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Implications of Sewage Discharge on Freshwater Ecosystems

Sami Ullah Bhat and Umara Qayoom

Abstract

Freshwater ecosystems such as lakes and rivers are among the sensitive ecosystems, which host rich biodiversity. Being major freshwater resources, they provide a wide range of ecosystem services, making their existence essential for the well-being of human societies. However, in the past few decades, there have been adverse impacts on the health of these ecosystems due to uncontrolled sewage disposal throughout the world. This is increasingly becoming a tough challenge to protect the freshwater ecosystems from the ramifications of the entry of untreated sewage. Loss of biodiversity, physiological and behavioral changes in species, community shifts, and fish mortality have been witnessed in aquatic ecosystems, which are the recipients of untreated or partially treated sewage. Nutrients such as nitrogen and phosphorus are abundant in sewage and are one of the leading causes of eutrophication of water bodies. Several freshwater ecosystems around the world have become a victim of eutrophication due to untreated sewage disposal, leading to a change in trophic status.

Keywords: biodiversity, eutrophication, phosphorus, species

1. Introduction

One of the biggest challenges we are confronting in the twenty-first century is the inaccessibility of clean water and improved sanitation [1]. Although safe drinking water, sanitation and hygiene (WASH) are required for an improved standard of living, they are equally important for the protection of health and environment. As the countries improvise their sanitation coverage, it is also important that they reduce the release of untreated sewage into the environment by exploiting the energy and nutrients present in it. Water plays an important role in various aspects of socio-economic development such as food production, economy, domestic water supply, environmental sustainability, health systems, and industrial applications. Lack of access to WASH could have a negative impact on the economy, health, and environment. Water pollution from sources such as agriculture, industries, urban runoffs, and waste disposal threatens clean drinking water supplies with detrimental impacts on freshwater ecosystems [2]. Several water bodies in developing countries such as rivers, streams, and lakes, which are located close to highly populated areas, have become filled with waste, which have turned them into dead or sewage streams. Most aquatic ecosystems have a natural tendency to dilute pollution to some extent, but severe contamination of aquatic ecosystems results in the alteration of their fauna and flora community [3]. The amount of nutrients received by aquatic ecosystems varies throughout the world depending on the characteristics of the ecosystem. Most

of them receive varying quantities of a wide range of nutrients that are unloaded from human settlements. Sewage is the used water-containing solids deposited from households, commercials, and industries, which is transported in sewers and disposed off into watercourses. Sewage disposal in a particular region depends on the accessibility of natural watercourses in that particular area. Worldwide around 65% of the river stretches are polluted [4], which have resulted in the degradation as well as loss of biodiversity in the water bodies and cannot be neglected.

Poorly managed human excreta has several detrimental consequences on the environment, polluting surface water such as lakes and rivers. Heavily polluted water has a serious impact on freshwater ecosystems, food webs, and biodiversity. Water bodies located in highly populated urban areas have a considerable amount of biological oxygen demand contributed mostly from wastewater. Untreated or partly treated urban wastewater consists of high concentration of nutrients as well as organic matter [5], which upon decomposition releases additional nutrients. Increased levels of nutrients especially nitrogen and phosphorus in aquatic ecosystems are associated with eutrophication. Algal blooms especially those of cyanophytes release cyanotoxins [6], which are known to have harmful effects on aquatic life, wildlife, livestock, agricultural crops, and humans [7]. Several toxins are liberated from sewage into the water, which are consumed by fishes and other forms of aquatic life thereby increasing their possibility of entering into the food chain. Several toxic substances including heavy metals have a high concentration in the wastewater generated from industries [8]. Due to their non-degradable nature, they tend to display high toxicity in aquatic systems and accumulate in the food webs. Thus, water pollution has received more attention during the past few years owing to their ecologic, biodiversity, economic, and social perspectives.

