River pollution and biodiversity loss: a global perspective

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Abstract: River ecosystems worldwide are facing unprecedented threats from pollution, habitat degradation, and climate change, leading to alarming biodiversity loss. Pollutants from industrial, agricultural, and domestic activities contaminate river waters, adversely affecting aquatic life and the ecosystem services they provide. Freshwater species, many of which are endemic, are particularly vulnerable to pollution, with many at risk of extinction due to habitat degradation, overfishing, and altered water flows. The impact of river pollution extends beyond the aquatic ecosystem; it also affects human health, economic development, and social well-being. Polluted rivers can lead to water scarcity, reduced fish populations, and loss of livelihoods for communities dependent on river resources. Furthermore, the degradation of river ecosystems can exacerbate the effects of climate change, reduce the resilience of ecosystems, and increase the risk of natural disasters. This global perspective highlights the far-reaching consequences of river pollution on biodiversity, including declines in freshwater species populations, disruptions to food chains, and reduced ecosystem resilience. The article emphasizes the urgent need for coordinated conservation efforts, sustainable practices, and policy interventions to mitigate river pollution and protect freshwater biodiversity for future generations.

Keywords: Climate change, conservation, future generations, habitat degradation, river ecosystems, sustainable

Rivers are veins of the Earth that pump fresh water throughout the Earth's surface along with supporting all the life forms (Wang and He, 2022). The biodiversity found in aquatic ecosystems forms intricate webs that are essential for survival and ensure the health and function of the river (Qu and Peng, 2025). However, this delicate balance is disrupted when pollutants enter the water system (Rhind, 2009). Pollution refers to the introduction of harmful substances into the environment, altering the natural equilibrium; these pollutants often include chemical discharges and physical debris (Shetty et al., 2023).

The influx of these pollutants often causes immediate and devastating consequences, leading to the deaths and extinction of several aquatic organisms due to changes in the water quality (Priya et al., 2023). Additionally, plants that are crucial for structural integrity and oxygen production are adversely affected by pollution (Anetor et al., 2022). River pollution and biodiversity loss are closely linked, with pollution acting as a major driver in the decline of aquatic life and degradation of the ecological balance (Ogidi and Akpan, 2022).

Pollutants - whether chemical, physical, or biological - disrupt ecosystems and negatively affect the survival, reproduction, and overall population of aquatic species. This, in turn, impacts other faunal species and humans who depend on these aquatic organisms for food (Bashir et al., 2020). Human activities and natural processes generate an astronomical amount of waste that is discharged into rivers and other water bodies (Han and Liu, 2024). Agricultural runoff carries washed-off pesticides and fertilisers washed off from fields, while household sewage and industrial discharges introduce heavy metals and processed chemicals. Additionally, climate change alters temperature and precipitation patterns, affecting the river flow, water quality, and aquatic ecosystems. These factors are major contributors to river pollution (Ejiohuo et al., 2025; Figure 1). The resulting effects on the aquatic biome include oxygen depletion, introduction of toxins, changes in water chemistry, and disruption of the food chain (Mustafa et al., 2024).
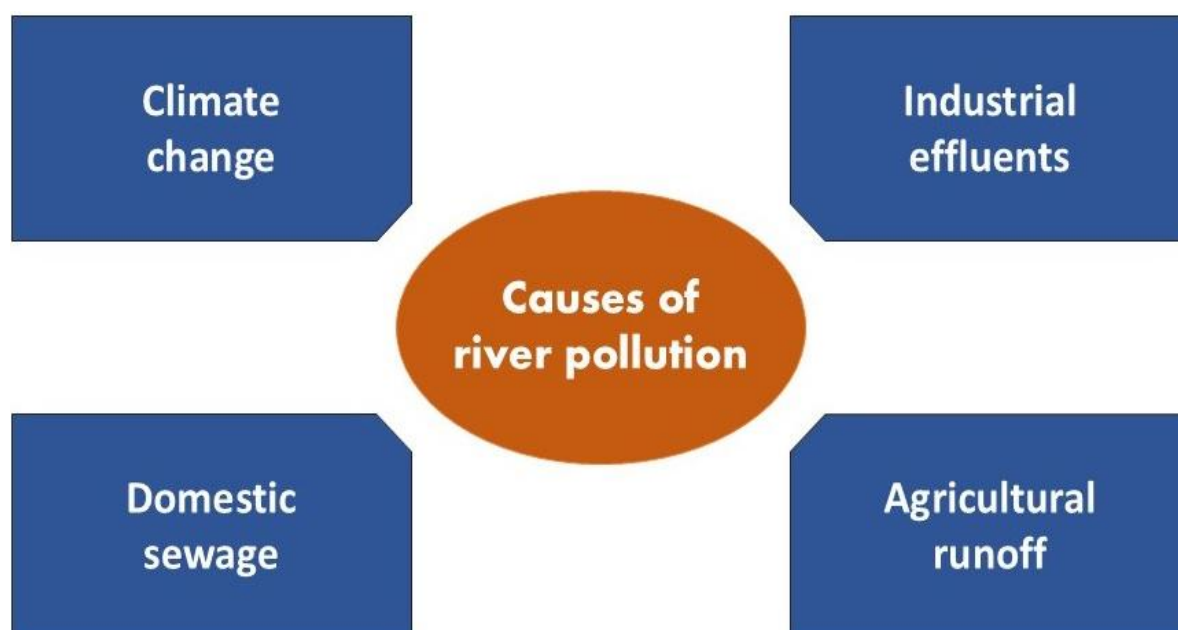

