge of ensuring a sustainable supply.

Even in areas with abundant water resources, seasonal and geographical differences can pose challenges. For example, monsoon-dependent areas may experience significant flooding during wet seasons, leading to water management challenges, while prolonged dry periods can result in severe droughts that strain agricultural activities and local water supplies. Additionally, geographic factors such as the remoteness of water sources or uneven infrastructure development can leave certain communities without reliable access, despite being located in water-abundant areas. These disparities underscore the critical importance of effective water management strategies to address both shortages and distribution challenges, ensuring that freshwater resources are utilized efficiently and equitably.

2.2. Current Situation of Water Pollution

Water pollution remains a pressing global issue, driven by sources such as industrial discharges, agricultural runoff, and untreated urban wastewater. In developing nations, a significant proportion of wastewater—often as much as 80%—is released directly into water bodies without treatment. In Pakistan, surface runoff through cities and pastures, septic tank and sewage disposal system leaks, overloaded sewage treatment plants, disposal systems, and raw sewage deep well injection are the main causes of bacterial contamination of surface and groundwater [3]. In contrast, developed nations face pollution challenges related to agricultural chemicals, microplastics, and emerging contaminants, which complicate water quality management.

The effects of pollution are extensive. Biodiversity loss, habitat destruction, and eutrophication are commonly observed in polluted ecosystems, with harmful algal blooms creating oxygen-deprived zones in many water bodies. Our environment's geochemical cycles are being impacted, either directly or indirectly, by the various heavy metals that are released from businesses [4]. For humans, polluted water contributes to diseases such as diarrhea and cholera, disproportionately impacting vulnerable populations in areas with inadequate water treatment infrastructure. The majority of the villages now suffer from water-borne (pollution-related) illnesses, highlighting the obvious negative effects of pollution on health [5].

Addressing water pollution requires a multifaceted approach that includes technological advancements, regulatory enforcement, and public engagement. Firstly, technological advancements in wastewater treatment are vital. By improving processes like oxidation and membrane filtration, contaminants can be efficiently removed before discharge, aiding compliance with water quality standards and protecting ecosystems. Secondly, regulatory enforcement is crucial. Governments must establish and enforce strict laws limiting pollutants' discharge, ensuring regular monitoring, and

imposing penalties for violations. This framework discourages polluting behaviors and promotes responsible water management. Lastly, public engagement is indispensable. Raising awareness encourages eco-friendly practices and supports water preservation initiatives. Community involvement and feedback strengthen decision-making, fostering a comprehensive approach to pollution reduction.

3. Sources and Management of Water Pollution

3.1. Traditional Causes of Water Pollution

Traditional causes of water pollution stem largely from industrial, agricultural, and urban activities. Water is polluted by many factors among which industrial wastes are the most important [6]. Factories often discharge untreated or inadequately treated wastewater containing toxic substances such as heavy metals (e.g., mercury, lead), persistent organic pollutants, and hydrocarbons. These contaminants degrade water quality and pose severe risks to aquatic ecosystems and human health. Numerous hazardous chemicals from industries kill aquatic life by interfering with the physiological systems of all living things, including plants and animals [4].

Agriculture is another significant contributor, primarily through nonpoint source pollution. Runoff from farmlands often carries fertilizers rich in nitrogen and phosphorus, leading to nutrient pollution in nearby water bodies. This runoff also includes pesticides and herbicides that contaminate water systems and disrupt ecosystems. Additionally, large-scale livestock farming produces enormous quantities of animal waste, which, if improperly managed, can seep into rivers and groundwater. Since the 1960s, agricultural NPS contamination of surface and ground water by pesticides and nutrients has been recognized as a significant issue in the United States [7].

Urban areas add to the burden through domestic wastewater and stormwater runoff. In cities without adequate sewage treatment facilities, untreated water containing pathogens, detergents, and organic waste is often released directly into water bodies. Moreover, urban stormwater runoff transports oils, trash, and other pollutants from impervious surfaces like roads and parking lots into nearby rivers and lakes. For instance, it is predicted that the yearly pollutant load of some pollutants (such as SS, Pb, Zn, Cu, etc.) in Malaysian cities may account for up to 50% of the total pollution load that enters the rivers [8].

3.2. Emerging Pollutants

Synthetic or naturally occurring compounds that are not frequently monitored in the environment but have the potential to do so and have known or suspected detrimental impacts on the environment and/or human health are known as emerging pollutants (EPs) [9]. Emerging pollutants, especially synthetic pollutants, have garnered increasing attention in recent years as they present new challenges to water quality. These pollutants include substances like microplastics, pharmaceuticals, personal care products, and industrial chemicals such as per- and polyfluoroalkyl substances (PFAS). Unlike traditional pollutants, emerging contaminants are often found in trace amounts but can still have significant ecological and health impacts.

Microplastics, for example, are tiny plastic particles that result from the breakdown of larger plastic debris, synthetic fibers shed from textiles during washing, and consumer products such as exfoliants and toothpaste. These particles have become ubiquitous, contaminating almost every water system, from vast oceans to remote freshwater lakes, and even Arctic ice. Their small size allows them to evade filtration systems, making them nearly impossible to remove once they enter the environment. Microplastics pose a severe threat to aquatic organisms, as they are often ingested, causing physical harm such as intestinal blockages or exposure to toxic substances that leach from the plastics. Additionally, these particles serve as carriers for other environmental toxins, such as persistent organic pollutants (POPs) and heavy metals, which adhere to their surfaces. Through the food chain, microplastics and their associated toxins can accumulate in larger organisms, including

humans, raising concerns about long-term health impacts. Their widespread presence highlights the urgent need for policies to reduce plastic waste and innovative methods to mitigate their spread.