2. Composition of sewage

Sewage is composed of domestic effluent consisting of black water (excreta, urine, and fecal sludge) and gray water (used water from washing and bathing); water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater and other urban runoff; and agricultural, horticultural and aquaculture runoff [9]. Sewage comprises 99.9% of water and 0.1% of solids, which includes dissolved as well as suspended organic and inorganic solids. Dissolved solids constitute a major portion as compared to suspended solids, while organic fraction consists of fats, carbohydrates, proteins, lignin, and their decomposition products. Similarly, the inorganic part includes several constituents derived from industrial as well as domestic sources including heavy metals like cadmium, mercury, arsenic, zinc, and copper. A varied and abundant diversity of microbes are present in sewage [10] and is contributed in human sewage from sources like human domestic waste such as feces, washing, bathing urine, and sweat. These microorganisms are added from the human body present in the skin, respiratory tract, oral cavity, gastrointestinal tract, and urogenital tract. Wastewater is considered as an important reservoir of pathogens, [11, 12], which includes Fecal Coliform, *E coli*, Salmonella, Shigella, Vibrio cholera, parasitic eggs and cysts, viruses and fungi [13, 14], intestinal nematodes like hookworm (*Ancylostoma duodenale*), roundworm (*Ascaris lumbricoides*), and whipworms (*Trichuris*). Sewage contains a rich concentration of nutrients such as nitrogen (N) and phosphorus (P). Around, 16.6 Tg (Tg = million metric ton) of nitrogen and 3.0 Tg of phosphorus are present in wastewater produced throughout the world annually. Human urine consists of a high concentration of nutrients such as nitrogen and phosphorus than the amount

present in the feces [15]. Thus, human urine is responsible for 50% of the phosphorus load and 80% of the nitrogen load in the sewage [16].

3. Sewage generation and treatment scenario throughout the world

Despite being a major factor in water quality, proper wastewater treatment is lacking in many developing countries of the world and it is estimated that 90% of developing countries do not treat wastewater before disposal into the receiving waters be it lakes or rivers. A large amount of untreated industrial, agricultural, and domestic wastes is discharged into the world's waterways due to which low-income countries are hit by contaminated water supplies and disease. Water sources such as rivers, lakes, and oceans are the major recipients of domestic and industrial wastes across the world. Country-specific data on wastewater generation reveal that around 390 billion m³ of wastewater is generated throughout the world, which is fivefold the amount of water released by Niagara Falls annually [17]. However, the amount of wastewater generated is projected to increase by 24% by 2020 and further about 51% by 2050 [18]. It is estimated that worldwide about 80% of the wastewater generated is discharged directly without any proper treatment into water bodies [19]. Around two million tons of sewage, industrial and agricultural waste is discharged into the world's waterways. Water sources such as rivers, lakes, and oceans are the major recipients of domestic and industrial wastes across the world. With regard to the wastewater generation and treatment in the world, it has been stated that high-income countries on an average treat around 70% of the wastewater generated by them, and upper- and lower middle-income countries provide treatment to 38% and 28% of the wastewater generated respectively, while as low-income countries treat only 8% of total wastewater generated [20]. Available figures reveal a shocking scenario of sewage disposal into water bodies across the world. Venezuela discharges 97% of sewage generated directly into the environment without providing any treatment. Developed nations like Turkey discharge 75% of the wastewater generated from industries directly into the environment. About 71% of the wastewater generated in European countries receives treatment owing to public awareness toward health and environmental or partly due to technological advancements. In Latin American countries, only 20% of the wastewater generated is being treated, while the rest is disposed off untreated into the water bodies. The Middle East and North Africa provide treatment to 51% [20], while Asian countries treat only 32% of generated wastewater. Asia is the largest producer of wastewater and generates 42% of wastewater produced globally with an annual estimate of 159 billion m³. North American countries generate 67 billion m³, while Europe generates 68 billion m³ [18]. With the ongoing freshwater crisis throughout the world, the available freshwater resources cannot be polluted and made unfit for human consumption. Proper treatment and disposal of wastewater should be regarded as a matter of urgency throughout the world [21].

4. Effects of sewage on freshwater biodiversity

Now a day's there is an increasing recognition that freshwater is a valuable resource due to overexploitation and pollution. Wastewater discharge contain several harmful substances or chemicals, which may cause adverse environmental impacts such as changes in aquatic habitats, species composition, and decrease in

biodiversity. All of these impacts lead to a less valuable environment, a less prosperous economy, and ultimately, a diminished quality of life. Several substances are present in sewage, which can potentially impact plant and animal communities in different ways.