Figure 1: Causes of river pollution

Types of river pollutants

Understanding various sources of pollution is essential for developing effective strategies for remediation and prevention of water pollution. Below are some of the sources of river pollution, along with the corresponding types of pollutants they contribute.

Nutrients: The presence of excess nutrients in the rivers is primarily due to various anthropogenic activities, which contribute to the discharge of wastewater from agricultural, industrial, or household sources into water bodies. Excess nutrients in the form of nitrogen and phosphorus stimulate excessive plant growth, leading to eutrophication and oxygen depletion (Tiwari and Pal, 2022).

Chemicals: Liquid discharge from industries, along with pesticides, pharmaceuticals, and heavy metals, directly poisons organisms or accumulates in their cells (bioaccumulation). This pollution can move up the food chain, ultimately harming apex predators (biomagnification), harming them (Reckendorf et al., 2023).

Sediment: These sediments include soil particles, biological matter, and organic matter make the water turbid and reduce the amount of sunlight that reaches the bottom of the water bodies (Figure 2). Suspended solid waste materials reduce light penetration for aquatic plants, hinder photosynthesis, and damage the river beds, which are crucial for fish spawning and coral reef formation (Bilotta and Brazier, 2008).

Thermal pollution: The degradation of water quality occurs when industrial waste or water from power plant cooling systems is discharged directly into river ecosystems at temperatures that significantly differ from the surrounding water bodies. This heated water decreases the levels of dissolved oxygen and brings temperature-sensitive species under stress, leading to changes in species distribution and diversity (Walkuska and Wilczek, 2010).

Plastics: Plastics, whether in the form of macro- or microplastics, and the chemicals that leach from them, pose significant risks to aquatic organisms. Macro and microplastics, when consumed by aquatic organisms, can induce damage at the physical as well as inner molecular level. Plastics in physical form can damage internal structures, alter the feeding pattern, and affect the reproductive behaviours of the aquatic organisms. Additionally, microplastics and chemical leachate from plastics into the water can cause oxidative stress in aquatic animals, disrupt their endocrine receptors, and accumulate in the body itself, leading to long-term health effects (Rossatto et al., 2023).

Impacts of river pollution

Toxicity from chemical pollution: Industrial discharges, pesticides, and heavy metals can be toxic to aquatic organisms, causing immediate death or long-term health problems that affect their reproduction and survival. Acid drainage into aquatic ecosystems lowers the pH, stressing organisms and mobilizing heavy metals, which makes the ecosystems more toxic (Hama Aziz et al., 2023).

Bioaccumulation and biomagnification: Pollutants can accumulate in organisms over time, moving up the food chain and impacting larger animals or top predators, including humans who consume them. This process, known as biomagnification, leads to higher concentrations of pollutants in larger predators (Saidon et al., 2024).

Figure 2: Pollution in the Ganga River at Haridwar (Photo credit: Ms. Paramita Ray)

Eutrophication: Excess nutrients like nitrogen and phosphorus from agricultural runoff and sewage can cause algae blooms, which deplete oxygen and create "dead zones" where aquatic life cannot survive (Akinnawo, 2023).

Habitat destruction: Altered water chemistry or pollution can change the pH, temperature, and oxygen levels of the water, making it unsuitable for many species. Reduced dissolved oxygen creates stress on temperature-sensitive species, altering the breeding cycles (Larance et al., 2025). Pollutant sediments settle in the riverbeds, harming benthic organisms, impacting the entire ecosystem, and smothering the aquatic habitat with reduced light, affecting every life process. It also causes gill damage in fish (Kjelland et al., 2015). Pollution can damage or alter several habitats, like wetlands and riparian areas, further reducing biodiversity (Bassi et al., 2014; Figure 3).

Disrupted food webs: Pollution can cause the decline or extinction of key species, disrupting the delicate and intricate balance of the food web. Pollution impacts the species directly as well as leads to a loss of overall biodiversity, making the ecosystem less resilient to change (Singh et al., 2023).

