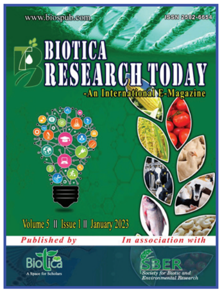

Biotica Research Today Vol 5:1 2023

25/28

Green Approaches for Freshwater Eutrophication Management

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Keywords
Eutrophication management, Green technologies, Phyto-remediation, Water quality

Article History
Received on: 02nd January 2023
Revised on: 08th January 2023
Accepted on: 09th January 2023

E-mail: *bioticapublications@gmail.com*

How to cite this article?
Jesna *et al.*, 2023. Green Approaches for Freshwater Eutrophication Management. Biotica Research Today 5(1):25-28.

Abstract

Phosphorus (P) plays an important role in the inland aquatic ecosystems. However, inland aquatic ecosystems like, wetlands, reservoirs, and rivers are gradually accumulating this element and as a consequence eutrophication becomes a global problem. Eutrophication causes excessive algal growth, disrupting the composition and distribution of aquatic flora and fauna, disturbing the aquatic food web and also degrading the recreational area. Therefore, the management of eutrophication is necessary for the restoration of freshwater aquatic bodies. Conventional treatments like chemical treatments lead to the addition of external chemicals to the ecosystem. Hence, technologies, for rapidly reducing phosphorus content or influx and reduction in organic matter are necessary to overcome the problem of eutrophication in long term. Green techniques are also referred to as an environmentally friendly solution to this problem. Various green techniques like phytoremediation, microbial remediation, and the use of agricultural waste as green adsorbent for remediation may be the alternative options for P mitigation in freshwater ecosystems.

Introduction

Eutrophication is the process by which water bodies are enriched with dissolved nutrients such as phosphorus and nitrogen that stimulates the exponential growth of primary producers, resulting in dissolved oxygen depletion. It occurs in lakes, streams, rivers, and coastal waters characterized by algal bloom and low dissolved oxygen and consequent fish kills (Paul *et al.*, 2022). In addition, the algal bloom causes lowered light penetration and consequent loss of submerged aquatic plants. Eutrophication can be natural eutrophication due to the sedimentation of nutrients over centuries as lakes age or cultural eutrophication due to human activities through both point-source discharges and non-point sources of nutrients *viz*. runoff from the catchment areas.

Fresh Water Eutrophication

In fresh water aquatic ecosystems, eutrophication is caused by over-enrichment with phosphorus in particular. Eutrophication is a persistent and extensive environmental problem prevailing globally. Reduction in nutrient input has helped in recovering some lakes. But in aged lakes, the sedimentation causes the leaching of nutrients to the water column consistently causing nutrient management and eutrophication control futile.

Causes of Eutrophication: Point and Non-Point Sources

Eutrophication is a result of nutrient over abundance in water bodies due to various sources, which may be categorized as point and non-point sources based on the source of nutrient input to the ecosystem. The point sources of nutrients include sewage discharge, industrial effluents, and discharge from aquaculture farms. Non-point sources of nutrients include mainly the runoff from agricultural land or urban lands. In addition, the higher water temperatures due to global warming add to the problem through accelerating primary production in presence of the high nutrient load.

Impacts of Eutrophication

Eutrophication affects an aquatic ecosystem in terms of unwarranted plant production, blooming of harmful algae, and fish kills. The process of eutrophication impairs the trophic level energy transfer in the food web with major transformations in the community structure (Chislock *et al.*, 2013). Eutrophication hinders the utilization of water for other purposes like drinking water supply, reduced fish production and loss of major fisheries, loss of vulnerable biota, and loss of recreational amenities. Additionally, the harmful algal blooms produce toxins that pose risks to the health of aquatic organisms as well as the human. Figure 1 depicts the direct and indirect impacts of eutrophication.

