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# Water Contaminants: Environmental Impact, Health Consequences, and Sustainable Remediation Approaches- A review

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**Abstract:**
The world confronts unparalleled environmental concerns, with water contamination being a significant worldwide issue that presents substantial risks to ecosystems and human health. This review consolidates findings from several studies published in major electronic databases, including PubMed and Google Scholar. Agricultural, industrial, municipal wastewater, and other sources require comprehensive methods to alleviate the effects of water contamination. Agricultural activities introduce contaminants such as nutrient runoff, concentrated animal feeding operations (CAFOs), and sedimentation. Industrial discharges include heavy metals, per- and polyfluoroalkyl substances (PFAS), industrial organic chemicals and solvents, and thermal pollution. Municipal wastewater contributes pathogens, organic matter, nutrients, pharmaceuticals and personal care products (PPCPs), and microplastics. Other sources encompass atmospheric deposition, solid waste leachate, aquaculture, and maritime activities, which can severely impact human health, resulting in conditions such as skin lesions, cancers, liver damage, elevated cholesterol levels, and methemoglobinemia ("blue baby syndrome") in infants. This pollution interferes with aquatic habitats, causing eutrophication and hypoxia, bioaccumulation and biomagnification, biodiversity loss, and disruption of ecosystem services. Mitigating water pollution necessitates a diverse strategy, encompassing rigorous environmental legislation and investments in modern water treatment technologies, such as Advanced Oxidation Processes (AOPs) and bioremediation, to diminish toxins. Addressing water contamination requires cooperative initiatives among governments, industries and communities, where Monitoring, risk assessment, water pollution management are essential for the protection of water resources. This review bridges a critical gap by providing a comprehensive integration of these diverse pollution sources that prior reviews lack, offering a strategic framework crucial for attaining the United Nations' sixth Sustainable Development Goal (Clean Water and Sanitation).
**Keywords:** Water pollution, Sources, Health impacts, Pathogens, Mitigation Strategies.

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## 1.Introduction

Water is one of the most important natural resources essential for the survival of all living organisms, including humans, economic development, and food. Today there are many cities worldwide confronting severe scarcity of water furthermore, nearly 40 % of the world's food supply is grown under irrigation while a wide variety of industrial processes rely heavily on water. Water, the availability of which significantly impacts the environment, economic growth, and development. The quality of surface and groundwater is also affected by human activities, increasing urbanization, population growth, climate change, agricultural production, and others. Water pollution resulting from these factors poses a serious threat to the Earth and living organisms (Halder and Islam, 2015).

Marine waste disposal, water tank leaks, the release of domestic and industrial wastewater, radioactive waste, and atmospheric deposition are among the major contributors to water pollution. The disposal of industrial waste and heavy metals into rivers and lakes can lead to their accumulation, posing a threat to human and animal health. Regarding human health, the most serious consequences arise from the lack of improved sanitation services, which is closely linked to the lack of access to safe drinking water, affecting more than a third of the world's population. Other potential threats include exposure to toxic chemicals through the food chain or pathogens. (Bhadarka *et al*., 2019). This comprehensive review critically examines the primary sources of water pollution, details their multifaceted impacts on human health and ecosystems, and identifies mitigation strategies essential for safeguarding water resources for future generations.

The literature discussed was identified through searches of peer reviewed databases for studies on water pollution sources, their environmental and health effects, and remediation technologies, with an emphasis on work published over roughly the past decade together with foundational earlier studies. Sources were selected for their relevance to the review's integrative scope rather than through a systematic protocol. While a strong body of literature addresses singular facets of water pollution, whether a exclusive contaminant class, a special health endpoint, or a specific treatment technology, relatively few reviews integrate sources, environmental and health consequences, and remediation options within an unified framework. This fragmentation makes it tough for researchers and decision makers to trace a given contaminant from its origin through its ecological and human health effects to the treatment approaches best suited to control it. The present review addresses this gap by linking these dimensions explicitly: each contaminant category is considered alongside its documented impacts and the prevention, treatment, and nature-based strategies most relevant to it, with specific attention to emerging pollutants such as microplastics, per and polyfluoroalkyl substances (PFAS), and pharmaceutical residues that conventional treatment is poorly equipped to remove.

## 2. Sources of Water Pollution and Key Contaminants:

Many natural and human activities contribute to the pollution of water sources with many organic and inorganic pollutants, the most important of which are plastic waste, agricultural and industrial waste, detergents, pharmaceuticals, wastewater, as well as soil erosion processes (Sharma *et al*., 2024). The sources of pollution include:

**2.1. Agricultural Activities:** Agricultural activities are a major source of many pollutants released into aquatic systems, such as nutrients, plastics, antibiotics, pathogens, and pesticides. As a result of these activities, many aquatic systems, such as groundwater, rivers, lakes, and coastal seas, are more polluted than in the past. Previously, water pollution was often associated with nutrients and nutrition. Now, with increasing agricultural activities and technological advances, aquatic systems face a new challenge related to emerging pollutants, such as plastics, antibiotics, and chemicals. (Figure 1) (Wang *et al.*,2023).

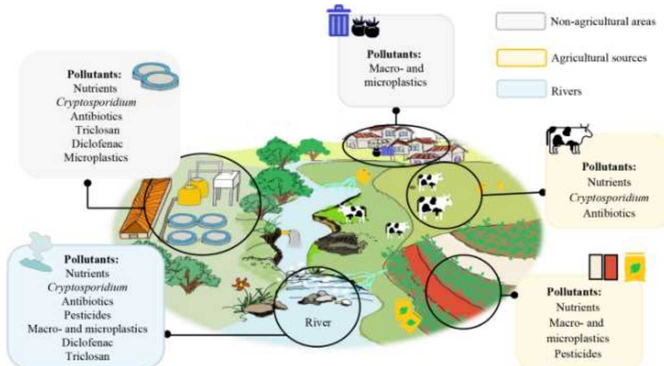


Figure 1. Concept model of multiple pollutant inputs to rivers from agricultural sources and non-agricultural areas

**Some agricultural pollutants that have a severe impact on aquatic environments:**

**2.1.1. Nutrient runoff**: Excessive use of phosphorus and nitrogen fertilizers leads to leaching and runoff, which increases the spread of nutrients into surface water (Carpenter *et al*., 2021; Reddy & Lee, 2020). Elevated levels of nutrients, such as phosphorus and nitrogen, lead to the pollution of water bodies as a result of their accumulation. However, the accelerated and uncontrolled nature of human activities has led to nutrient levels reaching historically high levels in freshwaters around the world (Bănăduc et al., 2024).