4.1 Temperature

4.1.1 Physical changes

Sewage discharge is often associated with physical changes in water bodies. Aquatic life sustains under an optimum temperature and an increase in the average temperature of the water body has ecological impacts resulting in thermal enhancement [22]. The shift in water temperature can seriously affect aquatic life, such as microbes, invertebrates, algae, and fish [23]. Temperature also affects the solubility and consequently, the availability of oxygen in the water. An increase in temperature results in less dissolution of oxygen in the water and hence, oxygen demand required by the bacteria for the degradation of wastes also increases. Tissue anoxia can occur at higher lethal temperatures in aquatic animals. Temperature also affects key physicochemical conditions such as oxygen concentrations as well as energetic processes associated with primary production and litter decomposition [24, 25].

4.1.2 Chemical changes

The effects of certain toxic substances like copper that increases metabolic demand or zinc which blocks oxygen uptake at the gill level for fish get enhanced by an increase in temperature. Toxicants that act on cellular enzymes involved in energy metabolism or that cause a change in the rate of uptake may also have their effect potentiated by a temperature increase. High water temperature also affects the toxicity of some chemicals in the water as well as the sensitivity of living organisms to toxic substances [26, 27].

4.1.3 Biological changes

Causes of thermal death include failure of osmoregulatory processes, alterations in cellular enzymes and membrane lipids, and protein denaturation. In addition, temperature controls the growth rates of phytoplankton, macrophytes, and epiphytes, making freshwater ecosystems sensitive to rising temperatures [28, 29]. Because most river organisms are ectotherms, changes in temperature have profound effects on their growth, phenology, survival, and distribution [30, 31].

4.2 Dissolved oxygen

4.2.1 Physical changes

Dissolved oxygen (DO) is a key parameter that determines the water quality as well as the health of an aquatic ecosystem. The presence of a certain amount of DO in water is important for the survival of higher forms of biodiversity [32]. A fluctuation in DO near its saturation is an indication of relatively healthy waters while as low dissolved oxygen indicates potential danger to the water body [33]. Oxygen-demanding wastes in the sewage are responsible for the depletion of DO levels, which impact both water quality and biodiversity in the water body [34]. The aquatic ecosystem suffering from hypoxic or anoxic conditions is responsible for the depletion of fish stocks and other forms of aquatic life. These losses can have harmful effects on ecological health, economy, and stability of the ecosystem [35].

4.2.2 Chemical changes

Development of hypoxic and anoxic conditions, increase in metal and phosphate release from sediments creation of hypoxic (reduced dissolved oxygen), anoxic (extremely low or no dissolved oxygen) and euxinic (sulfide production in the absence of oxygen) conditions take place in the water body [36, 37]. Low DO level affects the metabolic processes of species. Low levels of DO in receiving water bodies can result in the release of toxic substances, biomagnification in organisms, and increased nutrient loads.

4.2.3 Biological changes

Fish are among the most affected species as low DO concentration increases their susceptibility toward diseases, retarding their growth, hindering their swimming ability, changes in feeding habits, migration, and in extreme cases results in death.

It significantly affect mortality, reproduction, behavior, and physiological response in fishes [38]. If the decrease in oxygen continues for a long time, it can result in a change in species composition [39]. Among planktonic organisms most likely to suffer mortality from exposure to low oxygen in bottom waters are fish larvae lacking fully developed sensory and motor capabilities.

4.3 Total suspended solids

4.3.1 Physical changes

Suspended solids (SS) comprise of a fine particulate matter having a diameter of less than 62 μ m. They can cause physical damage to fish gills [40]. Blockage of filter-feeding apparatus of zooplankton, gills of the most sensitive benthic invertebrates like epibenthos, living on or above the sediment can be clogged by sediment particles.

4.3.2 Chemical changes

They can pose a number of direct as well as indirect environmental impacts like reduced sunlight penetration, which in turn affects photosynthesis, toxic effects due to contaminants attached with suspended solids [22]. A high concentration of salts can result in increase in the salt content of the water body with harmful effects on aquatic organisms and a brackish, salty taste to its consumers.

4.3.3 Biological changes

A high level of SS in receiving water body can cause flocculation and sinking of phytoplankton, reduced primary productivity in macrophytes and algae [41, 42], egg mortality in fish [43]. Further, SS in zooplankton can cause toxicity, as well as ingestion of sediment particles having no nutritional value, causing zooplankton starvation and death.