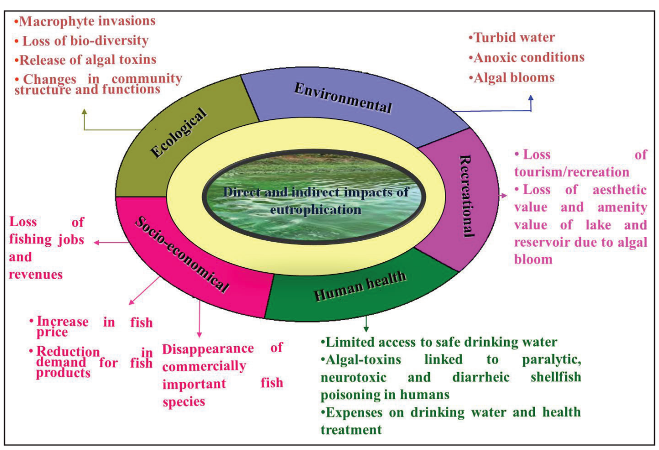

Figure 1: Potential negative impacts of eutrophication

Green Techniques

Technologies for rapidly reducing phosphorus content or influx and reduction in organic matter are necessary to overcome the problem of eutrophication in long term. The preventive measures include the controlled inflow of contaminated effluents, primary treatments before discharging into a water body, or to control the fertilizer input at catchment areas to reduce the nutrient input through runoff. The existing chemical treatments for phosphorus removal from water, for inhibiting the leaching of phosphorus from bottom sediments to the water column, and application of algicides involves the addition of chemicals to the ecosystem, which would be another threat to the aquatic ecosystem. Green techniques also referred to as bioremediation, offers an environmentally friendly solution to this problem. Various green techniques include the use of plants (phytoremediation) - both terrestrial and aquatic, microbes, algae, or a combination of microbes, algae, and plants as in constructed wetlands.

Phyto-Remediation

Phytoremediation is a process of bioremediation that utilizes plants or rhizosphere microbiota or its association to remove or lower the bioavailability of contaminants in soil, surface water, or ground water. Hence it is an eco-friendly, sustainable, and low cost method for the removal of phosphorus. Once the plants attain the maximum growth and biomass, the plants must be harvested and disposed of. It covers different approaches like:

(i) Phyto-sequestration or phyto-stabilisation, where, the mobility and migration potential of contaminants in soil is hindered by stabilizing the pollutants and thus the bioavailability is minimized.

(ii) Rhizo-degradation/ Phyto-stimulation is a water remediation technique involving the degradation of contaminants by the rhizosphere microbes stimulated by exudates from plants enhancing the growth, metabolism and the biodegradation potential of the microbes.

(iii) Phyto-hydraulic degradation uses deep-rooted plant which can degrade the contaminants in groundwater when they contact with the root of these plants.

(iv) Phyto-extraction or phyto-accumulation where the plant root absorbs the contaminant, followed by the translocation of contaminants into above-ground components of the plants. Phytoextraction is of two types, continuous and chelate-assisted.

(v) In Phyto-volatilisation, the contaminants are absorbed by the plant through it's roots which are then translocated to the leaves, transformed through metabolic activities into volatile form and then transpired.

(vi) Phyto-degradation/ Phyto-transformation: The contaminants are absorbed into the plant tissues are metabolized, or bio-transformed and biodegraded into simpler molecules. Also, the plants reduce runoff facilitating the adsorption of compounds on to root surface and promoting evapotranspiration.

Aquatic Macrophytes for Phytoremediation

Various terrestrial, as well as aquatic plants have been tested for their bioremediation efficiency for the treatment of polluted water as an alternative to conventional treatment methods. The efficiency of nutrient removal, rapid growth, and biomass production decide the bioremediation potential along with other environmental factors. Biodegradation of pollutants from the water was achieved by aquatic macrophytes such as *Eichhornia crassipes* (water hyacinth), *Typha latipholia* (common cattail), *Pistia stratiotes* (water lettuce), *Marsilea quadrifolia* (water clover), *Acorus calamus* (sweet flag), *Phragmites communis* (common reed), *Vallisneria spiralis* (channel grass), *Ipomoea aquatica* (water spinach), *Jussiaea repens* (water primrose), and *Lemna minor* (duck weed). In table 1, some of the plants utilized for their phytoremediation potential are summarized.

Table 1: A summary of research studies in which aquatic macrophytes were used for phytoremediation of eutrophic waters

Plants and aquatic macrophytes/ used for phytoremediation	Utilistaion/ phytoremediation efficiency
Pistia stratiotes	Effective in removing nitrogen and phosphorus from eutrophic stormwaters.
Ipomoea aquatica	Effective in nutrient removal from eutrophic water.
Eichhornia crassipes	Significant reduction in concentrations of total nitrogen, ammonium-N, and total phosphorus from an ultra-eutrophic lake.
Iris sanguinea	Efficient nitrogen and phosphorus removal to treat various eutrophic waters.

Improving the Plant Performance in Phytoremediation

Different plant hybridization or genetic engineering techniques to develop improved hyper-accumulator plant varieties with elevated growth rate, high biomass, or imparting hyper-accumulation capacity to suitable fast-growing plants are tested. Using microbes to improve plant performance and increasing the bioavailability of nutrients through the addition of chelating agents are also evaluated for augmenting the bioremediation process.