**2.1.2 Pesticides and Herbicides:** The immoderate application of pesticides and synthetic fertilizers represents a primary contributor to agricultural aquatic contamination. These materials can seep into and spread into nearby water sources, creating hazards for human well-being upon consumption or utilization in watering crops. They also harm aquatic life. While pesticides and chemical fertilizers are important for protecting crops from pests and increasing agricultural yields, they must be used responsibly and sustainably (Zahoor and Mushtaq, 2023).

**2.1.3. CAFOs**: Concentrated animal farms pose several risks to water quality and public health due to the large amount of manure produced and are a major source of agricultural pollution. The U.S. Environmental Protection Agency estimates that animal waste production in 1992 was thirteen times greater on a dry weight basis than human production. Sources of water pollution from concentrated animal farms include direct discharges, treatment and storage lagoons, open feedlots, manure stockpiles, and field applications. Animal waste from concentrated animal farms is a major source of nutrients such as nitrogen and phosphorus and gut microorganisms (Entry et al., 2002).

**2.1.4. Sedimentation:** Sediment pollution considerably affects aquatic life. Degraded water quality can damage wildlife and fish numbers, decreasing the value of recreational activities like swimming and fishing. This type of pollution represents a major environmental issue affecting aquatic habitats and water quality. Its damage can be mitigated by understanding its causes and consequences and implementing effective management best practices (Zahoor and Mushtaq, 2023).

**2.2. Industrial Discharges:**

Waterbodies are affected by industrial wastewaters in several ways, including possible hazards and hygienic obstacles (Sial et al., 1999). Industries can produce many hazardous pollutants and include:

**2.2.1.Heavy Metals:** Smelting, mining, manufacturing, and electroplating processes release toxic metals such as mercury, chromium, lead, arsenic, and cadmium into water bodies. Contaminated sediments in major rivers, such as the Yellow River in

China and various rivers in South Asia, pose serious environmental and health risks. (Ma et al., 2021; Bashir et al., 2020; Liu et al., 2022; Mohiuddin et al., 2021; Zhou et al., 2022).

**2.2.2.Per- and Polyfluoroalkyl Substances (PFAS):** These chemicals are used in textiles, non-stick coatings, and firefighting foams and are highly mobile, persistent, and bioaccumulate, contaminating surface and groundwater near industrial sites (Brusseau, 2021; Glüge et al., 2020; Post et al., 2022).

**2.2.3.Industrial Organic Chemicals and Solvents:** Persistent organic pollutants (POPs) are among the most important classes of persistent, toxic, bioaccumulative chemicals, including polychlorinated biphenyls, polycyclic aromatic hydrocarbons (PAHs), γ-hexachlorocyclohexane or 1,1,1-trichloro-2,2-diethane, polychlorinated dibenzo-p-dioxins, polychlorinated molecules like polybrominated diphenyl ethers and tetrabromobisphenol, as well as groups of brominated flame retardants (BFRs) such as polybrominated biphenyls. The extensive disposal of polycyclic aromatic hydrocarbons and brominated flame retardants is increasing the total amount of organic pollutants in the environment (Jacob ,2013)

**2.2.4.Heat (Thermal Pollution):** Most water pollution is due to increased human activities, as changes in water temperature negatively affect its quality and aquatic organisms. The most important sources of thermal pollution are electric and nuclear power plants, steel smelting plants, petroleum refineries, coal-fired power plants, and industrial boilers, which release large amounts of heat into water bodies, leading to changes in the physical, chemical, and biological properties of independent water bodies. The oxygen content in water also decreases as the temperature rises, which negatively affects reproductive cycles, respiration rates, and digestion, in addition to other physiological changes that cause problems for aquatic organisms (Gupta and Singh, 2016).

**2.3. Municipal Wastewater:** Pollutants discharged in wastewater are toxic to aquatic life and make natural water unsuitable as a source of drinking water) Sastry *et al*., 2013).

There are many wastewater pollutants, including:

**2.3.1. Pathogens:** Microorganisms play a key role in water quality. Among the microorganisms that cause waterborne diseases are Shigella sp., Salmonella sp., Vibrio cholerae, and E. coli. All of these organisms cause diarrhea, typhoid fever, gastroenteritis, cholera, and dysentery. The most serious forms of water contamination occur when feces enter water sources, as many diseases are transmitted through the fecal-oral route. Pathogens are transmitted only through human feces, and bacteria and E. coli are used as indicators of the presence of waterborne pathogens (Gupta and Singh, 2016). The causative diseases and mode of transmission are summarized schematically in Figure 2 (Magana-Arachchi and Wanigatunge, 2020).

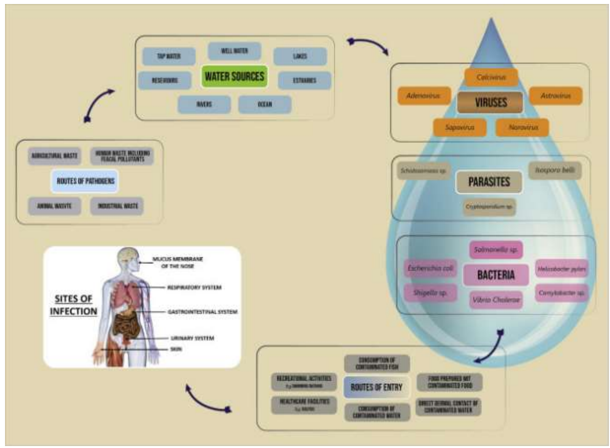


Figure 2. Generalized overview of ubiquitous waterborne pathogens, route of transmission, and sites of infection.

**2.3.2. Organic Matter:** Excess organic matter from phytoplankton blooms causes increased oxygen consumption, leading to oxygen depletion and the death of benthic organisms living on or near the seafloor (Wato *et al*., 2020).