4.4 Cyanide

This substance is an important toxicant to fish and other aquatic animals and its salts are frequently found in effluents from industrial wastes. Certain forms of cyanide are acutely toxic to many aquatic life forms and concentrations

<0.1 mg/l can be toxic to some sensitive aquatic species. At the cellular level, cyanide blocks the oxygen consumption of metabolizing cells, which is due to inhibition of the enzyme cytochrome oxidase catalyzing the final oxidation step in cellular respiration. Cyanide forms complexes with some heavy metals such as Zn, Pb, and Cd and is highly toxic. Several cyanide-containing substances display acute toxicity toward aquatic life [38]. However, it has been observed that cyanide-containing compounds also have effects on aquatic life at sublethal concentrations.

4.5 Pharmaceuticals

Pharmaceuticals are among the emerging contaminants in wastewater and are one of the most relevant group of substances having a possible impact on aquatic ecosystems due to their chemico-physical properties [44]. Water bodies that receive wastewater discharges are found to be heavily impacted by annual loadings of these substances. Pharmaceuticals along with their metabolites are readily excreted with urine and feces. While the main concern about pharmaceuticals and their metabolites is that they are being added continuously into lakes and rivers as pollutants, they can have certain adverse effects on aquatic ecosystems and harm freshwater resources including drinking water supplies on a long-term basis. Although concentrations of pharmaceutical compounds in aquatic ecosystems are low, they can cause toxic effects on organisms [45]. Uptake of pharmaceuticals into fish can occur *via* both dermal and gill surfaces for water-borne/sediment-associated pharmaceuticals, orally through the diet, or maternally, *via* the transfer of contaminants through the lipid reserve of eggs. Pharmaceutical drugs are generally designed to have low toxicity but there is the potential for unintended side effects. The active ingredients in pharmaceuticals are known to have potential risks to the aquatic ecosystem and are suspected to have direct toxicity to certain aquatic organisms. There is a global concern about the presence of estrogenic residues in the aquatic ecosystems. The source of these estrogenic residues is industrial wastes and medicines, and as additives in animal feed [46]. The effect of these traces is remarkable on aquatic animals and consequently on humans. Fishes are considered more susceptible to the high concentration of pharmaceuticals. It has been reported that substances such as diclofenac and 17 α -ethinylestradiol are responsible for inducing structural disruption in the kidney and intestine and also modify the expression genes, which are associated with the process-controlling metabolism [47, 48]. Their chronic exposure to fishes might affect their survival and reproduction. Another research stated that the presence of antibiotic compounds such as sulfamethoxazole might cause chronic toxicity effects on the photosynthetic apparatus of algae [49]. Therefore, the pharmaceuticals have an effect on the survival of algae due to their rate reduction of photosynthesis by affecting the functions of chloroplasts. A large amount of dead algae lead to secondary effects on the ecosystem such as eutrophication and disruption of the food chain. It threatens the equilibrium of the entire aquatic ecosystem [50].

4.6 Nitrogen

Some water-soluble forms of inorganic nitrogen, such as ionized ammonium, ammonia, nitrite, and nitrate, are present in waste streams, which can exert oxygen demand in surface water resources. Molecular ammonia or NH_4OH is considered as a most toxic form of ammonia, while the dissociated ammonium ion (NH_4) is relatively nontoxic. The discharge of ammonia is mostly from industries, agriculture,

and domestic wastewater. Organic wastes contributed from these sources are responsible for the increases in oxygen demand as a result of the increase in biological decomposition and production of ammonia due to the decomposition of organic nitrogen-containing compounds. Ammonia has toxic effects on aquatic life and high concentration can impair aquatic communities. [51]. It encourages eutrophication in receiving water bodies. Ammonia and nitrate are principal forms of nitrogen and in the presence of oxygen, ammonia is converted into nitrate creating low dissolved oxygen conditions in surface waters [52, 53]. Excess ammoniacal nitrogen is damaging to aquatic life due to its ability to destroy the aquatic enzyme hydrolysis reaction apart from damaging certain tissues and organs in organisms. Its elevated concentration can cause certain symptoms in aquatic organisms such as hypoxia, coma, and reduced immunity, resulting in slow growth and even large numbers of deaths [54]. Ammonia concentrations >2 mg/l are toxic to aquatic life, especially fishes. Several works done on ammonia toxicity on freshwater vegetation have shown that concentrations >2.4 mg/l inhibit photosynthesis. Further, nitrate causes a decline in amphibian populations and in adverse cases causes poor larval growth, reduced body size, and impaired swimming ability. Direct toxic effects from ammonia are those with a direct impact on individual organisms, typically death, reduced growth rate, or reduced reproductive success.