Spread of invasive species: Polluted environments can be more sensitive to the establishment and spread of invasive species, further threatening native biodiversity (Rai and Singh, 2020).

Loss of ecosystem services: Rivers provide essential ecosystem services, including water filtration, flood control, and habitat provision, which can be compromised by pollution (Vari et al., 2021).

Figure 3: Industrial and household pollution in the Yamuna River in Agra

Consequences for humans

River pollution can reduce the availability of clean water for human consumption, agriculture, and industry. Exposure to polluted water can lead to a range of health problems, including waterborne diseases and cancer (Lin et al., 2022). It can have significant economic costs, including damage to fisheries, tourism, and other industries that depend on healthy rivers.

Consequences of biodiversity loss

Biodiversity loss reduces the resilience of ecosystems and decreases their ability to withstand environmental changes and climate change (Weiskopf et al., 2020). Disrupted water purification, nutrient cycling, and food provision impair the ecosystem services (Spence et al., 2016). Lower adaptive capacity leads to increased susceptibility of the ecosystem to disease outbreaks and environmental stressors, and thus increases the vulnerability of the ecosystem (Abbass et al., 2022). There is a loss of primary consumers, that an increase in pollution-tolerant scavenger populations (Klamt et al., 2021). Significant loss of biodiversity also causes the loss of spawning grounds, hiding places, and foraging areas for aquatic organisms (Kawade, 2022).

Solution to the issue

A multi-faceted approach is required to effectively address the problem of river pollution. These include improvisation in existing wastewater treatment facilities, sustainable agriculture, restoration of riparian zones, and public awareness campaigns. Below are some of the proposed solutions to the existing problem of river pollution.

Stricter pollution control measures – Implementing and enforcing regulations for industries, agriculture, and households, while ensuring that these rules are properly enforced, is essential. Strong policies and regulations can help prevent river pollution and promote sustainable management of river ecosystems (Ejiohuo et al., 2025).

Improved wastewater treatment – Upgrading and expanding sanitation systems and wastewater management infrastructure is crucial. Better wastewater treatment facilities can significantly reduce the number of pollutants entering rivers (Al-Khatib and AlHanaktah, 2025). The implementation of cutting-edge technologies to remove contaminants such as nutrients, heavy metals, and harmful chemicals from wastewater can be very beneficial (Shofia et al., 2025). Stricter regulations should be enforced on industries to ensure proper treatment of their wastewater before it is discharged into the riverine ecosystems. Additionally, fostering collaboration between public and private entities to develop and implement wastewater treatment solutions is important (Breitenmoser et al., 2022). Exploring ways to make effluent treatment a viable business model and incentivizing industries to adopt cleaner technologies can further enhance these efforts.

Sustainable practices – Promoting eco-friendly land and water management techniques is important. Adopting sustainable agricultural practices can minimize runoff and lessen the negative impact of farming on rivers (Teweldebrihan and Dinka, 2025).

Conservation efforts – Protecting and restoring river habitats and natural vegetation around the rivers are crucial steps and can help to preserve biodiversity and the essential ecosystem services they provide (Piczak et al., 2023).

Public awareness – Educating the community about the impacts of pollution on biodiversity is essential for fostering a responsible behaviour (Borresen et al., 2021). Encouraging individuals to adopt eco-friendly practices like reducing the use of plastics and ensuring their safe disposal, conserving water, properly disposing of waste, and using phosphate-free detergents. These measures can contribute significantly at the individual level (Pandey et al., 2023).

Research and monitoring – It is important to understand the effects of pollution on aquatic ecosystems through scientific research and continuous monitoring. Continuous monitoring provides valuable insights into how various pollutants affect these ecosystems and aids in the development of effective treatment and mitigation strategies (Samsuria et al., 2025). Scientific research helps identify pollutants, understand the impact of harmful substances in water, and create models that can predict the spread and effect of pollutants (Mishra et al., 2023). Furthermore, continuous monitoring enables the detection of pollution at its source and allows for tracking changes in the water properties to assess the overall health of the ecosystems (Zulkifli et al., 2017). Together, these efforts facilitate informed decision-making regarding pollution control, resource management, the development of effective strategies, and the conservation of aquatic biodiversity and public health.

Conclusion

By addressing the root causes of river pollution and promoting sustainable practices, we can protect the biodiversity and ensure the health of rivers for future generations. This global perspective highlights the urgent need for coordinated conservation efforts, sustainable practices, and policy interventions to mitigate river pollution and safeguard freshwater biodiversity. Effective management of river ecosystems requires a multi-faceted approach, incorporating wastewater treatment, sustainable agriculture, and conservation of river habitats. By working together, we can reduce the impact of river pollution and preserve the health and resilience of river ecosystems, ensuring the long-term sustainability of freshwater resources and the biodiversity they support.

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