**2.3.3. Nutrients:** High nutrient concentrations resulting from the runoff of fertilizers used to increase crop yields, particularly nitrogen and phosphorus, into waterways and groundwater stimulate algal blooms, disrupting aquatic ecosystems and potentially impacting river and groundwater quality. Pesticides carried by surface runoff or spray drift into rivers, lakes, and ponds can cause acute poisoning, such as fish kills, or chronic poisoning, such as exposing wildlife to levels of pesticides that are not immediately lethal. Negative effects on fish receiving repeated doses of sublethal pesticides include reduced resistance to disease, decreased egg production, and decreased predator avoidance (Wato *et al.,* 2020).

**2.3.4. Pharmaceuticals and Personal Care Products (PPCPs):** improperly disposed drugs (e.g., antibiotics, painkillers, hormones, antidepressants) and cosmetics residues are increasingly detected in waterways. They contribute to endocrine disruption and AMR in aquatic life (Lu *et al.,* 2020; Tao *et al.,* 2021).

**2.3.5. Microplastics:** Synthetic fibers from fragments from personal care products and laundry enter wastewater streams (Koelmans *et al.,* 2022; Kaur *et al.,* 2021). The use of plastics is the main threat to the freshwater environment. The existence of microplastics in freshwater environments is harmful to the health of organisms. This threat exists due to the size, surface characteristics and adsorption of chemicals on the surface of microplastics. Local anthropogenic sources are the top cause of the accumulation of microplastics in the muscles of fish. Reduced growth, a limited feeding capability, variation in oxygen ($O_2$) consumption, amplified antioxidant-related enzyme action has been reported after the ingestion of microplastics and a decreased lifespan. As a result of decreased feeding capacity, less energy is produced to carry out life functions resulting in neurological and reproductive toxicity (Bhardwaj *et al.,* 2024).

**2.4. Other Sources:**

**2.4.1.Atmospheric Deposition:** Rainwater dissolves air pollutants and releases them along with it. For example, acid rain results from the dissolution of acidic gases such as nitrogen, sulfur, and oxides, making it a major source of water pollution. (Kordbacheh and Heidari, 2023).

**2.4.2.Solid Waste Leachate:** Leachate is one of the major pollution problems caused by municipal waste dumps. It is the liquid that flows through waste in a landfill and is generated primarily by the biochemical decomposition of organic waste, rainwater infiltration, groundwater infiltration, and surface runoff. Its characteristics depend on the type and content of waste and the climatic conditions of the area. Therefore, open dumping of waste, landfill sites, and waste near water sources are major causes of water quality degradation and serious damage (Adhikari *et al.,* 2014).

**2.4.3.Aquaculture:** Although few studies have been conducted in relation with such topic, but there is some evidence that inland aquaculture is responsible for the degradation of water bodies used for human consumption. Although most aquaculture farms produce marine species, there is a growing sector of aquaculture farms that produce freshwater fish species. For example, preliminary calculations have revealed that an intensive aquaculture system produces three tons of freshwater fish, equivalent in waste to a community of approximately 240 people, which is alarming (Martinez and Martinez, 2012).

**2.4.4.Maritime Activities:** Oil pollution in aquatic environments originates from various sources, including maritime operations like shipping and accidental tanker spills, as well as land-based discharges from cities, factories, and agricultural runoff. Prominent historical examples illustrating the catastrophic scale of these accidental spills include the Exxon Valdez tanker in 1989 and the Deepwater Horizon oil rig in 2010. Ultimately, these oil slicks drift toward coastal areas, causing severe harm to marine life and devastating recreational zones (Okechukwu, 2021).

The relationships between the discussed pollution sources and their respective contaminants are comprehensively compiled in **Table** 1.

**Table 1:** Matrix of Water Pollution Sources and Associated Key Contaminants

| No | Sources | Contaminants |
|---|---|---|
| 1. | Agricultural Activities | Nutrient runoff, Pesticides and Herbicides, Concentrated animal farms pose several and Sediment pollution. |
| 2. | Industrial Discharges | Heavy Metals, Per- and Polyfluoroalkyl Substances (PFAS), Industrial Organic Chemicals and Solvents and Heat (Thermal Pollution). |
| 3. | Municipal Wastewater | Pathogens, Organic Matter, Nutrients, Pharmaceuticals and Personal Care Products (PPCPs) and Microplastics. |
| 4. | Atmospheric Deposition | acid rain |
| 5. | Solid Waste Leachate | liquid that flows through waste in a landfill and is generated primarily by the biochemical decomposition of organic waste. |
| 6. | Aquaculture | excessive biological load of cultureed fish |
| 7. | Maritime Activities | farms,factories,Accidental oil spills |

## 3. Effects of Water Pollution

Ecosystems and human health are significantly impacted by water pollution. The following are some of the primary effects of water contamination:

**3.1. Human Health Impacts:** Worldwide, contaminated water is a major source of long-term health problems and sickness (Ali et al., 2023; Nnadozie & Odume, 2021). Poor drinking water quality has contributed to the occurrence of water-borne diseases. According to a World Health Organization (WHO) survey, poor drinking water quality is the reason for 80% of the world's diseases and 50% of the world's child deaths, as well as more than 50 diseases. The quality of drinking water in developing countries is alarming, and water pollution continues to be the leading cause of disease and mortality in developing countries (Lin *et al.,* 2022).

**3.1.1.Heavy Metals:** Chronic exposure causes serious health problems, including arsenic (skin lesions, cancers, cardiovascular disease - Iqbal *et al.,* 2020; Kumar & Panneerselvam, 2023), Lead (neurodevelopmental deficits in children, hypertension - Rai *et al.,* 2021), Mercury (neurological damage - Minamata disease), Cadmium (kidney damage, osteoporosis).

**3.1.2.Pesticides**: Due to their specific biochemical characteristics, these compounds induce deep imbalances within the ecosystem. They are incredibly harmful to many living organisms, causing effects such as bioaccumulation in animal tissues and high environmental persistence with direct damage to aquatic ecosystems (fish, amphibians, etc.) (Campanale *et al.,* 2021).

**3.1.3.PFAS:** is responsible for liver damage, thyroid disease, immune suppression, high cholesterol, developmental effects, and kidney and testicular cancer (Post et al., 2022; Glüge *et al.,* 2020).