4.7 Heavy metals

Heavy metals comprise one of the most toxic pollutants in aquatic ecosystems due to the detrimental impacts they display in aquatic biota [55]. The heavy metal present in sewage has severe detrimental effects on the ecological balance of the aquatic environment including organisms [56]. Fishes are among the severely affected species and cannot escape from the detrimental impacts of metals. They accumulate a considerable amount of heavy metals in their body tissues and represent a major dietary source of this element for humans. The presence of heavy metals can inhibit the growth of fish as well as its larvae, reduce the size of fish populations, and can threaten the entire fish population if present in high concentration. A high concentration of aluminum can result in osmoregulatory failure in aquatic animals like fishes [57, 58]. It has the potential to bind with fish gills causing several kinds of diseases, suffocation and ultimately death, change in blood plasma levels, and decrease in nutrient intake at gills. More residence time of water in lakes results in the accumulation of heavy metals in biota, while a significant portion finds its way into the sediments. Mercury has carcinogenic and neuro-toxic properties with the ability to accumulate in living organisms, which gradually increases in the food web. Apart from its toxic effects on humans due to biomagnification in fish, mercury compounds have certain toxic effects on aquatic animals as well.

4.8 Phosphorus

One of the major pollutants found in aquatic environments is phosphorus. The average amount of phosphorus in water resources is <1 mg/l; exceeding the amounts permitted in water causes a serious threat to the environment, animals, and aquatic life. Phosphorous is one of the essential nutrients which promotes algal blooms in rivers and lakes and finally leads to eutrophication which causes oxygen depletion in water *via* algal decay, which has harmful effects on aquatic life. A little rise in the content of this nutrient influences toxin production since it increases the growth of the algae.

5. Eutrophication

5.1 Classification of lakes

Lakes are often classified according to their trophic or degree of enrichment with nutrients and organic matter. They are classified by their trophic state with the main classes of oligotrophic, mesotrophic, eutrophic, and dystrophic (**Table 1**).

Several natural water bodies referred as oligotrophic have clearwater ecosystems with limited primary and secondary productivities due to a shortage of major nutrients [60]. These water bodies under natural succession will require thousands of years to transform into eutrophic. The oligotrophic lake is deep and receiving effluents that are nutrient-poor from its drainage basin. Organic matter production is less in the well-illuminated epilimnion. Therefore, the material sinking into the hypolimnion is the small quantity and little oxygen is consumed there during the summer. In contrast, a eutrophic lake is often, but not necessarily, shallower, the drainage basin is richer, and rivers and groundwater discharge into its epilimnion a substantial amount of nutrients. Primary productivity is higher as compared to that of oligotrophic lakes, and therefore, more organic material settles into the hypolimnion resulting in oxygen depletion. As a result, the deeper layers of water of a eutrophic lake become anoxic during summer. Oligotrophic water bodies have $<5\text{--}10\ \mu\text{g l}^{-1}$ of phosphorus and $< 250\text{--}600\ \mu\text{g l}^{-1}$ nitrogen. Oligotrophic water bodies have mean primary productivity ranging between 50 and 300 mg carbon $\text{m}^{-2}\ \text{day}^{-1}$. In eutrophic water bodies, the phosphorus concentration is $10\text{--}30\ \mu\text{g l}^{-1}$, while nitrogen concentration content is $500\text{--}100\ \mu\text{g l}^{-1}$. Primary productivity in eutrophic water bodies is $>1\ \text{g carbon m}^{-2}/\text{day}^{-1}$. If excessive quantities of phosphorus and nitrogen are added to the water, excessive growth of aquatic plants and

Trophic status	Characteristics	TP (mg m^{-2})	TN (mg m^{-2})
Oligotrophic	Oligotrophic lakes have poor nutrients and support little plant growth due to which biological productivity is usually low. The waters are clear and the bottom layers have a good oxygen supply throughout the year.	3.0–17.7	307_1630
Mesotrophic	Mesotrophic lakes have transitional characteristics. They are moderately enriched with nutrients and have moderate plant growth.	10.9–95.6	361_1387
Eutrophic	Eutrophic lakes have a rich supply of nutrients that support dense plant growths due to which biological productivity is usually high. The waters are turbid, which support heavy growths of phytoplankton and an abundance of rooted aquatic vegetation. Deepwaters have less concentrations of dissolved oxygen during the seasons of restricted circulation.	16–386	393_6100
Dystrophic	Lakes in the dystrophic state have highly polluted water quality due to which oxygen is absent and the presence of toxins that support no desirable species.	750–1200	—

Table 1.