3.3. Environmental and Economic Impacts of Water Pollution

The consequences of water pollution extend far beyond the immediate degradation of water quality. Environmental impacts are often the most visible, with pollution causing habitat destruction and loss of biodiversity. Industrial waste will reduce the light passing capacity of water bodies. Because of this, the microorganisms in the water body will not be able to carry out their regular task of cleaning the surroundings [4]. For example, nutrient pollution from agricultural runoff has led to widespread eutrophication, creating “dead zones” in major water bodies like the Gulf of Mexico and the Baltic Sea. These zones, deprived of oxygen, can no longer support aquatic life, leading to the collapse of local ecosystems.

On an economic level, water pollution imposes significant costs on societies. Because they graze on contaminated grasses or grazing meadows and drink contaminated water, livestock have been afflicted with a number of ailments. The villagers indicated that during the previous five years, around 149 animals perished as a result of drinking contaminated water [5]. Polluted water bodies are less useful for agriculture, fishing, and recreation. Contaminated irrigation water can reduce crop yields or render produce unsafe for consumption. Similarly, fisheries suffer from reduced stocks, as polluted habitats lead to declines in fish populations. This directly impacts food security and the livelihoods of communities dependent on fishing and farming.

Treating polluted water to make it safe for consumption is a costly and resource-intensive process for both governments and private entities. The infrastructure required for advanced water treatment technologies, coupled with the energy and chemical inputs, often makes this effort financially burdensome. In many cases, the cost of restoring polluted water bodies far exceeds the expenses that would have been incurred by implementing preventative measures, such as stricter regulations or sustainable practices. Beyond treatment costs, waterborne diseases caused by exposure to contaminated water impose additional economic burdens. These include healthcare expenditures, loss of productivity, and impacts on local economies reliant on agriculture or fisheries. Together, these factors underline the importance of proactive pollution prevention strategies to reduce long-term costs and ensure sustainable water management.

3.4. Case Studies in Water Pollution Management

Pakistan's water pollution crisis exemplifies the consequences of inadequate water management and monitoring, ranking poorly at 80th out of 122 nations for drinking water quality. The contamination of both surface and groundwater with coliforms, toxic metals, and pesticides frequently violates WHO standards, largely due to human activities such as improper waste disposal and excessive use of agrochemicals. Fertilizers and insecticides used on Pakistani croplands combine with irrigation water, which seeps into the soil and eventually reaches natural water supplies. Flooding during monsoon seasons and high agricultural runoff exacerbate the issue [3]. These pollutants lead to significant public health issues, highlighting the urgent need for improved water quality control measures.

On the other hand, China has demonstrated notable success in combating water pollution through extensive efforts and investment. The country has implemented stringent environmental regulations and advanced wastewater treatment technologies, leading to substantial improvements in water quality. These measures have not only restored ecosystems but also safeguarded public health by reducing waterborne diseases. The proactive approach to water management has set a precedent for effective pollution control strategies globally. Domestic sewage treatment ratios in China climbed to above 90% in both urban and rural areas between 2001 and 2017 as the number of WWTPs expanded [10]. The successful experience of China in controlling water pollution shows that a good water resources management system requires strict regulation and substantial investment in water pollution treatment facilities.

4. Future Perspectives and Strategies for Water Pollution Control

Addressing water pollution in the future will require a combination of innovative technologies, stronger regulations, and increased public awareness. Advanced treatment methods, such as nanofiltration and bioremediation, offer effective solutions for removing both traditional and emerging pollutants like microplastics and pharmaceuticals. To provide focused, high-quality monitoring data on the concentration of the most pertinent EPs for risk assessment throughout the river basins, a novel mechanism is required [9]. Real-time monitoring systems, powered by sensors and artificial intelligence, will help manage water quality more efficiently, enabling quicker responses to pollution events and optimizing treatment processes.

Stronger environmental regulations and enforcement are essential for reducing water contamination. Stricter pollution limits for industries, along with incentives for adopting cleaner technologies, will be key to reducing the discharge of harmful substances. Currently, the DOE enforces roughly 16 of 43 sets of rules and orders to prevent environmental harm, specifically for different types of pollution, under the EQA, 1974 [8]. Additionally, international cooperation is necessary, especially for managing shared water resources and addressing transboundary pollution.

Public engagement will also be crucial in tackling nonpoint source pollution, which is often driven by everyday human activities. Raising awareness about the importance of sustainable farming practices, proper waste disposal, and water conservation can help reduce pollution at its source.

Finally, adapting to the impacts of climate change is vital. Increased flooding and rising temperatures will exacerbate pollution challenges, requiring infrastructure designed to withstand extreme weather events, as well as the restoration of natural filtration systems like wetlands. Collaboration across sectors—governments, industries, scientists, and local communities—will ensure the successful implementation of water pollution management strategies at both local and global levels.

5. Conclusion

This paper has explored the causes of water pollution, addressing both traditional pollutants such as industrial discharge and agricultural runoff, as well as emerging pollutants like microplastics and pharmaceuticals. In addition, this article analyzes water pollution management work in different regions as examples, highlighting the successes and persistent challenges. The findings reveal that while significant progress has been made in some regions, water pollution remains a complex and multifaceted issue that requires continuous innovation and international cooperation.

By examining the current state of water pollution and its causes, this paper contributes to a deeper understanding of the problem, emphasizing the need for more effective management strategies and increased public awareness. Ultimately, it is hoped that this work will help inform policies and actions that can more effectively mitigate water pollution, protect vital water resources, and ensure a sustainable future for generations to come.

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