**3.1.4.Disinfection Byproducts (DBPs):** Chlorination of water containing organic matter forms compounds like trihalomethanes (THMs), related to reproductive issues and bladder cancer (Chowdhury & Alhooshani, 2021).

**3.1.5.Emerging Concerns - Microplastics:** Potential health effects when humans are exposed to them through (seafood, drinking water, inhalation) include inflammation, oxidative stress, gut microbiome disruption, and transfer of absorbed toxic chemicals (Jin *et al.,* 2021; Koelmans et al., 2022; de Sá *et al.,* 2021).

**3.2.Ecological Impacts:**

There are many environmental impacts because of water pollution, the most important of which are:

**3.2.1. Eutrophication and Hypoxia:** Excess nutrients stimulate algae, where oxygen is depleted upon death and decomposition, forming "dead zones" creating hypoxic or anoxic that do not have the ability to support most aquatic organisms such as the Gulf of Mexico and the Baltic Sea. Toxic cyanobacteria such as (e.g., Microcystis) also pollute the drinking water and cause damage to wildlife. (Carpenter *et al.,* 2021; Reddy & Lee, 2020).

**3.2.2. Acute and Chronic Toxicity:** Pollutants cause direct harm to aquatic organisms. Heavy metals impact reproduction, growth, and behavior (Bashir et al., 2020; Zhou et al., 2022). Pesticides cause fish kills and disrupt invertebrate communities (Ahmed et al., 2020). PPCPs affect fish physiology, behavior, and reproduction (Lu *et al.,* 2020).

**3.2.3. Bioaccumulation and Biomagnification:** Persistent contaminants concentrate (e.g., mercury, PCBs, DDT, PFAS) up the food chain, by accumulating in the tissues of organisms reaching toxic levels in top predators (fish, birds, mammals), accounting for reproductive failure, immune suppression, and population declines (Brusseau, 2021; Glüge *et al.,* 2020).

**3.2.4. Biodiversity Loss:** Pollution is to blame for freshwater biodiversity decline, where sensitive species disappear, leading to simplified communities dominated by pollution-tolerant organisms (Schwarzenbach *et al.,* 2022; Mohiuddin *et al.,* 2021).

**3.2.5. Habitat Degradation:** Pollutants can disrupt ecological processes, cause biodiversity loss, and habitat degradation. Some species may face extinction as a result of water pollution. Invertebrates, fish, and amphibians are examples of aquatic organisms that may suffer from population declines, reproductive problems, and developmental abnormalities (Baba, 2024).

**3.2.6. Microplastic Impacts:** Particles are consumed by organisms across trophic levels, from plankton to fish and mammals, causing physical damage (blockage, internal injury), reduced feeding, impaired reproduction, and acting as vectors for pathogens and toxic chemicals (Akdogan & Guven, 2020; de Sá *et al.,* 2021; Koelmans *et al.,* 2022).

**3.2.7. Disruption of Ecosystem Services:** Environmental change resulting from human activities causes higher water temperatures, decreased dissolved oxygen content, increased pollution-related toxicity, and habitat degradation and loss, and sea level rises, among other changes. These impacts will impose strong pressures on ecosystems, their associated resources and services, and aquatic and semi-aquatic habitats and render future water availability uncertain (Bănăduc *et al.,* 2024).

## 4. Strategies for Water Pollution and Solutions

Efficient control of water pollution necessitatesintegrated approaches that include prevention, treatment, and restoration. Several strategies:

### 4.1. Governance, Regulation, and Policy:

**4.1.1.Regulatory Frameworks**: One of the primary approaches to managing water quality is the creation and enforcement of rigorous mandates that control the discharge of pollutants. This includes setting limits for agricultural runoff, industrial effluents, and wastewater treatment (Luo and Su, 2025). The Clean Water Act of the USA strives to lower both phosphorus and nitrogen discharges to streams. In addition to prioritizing steps to decrease nitrogen and phosphorus pollution of rivers and streams, all states are expected to submit a list of contaminated and vulnerable watercourses (Bai *et al.,* 2018).

**4.1.2. Agricultural Best Management Practices (BMPs)**: support legislation and incentives for cover cropping, buffer strips, management of manure, and precision agriculture (which uses fewer fertilizers and pesticides) (FAO, 2023; Tang *et al.,* 2021).

**4.1.3.Chemical Regulation**: At national and international levels, it is necessary to phase out or restrict the use of persistent, bioaccumulative, and toxic (PBT) chemicals (e.g., high-risk pesticides, certain PFAS) (Glüge *et al.,* 2020; Pruden *et al.,* 2021).

**4.1.4.Collaborative Management**: Because water bodies often transcend political boundaries, a collaborative management approach should be adopted, involving stakeholders from different sectors (government, academia, industry, and society) and taking into account diverse viewpoints in decision-making processes (Luo and Su, 2025).

**4.1.5.Circular Economy Approaches**: In order to prevent trash from leaking into waterways, implement policies promoting waste reduction, reuse, and recycling, specifically of plastic waste and electronic waste (Borthakur, 2021; UNEP, 2021).

**4.2. Advanced Treatment of Water and Wastewater:** Upgrading WWTPs to go beyond primary and secondary treatment. Implement tertiary treatments (e.g., UV disinfection, sand filtration) and advanced processes that specifically target recalcitrant pollutants:

**4.2.1.**Membrane Technologies: Reverse Osmosis (RO) and Nanofiltration (NF) are considered effective methods for removing microplastics, micro-contaminants (PCBs, PFAS), and salts (Adeleye *et al.,* 2021; Kaur *et al*., 2021; Post *et al.,* 2022).

**4.2.2.Advanced Oxidation Processes (AOPs):** Advanced oxidation refers to the method used to decompose contaminants from a substance and remove them using strong oxidizing agents. In some cases, a single oxidation system is not sufficient to completely decompose organic contaminants in wastewater. Therefore, advanced oxidation processes are defined as methods that utilize multiple oxidation processes simultaneously, resulting in the rapid generation of highly reactive hydroxyl free radicals. These processes include UV photolysis, Fenton's reagent oxidation, and ultrasonic decomposition, all of which have the ability to decompose organic contaminants under normal temperature and pressure conditions. Among the benefits of advanced oxidation is the efficient oxidation of organic contaminants to carbon dioxide, and there are many other advanced oxidation processes that can be utilized. Including advanced UV oxidation technologies such as wet air catalytic oxidation (where air is used as the oxidant), wet air UV/air oxidation, UV/hydrogen peroxide, UV/ozone, UV/Fenton or photo-Fenton as well as chemical oxidation processes involving ozone, which is a mixture of ozone and peroxide (Mustafa and Hassan, 2024).