Lake classification on the basis of trophic or degree of enrichment with nutrients and in relation to P and N [59].

algae takes place. As these algae die, they are decomposed by bacteria and in this process, dissolved oxygen is utilized. The decomposers use up the dissolved oxygen of the water body. Due to this dissolved oxygen, concentrations often fall considerably for fish to breathe resulting in fish kills [61].

5.2 Causes of eutrophication

The term “eutrophic” has been derived from the Greek words eu meaning “well” and trophe meaning “nourishment.” Eutrophication refers to the abundant growth of phytoplanktons causing imbalanced primary as well as secondary productivity with a high rate of succession from the existing seral stage to a higher seral stage as a result of nutrient enrichment from fertilizer runoff and humans waste. It takes place at the point when a water body moves toward becoming enriched in key-limiting nutrients, such as nitrates, phosphates, and initiating symptomatic changes, including the expanded production of algae (**Figure 1**). Nitrogen (N) and phosphorus (P) are present in all aquatic ecosystems in some limited amount and are considered as an essential nutrient for the biological growth of organisms. Phosphorus being a macronutrient is essential for all living cells as it is an important constituent of adenosine diphosphate, adenosine triphosphate, nicotinamide adenosine dinucleotide phosphate, nucleic acids as well as phospholipids in the cell wall. Phosphorus is stored as polyphosphates in intracellular volutin granules in prokaryotes as well as eukaryotes. Both N and P are essential nutrients that are required by plants and animals for maintaining their growth and metabolism. However, in wastewater, these essential nutrients are available in abundant as phosphates, combined organic nitrogen, nitrates, and ammonia. On discharge into some receiving water body, their increased concentration can initiate