**4.2.3.Adsorption:** Adsorption shows the highest ability to remove industrial pollutants, organic and inorganic, as it requires less space for application and has a low cost, which is why it has become a subject of great interest recently (Kaur *et al.,* 2021). Adsorption technology on nanomaterials such as carbon nanomaterials, magnetic materials, zeolite, metal oxides, natural polymers, and silica is one of the most important technologies used to remove organic and inorganic contaminants in water (Ethaib *et al.,* 2022). Figure 3 shows the treatment of water pollution using nanomaterials.


Figure 3. using nanotechnology to remove pollutants from water (Adeleye et al., 2016)

**4.2.4.Point-of-Use/Point-of-Entry (POU/POE) Treatment:** Point-of-use (POU) water treatment systems offer a lower-cost alternative to centralized water systems. POU/POE systems can be installed in homes with piped water, reducing the cost of treating large quantities of water at a central facility. POU systems are a lower-cost alternative, but they only treat water from one tap (Lahlou, 2003).

**4.2.5.Industrial-Pretreatment-Programs:** The primary goal of industrial pretreatment is to remove or reduce emissions of specific wastewater pollutants from central treatment units prior to their discharge into a wastewater treatment plant. This task is critical for protecting treatment-plant infrastructure, ensuring the proper functioning of biological treatment processes, and preventing the pass-through of pollutants that municipal facilities are not designed to remove (Thomas *et al.,* 2024).

Taken together, these treatment options are complemental kinda than interchangeable, and no exclusive method addresses the full range of contaminants discussed above.

Membrane processes such as reverse osmosis and nanofiltration achieve high removal of salts, microplastics, and micro-contaminants including PFAS, but they carry strong energy demands and generate a focused reject stream that itself requires disposal. innovative oxidation processes are considerably suited to breaking down defiant natural compounds that membranes and accepted treatment leave behind, yet their reagent and energy costs, and the potential for partial oxidation by products, constrain large scale use. Adsorption particularly onto engineered nanomaterials offers comparatively low cost and operational simplicity for both natural and artificial pollutants, but performance depends on adsorbent regeneration and eventual disposal of spent media. Point of use and pretreatment approaches, by contrast, are valued less for breadth of removal than for placement: they protect downstream systems or provide a safeguard where centralized infrastructure is absent or unreliable. Because each method is strongest against a specific pollutant class and weakest elsewhere, the most operative real-world strategies generally combine them into integrated treatment trains for example, pretreatment and membrane separation followed by advanced oxidation or adsorption polishing matched to the specific contaminant profile and to local cost and capacity constraints. Comparative, life cycle-based evaluation of such combinations under field conditions remains an important gap in the literature.

**4.3. Nature-Based Solutions and Bioremediation:**

**4.3.1.Constructed Wetlands:** efficiently treat agricultural runoff, stormwater, and municipal and some industrial wastewater by leveraging natural processes (filtration, sedimentation, plant uptake, microbial degradation) for some metal, nutrient, and organic matter removal (Reddy & Lee, 2020; Dixit et al., 2021). There is no single global classification for constructed wetlands, but their categorization is more straightforward and is based on (i) type of vegetation growth (i.e., free-floating, floating-leaved, emergent, submergent), and (ii) water flow regime (surface, subsurface) and flow direction (horizontal, vertical) (Figure 4). Constructed wetlands are usually characterized by a relatively simple design and great scalability and flexibility (Ferreira et al., 2023).

**4.3.2.Bioremediation:** employ plants (phytoremediation) or microorganisms (fungi, bacteria) to immobilize or degrade contaminants (e.g., some pesticides, heavy metals, hydrocarbons) in soil and water (Dixit *et al.,* 2021).

**4.3.3.Riparian Buffers:** For a long time, the preservation of intact riparian zones has been acknowledged as a crucial component of biodiversity conservation. In recent decades, developments in riparian-buffer conservation have undergone paradigm shifts toward sustainable resource use, endangered species conservation, landscape-scale connectivity, and climate resilience (Graziano *et al.,* 2022).

**4.3.4.Sustainable Urban Drainage Systems (SUDS):** Sustainable urban drainage systems utilize green infrastructure that mimics natural filtration. Water is allowed to seep through layers of soil via permeable pavements, which removes pollutants prior to reaching groundwater aquifers and rivers. Vegetated areas such as marshes and rain gardens absorb rainwater and enhance the decomposition of pollutants through plants and soil (Monachese *et al.,* 2024).

**Conclusions**:

Water pollution resulting from population growth and urban, industrial and agricultural expansion is one of the most serious environmental challenges in the world. This review shows that industrial waste, pharmaceutical preparations, runoff from agricultural areas, wastewater, as well as microplastics are among the most important pollutants that contribute to water pollution. These pollutants pose a high-risk threat to water sources and water systems through the destruction of biodiversity, the contamination of freshwater water resources, the occurrence of food enrichment and environmental imbalance in these water systems.

Water pollution contributes to the spread of pathogens that cause and contribute to many diseases, including kidney disease, cancer, endocrine disorders, and neurological disorders. This review also addressed some water treatment techniques and explained that traditional treatment techniques are insufficient to remove some hazardous pollutants, which necessitates the use of advanced water treatment techniques such as advanced oxidation processes and bioremediation such as artificial wetlands and vegetation belts between rivers, as well as membrane filtration technology.

Effective management to solve the problem of water pollution requires integrated strategies such as the development of water treatment technologies, the enactment of stringent laws, the use of sustainable agricultural practices, and the dissemination of environmental awareness to protect water resources for future generations and reduce their pollution and its danger to human health and the environment.

Looking ahead, several priorities emerge from this synthesis. First, monitoring and regulatory frameworks must urgently adapt to emergent and recalcitrant contaminants highlighted in this body, particularly per- and polyfluoroalkyl substances (PFAS); currently, standardized detection methods treatment and remediation: Costs, benefits, and applicability. Chemical engineering journal, 286, 640-662.