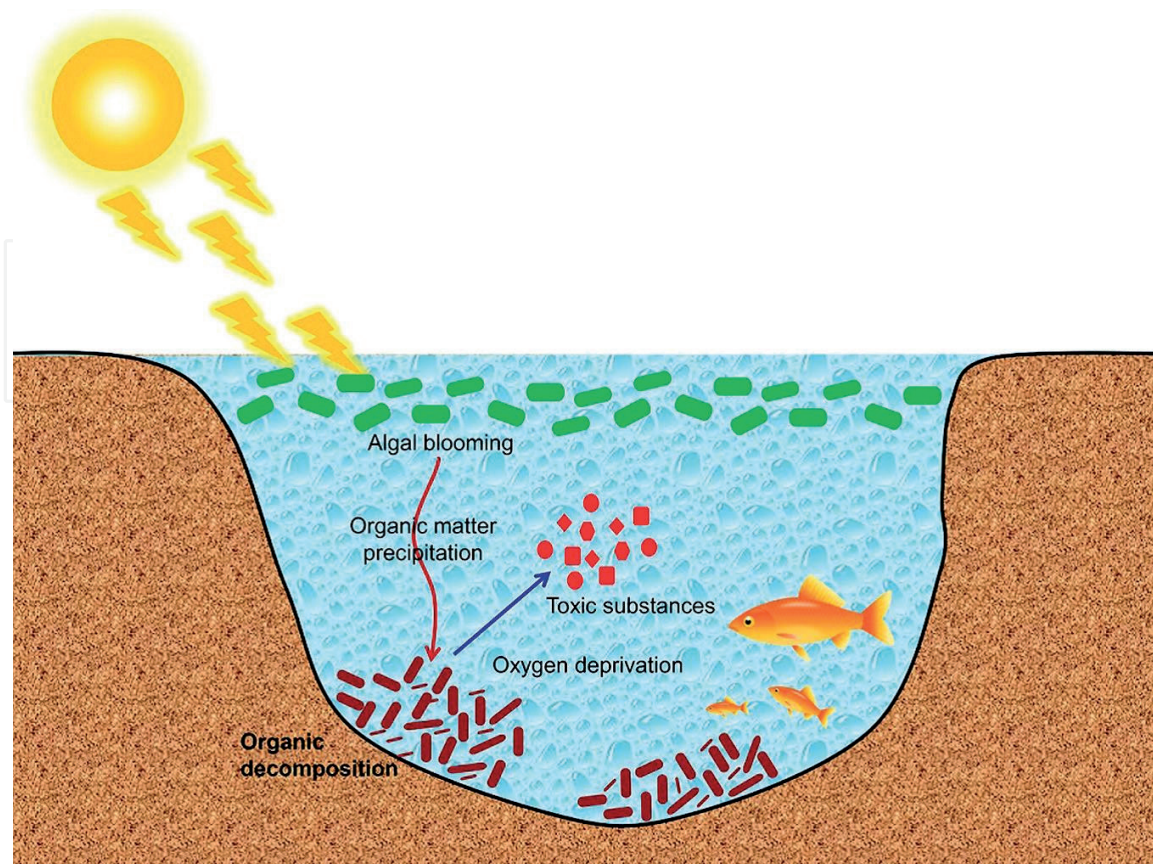


Figure 1.
Eutrophication process [62].

eutrophication with several adverse consequences on the ecological health of the water body [63, 64]. Eutrophication is a natural phenomenon that takes thousands of years to occur in water bodies such as lakes, rivers, and reservoirs. However, an increased rate of nutrient input as a result of anthropogenic activities initiates the process of completing it within a short time period, which is referred to as artificial or cultural eutrophication [65]. Natural eutrophication pushes the succession from open water lake to the marsh to the meadow to the forest, which may take place anywhere within a time period of 500–10,000 years or more depending on the initial condition of that area. Human activities accelerate the rate at which the influx of nutrients into the ecosystems takes place. Runoff resulting from agriculture, urban, and industrial development, mainly from septic systems, sewers, and other human-related actions, increases the rate of entry of both inorganic nutrients and organic substances into aquatic ecosystems.

5.3 Nutrients in aquatic ecosystems

The minimum acceptable concentration of total inorganic phosphate in water is $0.03\text{--}0.04\text{ mg l}^{-1}$ and in many lakes, streams, and rivers where the problem of eutrophication is found to occur and its value has been found to increase by 20–25 times during the past 10–15 years especially in cities and industries. Around 60% of the phosphate present in the waterways of the US is contributed from domestic sewage. Phosphate is also contributed from mines, fertilizer runoff, and domestic sewage containing a high concentration of phosphate with about 50% resulting from human waste and 20–30% from detergents. Animal wastes are also rich in nitrate as well as phosphates [66]. Phosphorus resulting from agriculture runoff is the major source of phosphorus loading in riverine sediments, which is being utilized by benthic algae and rooted plants. Eutrophication has become a major concern in many developed as well as developing countries, especially in highly populated countries such as India, China, Bangladesh, Indonesia, and Pakistan. Lakes as well as reservoirs of several industrialized countries of Europe and North America including the Great Lakes of USA and Canada are facing severe threats due to eutrophication. Several lakes of Asia (54%), Europe (53%), North America (48%), South America (41%), and Africa (28%) are eutrophic. As compared to point source pollution, management of diffuse sources is far more challenging due to the difficulty in controlling nutrients contributing from runoff arising from agricultural and urban areas. Most of the phosphorus enters to water body *via* runoff and erosion taking during winter storm events. Thus, phosphorus influx from diffuse sources may be of little significance in the eutrophication of rivers due to the fact that the timing of the transfers does not usually overlap with the period of maximum biological demand. On the other hand, phosphorus being a significant element in the process of eutrophication needs to be identified and quantified from various sources during periods of low flow. Symptoms of eutrophication mostly take place during the plant growing season, that is, spring and summer, when there is a low flow, high water residence times, abundant sunlight levels, and water temperature is on the higher side, which cause fast algal growth. During the growing period, phosphorus originating from point discharge in rivers is a source of high concentrations of dissolved, bioavailable phosphorus fractions into the water body. According to Meybeck [67], streams and rivers around the world have nearly doubled their concentration of nutrients that is, nitrogen and phosphorus, with local increases of about 50 times. Overall, cultural eutrophication of river ecosystems is a global phenomenon that has, during the past few years, gained much less attention than lake eutrophication. This may be partly due to the effects of increased nutrient concentrations in rivers that are least affected because some factors apart from the