Adhikari, B., Dahal, K. R., & Khanal, S. N. (2014). A review of factors affecting the and enforceable discharge limits for these persistent, bioaccumulative, and highly mobile chemicals remain underdeveloped, making their tracking in surface and groundwater a critical priority. Second, while innovative treatment processes and nature-based solutions, there is a critical lack of comparative, long-term evidence regarding their real-world scalability and cost-effectiveness. Specifically, future research should focus on comparing the performance of engineered treatment trains—such as utilizing advanced oxidation processes (AOPs) including UV photolysis, Fenton's reagent, and ozone-based systems to decompose complex organic fractions—against green infrastructure alternatives like sustainable urban drainage systems (SUDS) and constructed wetlands. Third, future work would benefit from source-to-impact-to-remediation studies that evaluate these interventions across the whole ecological pathway—such as tracking agricultural and industrial runoff from the point of origin through permeable pavements and vegetated basins down to groundwater aquifers—rather than evaluating individual treatment technologies in isolation. Addressing these specific technical gaps and establishing standardized protocols will be essential to securing sustainable water management.

**References:**

Adeleye, A. S., Conway, J. R., Garner, K., Huang, Y., Su, Y., & Keller, A. A. (2016). Engineered nanomaterials for water treatment and remediation: Costs, benefits, and applicability. Chemical engineering journal, 286, 640-662.

Adeleye, A. S., Conway, J. R., Garner, K., Huang, Y., Su, Y., & Keller, A. A. (2016). Engineered nanomaterials for water composition of municipal solid waste landfill leachate. International journal of engineering science and innovative technology, 3(5), 273-281.

Ahmed, A., Rauf, M., Mukhtar, H., & Saeed, R. (2020). Assessment of pesticide residues in surface water: A case study of the River Ravi, Pakistan. Environmental Monitoring and Assessment, 192(4), Article 242. https://doi.org/10.1007/s10661-020-8137-4

Akdogan, Z., & Guven, B. (2020). Microplastics in the environment: A critical review of current understanding and future challenges. Environmental Pollution, 258, 113488. https://doi.org/10.1016/j.envpol.2019.113488

Ali, F. M., Al-Gheethi, A., & Afifi, M. (2023). Water pollution sources and their impact on public health: An integrative review. Journal of Environmental Management, 336, 117641. https://doi.org/10.1016/j.jenvman.2023.117641

Baba, F. (2024). Water pollution: Causes, impacts, and solutions: A critical review. Journal of Sustainable Health, 76, 1-18.

Bai, Z., Lu, J., Zhao, H., Velthof, G. L., Oenema, O., Chadwick, D., ... & Ma, L. (2018). Designing vulnerable zones of nitrogen and phosphorus transfers to control water pollution in China.

Bănăduc, D., Curtean-Bănăduc, A., Barinova, S., Lozano, V. L., Afanasyev, S., Leite, T., ... & Cianfanglione, K. (2024). Multi-interacting natural and anthropogenic stressors on freshwater ecosystems: their current status and future prospects for 21st century. Water, 16(11), 1483.

Bashir, A., Shahid, M., Niazi, N. K., et al. (2020). Ecotoxicology, source apportionment and risk assessment of potentially toxic elements in the water bodies of South Asia. Environmental Pollution, 259, 113850. https://doi.org/10.1016/j.envpol.2019.113850

Bhadarka, M., Vaghela, D. T., Bamaniya, P. K., Sikotariya, H., Kharadi, N., Bamaniya, M., & Verma, P. (2019). Water pollution: Impacts on environment.

Bhardwaj, L. K., Rath, P., Yadav, P., & Gupta, U. (2024). Microplastic contamination, an emerging threat to the freshwater environment: a systematic review. Environmental Systems Research, 13(1), 8.

Borthakur, A., & Govind, M. (2021). Plastic waste generation and management in India. Resources, Conservation and Recycling, 168, 105451. https://doi.org/10.1016/j.resconrec.2020.105451

Brusseau, M. L. (2021). The extensive persistence of PFAS in the environment: A review. Environmental Science & Technology, 55(13), 7728–7735. https://doi.org/10.1021/acs.est.0c07483

Campanale, C., Massarelli, C., Losacco, D., Bisaccia, D., Triozzi, M., & Uricchio, V. F. (2021). The monitoring of pesticides in water matrices and the analytical criticalities: A review. TrAC Trends in Analytical Chemistry, 144, 116423.

Carpenter, S. R., Eberhardt, R., & Reddy, K. R. (2021). Ecological impacts of eutrophication: Legacy nutrient dynamics and lake recovery. Limnology and Oceanography Letters, 6(3), 209–221. https://doi.org/10.1002/lol2.10214

Chowdhury, S., & Alhooshani, K. (2021). Disinfection by-products in drinking water: Occurrence, toxicological effects, and mitigation strategies. Chemosphere, 281, 130798. https://doi.org/10.1016/j.chemosphere.2021.130798

De Sá, L. C., Oliveira, M., Ribeiro, F., Rocha, T. L., & Futter, M. N. (2021). Studies of the effects of microplastics on aquatic organisms: What do we know and where should we focus our efforts in the