nutrients limit algal growth. Although some progress has been made, still there is a less conceptual understanding of eutrophication in rivers and streams. Hydraulic flushing of nutrients, water velocity, and light limitation are indeed significant in regulatory algal growth interacting in several ways. Moreover, short residence time in rivers (<3 days) will have different effects in comparison with longer residence time in impounded rivers or riverine lakes (>3 days). In comparison with lakes (>30 days retention time) and considering some of the factors mentioned above, Hilton [68] devised a conceptual model of how the process of eutrophication takes place in rivers. Since natural streams are net heterotrophic, Dodds [69] formulated the trophic state of rivers into autotrophic, nutrient controlled, and heterotrophic, external carbon-regulated state. The autotrophic state in lotic water bodies is mostly dependent on phosphorus and nitrogen values. Algal biomass is positively correlated with gross primary production in streams and rivers. Eutrophication is a problem that is persistent worldwide. In Spain for example, 80% of the lakes, 70% of the reservoirs, and 60% of the river sites were eutrophic in the 1990s with hypertrophy increasing downstream [70]. There may be several deleterious effects of eutrophication on the environment, which have adverse consequences on the health of the exposed animal population apart from humans through several pathways. Certain health risks appear when extracted freshwater from eutrophic water bodies is supplied for drinking purposes. A severe impact can also occur during animal watering from eutrophic waters.

5.4 Symptoms and effects of eutrophication

The following are the symptoms of eutrophication:

1. Release of limiting nutrients such as phosphorus and nitrogen into the water body.
2. Degradation of water quality such as the appearance of red tides or excessive foam over the surface of the water.
3. Increase in the productivity of the ecosystem along with biomass of phytoplankton, macrophytes, and harmful algal blooms.
4. Reduction in the water clarity and sediments are visible from a depth of few feet. Due to the greenish color of water, turbidity, and high levels of planktonic algae, the clarity of the water is drastically reduced.
5. Oxygen depletion due to increased production of organic matter and formation and release of hydrogen sulfide.
6. Shifts in the composition of species, for example, increased concentration of nitrogen causes new and more competitive forms to invade and compete with original ones.

The following are the effects of eutrophication:

1. Microcystins are certain toxins produced by various genera of cyanobacteria, the predominant one being *Microcystis* sp. These toxins are highly water-stable and resistant to boiling, and thus pose a threat to water and food quality if not properly monitored. Exposure to microcystins represents a health risk to aquatic organisms, wildlife, domestic animals, and humans upon drinking or

ingesting cyanobacteria in the water. These substances can enter the food chain and cause mortality in an animal apart from other health effects in humans.

2. If the water body affected by eutrophication is used for supplying drinking water to a community, it can cause an increase in the cost of treatment due to prevailing taste and odor problems. Raw water is a source of algae and several other aquatic plants, which also increases the treatment cost, while the quality of water supply may decrease. Planktonic algae when present can shorten filter runs.
3. Certain algae have been found to release organic compounds that are supposed to cause tastes and odors problems besides which they also produce trihalo-methanes (THMs) and halo acetic acid (HAA) precursors which are considered as human carcinogens. These compounds react with chlorine, which is used during the disinfection process in wastewater treatment plants and is released with the treated effluent.
4. As the algae die, they become a source of food for the bacterial population, which consumes oxygen during the process. This may cause hypoxia, especially during the night due to which animals especially fish may suffocate resulting in fish kills. Mass deaths are also due to the release of hydrogen sulfide.
5. Aquatic weeds have been often found to block irrigation canals and other water supplies.
6. Excessive growth of macrophytes and algae can impair recreational purposes of water such as swimming, boating, and fishing. Odor problems can arise due to water weeds, dead decaying algae as well as algal scum.
7. Economic loss is also suffered due to change in the composition of species, fish kills, loss of recreational value, and reduction in tourism activities.

6. Conclusion

There has been a continuous increase in the sewage generation throughout the world from domestic, industrial as well as agricultural sources. This has put a serious threat on the freshwater ecosystems as a significant part of them goes untreated into freshwater ecosystems. Due to the presence of a wide variety of contaminants such as suspended solids, pharmaceuticals, heavy metals, sewage disposal has affected several aspects of flora and fauna. It has taken a heavy toll on aquatic life causing several undesirable changes in their structure and composition. Sewage disposal is regarded as a primary culprit in the deterioration of the health of freshwater bodies around the world. It is responsible for the process of eutrophication, which has several negative repercussions on the water bodies including harmful algal blooms, the decline in water quality, loss of economic as well as the esthetic value of the water body.

Conflict of interest

The authors declare no conflict of interest.

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