future? Science of The Total Environment, 645, 1029–1039. https://doi.org/10.1016/j.scitotenv.2018.07.207
Dixit, R., Wasiullah, Malaviya, D., Pandiyan, K., Singh, U. B., Sahu, A., ... & Paul, D. (2021). Bioremediation of heavy metals from soil and aquatic environment: An overview of principles and criteria. Environmental Science and Pollution Research, 28, 7368–7388. https://doi.org/10.1007/s11356-020-10815-9
Entry, J. A., Sojka, R. E., Watwood, M., & Ross, C. (2002). Polyacrylamide preparations for protection of water quality threatened by agricultural runoff contaminants. Environmental Pollution, 120(2), 191-200.
Ethaib, S., Al-Qutaifia, S., Al-Ansari, N., & Zubaidi, S. L. (2022). Function of nanomaterials in removing heavy metals for water and wastewater remediation: A review. Environments, 9(10), 123.
Ferreira, C. S., Kašanin-Grubin, M., Solomun, M. K., Sushkova, S., Minkina, T., Zhao, W., & Kalantari, Z. (2023). Wetlands as nature-based solutions for water management in different environments. Current Opinion in Environmental Science & Health, 33, 100476.
Food and Agriculture Organization of the United Nations (FAO). (2023). The state of food and agriculture: Water pollution and the agricultural sector. https://www.fao.org/documents/card/en/c/cc6582en
Glüge, J., Scheringer, M., Cousins, I. T., DeWitt, J. C., Goldenman, G., Herzke, D., Lohmann, R., Ng, C. A., Trier, X., & Wang, Z. (2020). An overview of the uses of per- and polyfluoroalkyl substances (PFAS). Environmental Science: Processes & Impacts, 22(12), 2345–2373. https://doi.org/10.1039/D0EM00291G
Graziano, M. P., Deguire, A. K., & Surasinghe, T. D. (2022). Riparian buffers as a critical landscape feature: insights for riverscape conservation and policy renovations. Diversity, 14(3), 172.
Gupta, A., & Singh, M. R. (2016). Water pollution-sources, effects and control. ResearchGate.
Halder, J. N., & Islam, M. N. (2015). Water pollution and its impact on the human health. Journal of environment and human, 2(1), 36-46.
Iqbal, J., Shah, M. T., Khan, S., & Sulaiman, S. (2020). Heavy metal contamination and risk assessment in the drinking water of Swat, Pakistan. Environmental Monitoring and Assessment, 192(2), Article 91. https://doi.org/10.1007/s10661-019-8034-z
Jacob, J. (2013). A review of the accumulation and distribution of persistent organic pollutants in the environment. International Journal of Bioscience, Biochemistry and Bioinformatics, 3(6), 657.
Jin, Y., Wu, S., Zeng, Z., & Fu, Z. (2021). Effects of environmental pollutants on gut microbiota. Environmental Pollution, 272, 115986. https://doi.org/10.1016/j.envpol.2020.115986
Kaur, R., Singh, J., & Kaur, H. (2021). Removal of microplastics from wastewater using coagulation: A review. Science of The Total Environment, 789, 147956. https://doi.org/10.1016/j.scitotenv.2021.147956
Koelmans, A. A., Redondo-Hasselerharm, P. E., Mohamed Nor, N. H., Kooi, M., & van Wezel, A. P. (2022). Microplastics in freshwaters and drinking water: Critical review and assessment of data

quality. Water Research, 217, 118409. https://doi.org/10.1016/j.watres.2022.118409

Kordbacheh, F., & Heidari, G. (2023). Water pollutants and approaches for their removal. Materials Chemistry Horizons, 2(2), 139-153.

Kumar, M., & Panneerselvam, M. (2023). Human health risk from heavy metal exposure through contaminated water: A systematic review. Environmental Research, 216(Part 3), 114653. https://doi.org/10.1016/j.envres.2022.114653

Lahlou, Z. M. (2003). Point-of-Use/Point-of-Entry Systems (POU/POE). Tech brief. National.

Lin, L., Yang, H., & Xu, X. (2022). Effects of water pollution on human health and disease heterogeneity: a review. Frontiers in environmental science, 10, 880246.

Liu, H., Yang, Y., Wang, X., et al. (2022). Risk assessment and source apportionment of heavy metals in urban river sediments. Journal of Hazardous Materials, 432, 128663. https://doi.org/10.1016/j.jhazmat.2022.128663

Lu, X., Wang, L., Li, L., & Qiu, X. (2020). Pharmaceutical contamination in aquatic environments: Source, impact, and control. Environmental Science and Pollution Research, 27, 11537–11548. https://doi.org/10.1007/s11356-020-07685-6

Luo, Y., & Su, R. (2025). Water Pollution Monitoring, Modeling, and Management. Water, 17(13), 1871.

Ma, Y., Guo, Y., Hu, C., & Zhang, C. (2021). Pollution characteristics and ecological risk assessment of heavy metals in river sediment: A case study from China. Chemosphere, 263, 127908. https://doi.org/10.1016/j.chemosphere.2020.127908

Magana-Arachchi, D. N., & Wanigatunge, R. P. (2020). Ubiquitous waterborne pathogens. In Waterborne pathogens (pp. 15-42). Butterworth-Heinemann.

Martinez-Porchas, M., & Martinez-Cordova, L. R. (2012). World aquaculture: environmental impacts and troubleshooting alternatives. The Scientific World Journal, 2012(1), 389623.

Mohiuddin, K. M., Ogawa, Y., Zakir, H. M., Otomo, K., & Shikazono, N. (2021). Sources and ecological risk assessment of heavy metals in water and sediments of an urban river. Environmental Monitoring and Assessment, 193(3), Article 158. https://doi.org/10.1007/s10661-021-08912-6

Monachese, A. P., Gómez-Villarino, M. T., López-Santiago, J., Sanz, E., Almeida-Ñauñay, A. F., & Zubelzu, S. (2024). Challenges and innovations in urban drainage systems: sustainable drainage systems focus. Water, 17(1), 76.

Mustafa, B. M., & Hassan, N. E. (2024). Water contamination and its effects on human health: A review. Journal of Geography, Environment and Earth Science International, 28(1), 38-49.

Nnadozie, C., & Odume, O. N. (2021). Freshwater pollution and human health: A review of global evidence. International Journal of Environmental Research and Public Health, 18(21), 11694. https://doi.org/10.3390/ijerph182111694

Okechukwu Ozueigbo.(2021). Water Pollution, Its Treatment, and Its Adverse Impact on Humans. International Journal of Scientific and Engineering Research 12(9), 77 – 83

Post, G. B., Gleason, J. A., & Cooper, K. R. (2022). Key scientific issues in developing drinking water guidelines for perfluoroalkyl acids: Contaminants of emerging concern. Environmental

Science & Technology, 56(5), 2870–2880. https://doi.org/10.1021/acs.est.1c08210
Pruden, A., Larsson, D. J., Amézquita, A., Collignon, P., Brandt, K. K., Graham, D. W., Lazorchak, J. M., Suzuki, S., Silley, P., Snape, J. R., Topp, E., Zhang, T., & Zhu, Y. G. (2021). Management options for reducing the release of antibiotics and antibiotic resistance genes to the environment. Environmental Health Perspectives, 129(12), 125001. https://doi.org/10.1289/EHP7200
Rai, P. K., Lee, S. S., Zhang, M., Tsang, Y. F., & Kim, K. H. (2021). Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environment International, 125, 365–385. https://doi.org/10.1016/j.envint.2019.01.067
Reddy, K. R., & Lee, J. M. (2020). Mechanisms of nutrient pollution and control strategies in aquatic ecosystems. Water Environment Research, 92(9), 1392–1404. https://doi.org/10.1002/wer.1371
Sastry, S. V. A. R., Rao, B. S., & Nahata, K. (2013). Study of parameters before and after treatment of municipal waste water from an urban town. Global Journal of Applied Environmental Sciences, 3(1), 41-48.
Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., von Gunten, U., & Wehrli, B. (2022). Global water pollution and human health. Annual Review of Environment and Resources, 47, 123–153. https://doi.org/10.1146/annurev-environ-110821-083258
Sharma, K., Rajan, S., & Nayak, S. K. (2024). Water pollution: Primary sources and associated human health hazards with special emphasis on rural areas. In Water resources management for rural development (pp. 3-14). Elsevier.
Sial, J. K., & Mehmood, S. (1999). Water pollution from agriculture and industry. Proceedings: Water Resources. In Proceeding of Achievements and Issues in 20th Century and Challenges for Next Millennium. Pakistan Council of Res. in Water Resources, Islamabad, Pakistan.
Tang, F. H. M., Lenzen, M., McBratney, A., & Maggi, F. (2021). Risk of pesticide pollution at the global scale. Nature Geoscience, 14(3), 206–210. https://doi.org/10.1038/s41561-021-00712-5
Tao, R., Liu, Y., & Wang, S. (2021). Antibiotics in the aquatic environment: A review on fate and treatment technologies. Environmental Research, 196, 110984. https://doi.org/10.1016/j.envres.2020.110984
Thomas, D., Begley, D., Adams, H., Ash, S., & Southard, M. (2024). Operators Need to Know Industrial Pretreatment Programs. Opflow, 50(5), 14-18.
United Nations Environment Programme (UNEP). (2021). From pollution to solution: A global assessment of marine litter and plastic pollution. https://www.unep.org/resources/pollution-solution-global-assessment-marine-litter-and-plastic-pollution
Wang, M., Zhang, Q., Li, Y., Bak, M., Feng, S., Kroeze, C., ... & Strokal, M. (2023). Water pollution and agriculture: multi-pollutant perspectives. Frontiers of Agricultural Science and Engineering, 10(4), 639-647.
Wato, T., Amare, M., Bonga, E., Demand, B. B. O., & Coalition, B. B. R. (2020). The agricultural water pollution and its minimization strategies—A review. J. Resour. Dev. Manag, 64, 10-22.
Zahoor, I., & Mushtaq, A. (2023). Water pollution from agricultural activities: A

critical global review. Int. J. Chem. Biochem. Sci, 23(1), 164-176.

Zhou, Y., Liu, G., & He, Y. (2022). Sediment contamination by heavy metals and ecological risk in Chinese rivers. Chemosphere, 297, 134169. https://doi.org/10.1016/j.chemosphere.2022.134169

**ملوثات المياه: الأثر البيئي، والعواقب الصحية، ونهج المعالجة المستدامة – مراجعة**

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**الملخص**

يواجه العالم تحديات بيئية غير مسبوقة، حيث يُعد تلوث المياه مشكلة عالمية خطيرة تُشكل مخاطر جسيمة على النظم البيئية وصحة الإنسان. تُجمع هذه المراجعة نتائج العديد من الدراسات المنشورة في قواعد البيانات الإلكترونية الرئيسية، بما في ذلك PubMed وGoogle Scholar. تتطلب مصادر التلوث، الزراعية والصناعية ومياه الصرف الصحي البلدية وغيرها، أساليب شاملة للتخفيف من آثار تلوث المياه. تُدخل الأنشطة الزراعية ملوثات مثل جريان المغذيات، وعمليات التغذية الحيوانية المركزة، والترسبات. وتشمل لتصريفات الصناعية المعادن الثقيلة، ومواد البيرفلورو ألكيل والبولي فلورو ألكيل (PFAS)، والمواد الكيميائية العضوية الصناعية والمذيبات، والتلوث الحراري. في حين تُساهم مياه الصرف الصحي البلدية في التلوث بمسببات الأمراض، والمواد العضوية، والمغذيات، والمستحضرات الصيدلانية ومنتجات العناية الشخصية، والجسيمات البلاستيكية الدقيقة. وتشمل المصادر الأخرى الترسيب الجوي، ورشح النفايات الصلبة، وتربية الأحياء المائية، والأنشطة البحرية، والتي يُمكن أن تُؤثر بشدة على صحة الإنسان، مُسببةً حالات مثل آفات الجلد، والسرطانات، وتلف الكبد، وارتفاع مستويات الكوليسترول، وميثيموغلوبين الدم (متلازمة الطفل الأزرق) لدى الرضع. يُؤثر هذا التلوث سلبًا على الموائل المائية، مُسببًا التخثث ونقص الأكسجين، والتراكم الحيوي والتضخم الحيوي، وفقدان التنوع البيولوجي، واضطراب خدمات النظام البيئي. ويتطلب الحد من تلوث المياه استراتيجية شاملة، تتضمن تشريعات بيئية صارمة واستثمارات في تقنيات معالجة المياه الحديثة، مثل عمليات الأكسدة المتقدمة والمعالجة الحيوية، لتقليل السموم. كما يتطلب معالجة تلوث المياه مبادرات تعاونية بين الحكومات والصناعات والمجتمعات، حيث تعد المراقبة وتقييم المخاطر وإدارة تلوث المياه أموراً أساسية لحماية الموارد المائية. وتسد هذه المراجعة فجوةً حرجة من خلال تقديم تكامل شامل لمصادر التلوث المتنوعة هذه، وهو ما تفتقر إليه المراجعات السابقة، مما يوفر إطار عمل إستراتيجي حاسم لتحقيق الهدف السادس من أهداف التنمية المستدامة للأمم المتحدة (المياه النظيفة والنظافة الصحية).

**الكلمات المفتاحية:** تلوث المياه، المصادر، الآثار الصحية، مسببات الأمراض، استراتيجيات التخفيف.