Constructed Wetland

To control anthropogenic eutrophication, the reduction of nutrient loading is the first step. This bottom-up strategy has been widely used for controlling point sources of pollution. However, controlling non-point sources of pollution, challenges are more. To meet these challenges, the role of constructed wetlands is very important. They are designed and constructed for utilizing the natural processes involving plant, soil, and associated microbial assembly for controlling wastewater, are built next to the banks of the tributaries or around the water body to avoid nutrient loading by runoff. They are the natural solution for the removal of nutrient pollution in the aquatic ecosystems. These low-tech management systems are sometimes far better than energy-intensive, costly engineering processes for wastewater treatment. Additionally, they can prove secondary benefits such as improvement of biodiversity. Due to their aesthetical appearance and lesser energy consumption, they can be considered as a 'green' treatment technique and thus contribute to sustainable development. Researchers reported that these constructed wetlands can remove the P inputs by almost 30-94%.

Agricultural Waste-based Biosorbents (AWBs) from Water and Wastewater

Agricultural waste-based biosorbents (AWBs) have been tested and utilized for the removal of phosphorus from polluted waters. The AWBs include waste fruit residues, sugarcane bagasse, coir pith, and wood for their beneficial roles. AWBs have many advantages like reducing the P contamination caused by mining practices and thus preventing the surface water from being in a eutrophicated state. This is one of the best methods to utilize agricultural waste since it is a sustainable technology as well as a better option to reuse or recycle the waste at low cost without contaminating the environment. There are many factors like pH, temperature, initial P concentration, dosage of the AWBs applied, interfering anions, and contact time that influence the performance of AWBs in P removal. However, the AWBs have low P removal capacity due to the lack of anion binding sites on the surface of it. Hence to cationize the surface of AWBs, metal loading, and hybridizing with inorganic chemicals are feasible options to enhance the performance.

Innovative Techniques for Phosphorus Removal

The innovative and economical wastewater treatment methods are:

• Multi-stage constructed wetlands and phosphorus evacuation channel frameworks.

• Phosphorus expulsion and sequestration channels to treat the point sources of P pollution.

• The 'torpedo' channel frameworks for farming tile deplete and urban tempest water surges for treating phosphorus from non-point sources. These treatment methods are efficient to remediate P as well as few other contaminants such as metals and minerals (El-Sheekh *et al.*, 2021).

Microbial Bioremediation

Wastewater is rich in nutrients and their release into the surface water without treatment may result in poisonous cyanobacterial blooms. The heterotrophic microorganisms can be used for wastewater treatment as they also require carbon and different nutrients for their growth and development. In general, the algal-bacterial combination has been widely used for the treatment of wastewater. Carbon and macro- and micro-nutrients seem to play a central role in the mechanism. The mechanism involves the exchange of vitamins, nitrogen, carbon, and phytohormones between algae and bacteria. Here, both algae and bacteria suit each other needs by converting the metabolism. The algal-bacterial symbiosis is of great importance to environmental green technology. Algae produce photosynthetic oxygen that could be used for algae-bacteria-based wastewater treatment. Algae and bacteria combination/ symbiosis is proven to be important in the bioremediation of toxic chemicals and metals.

Green Nanomaterials for Combating Freshwater Eutrophication

One of the novel approaches for the remediation of contaminants in the 21st century is the use of nanomaterials. Due to their unique character of high surface-to-volume ratio, they can be widely used for pollution remediation. The nanostructure titanium oxide (TiO_2) has been widely used for drinking water treatment. Moreover, naturally-synthesized nanomaterials have been used for the treatment of eutrophic wastewater. Iron (Fe) nanoparticle was synthesized using the leaf extracts of green tea and eucalyptus (Wang *et al.*, 2014) for the treatment of eutrophic water. In spite of the rapid increase in the number of engineered nanomaterials in eutrophication management, their impacts on the structure and function of aquatic ecosystems is not known. Hence, it is important for an in-depth study on the impacts of these emerging materials on the structure and function of aquatic ecosystems. Moreover, little is known about how manufactured nanomaterials may interact with nutrient pollution in altering aquatic ecosystem productivity, despite the recognition that eutrophication is the primary water quality issue in freshwater ecosystems worldwide.

Conclusion

Eutrophication is a serious problem worldwide. Many anthropogenic factors have caused nutrient enrichment of freshwater ecosystem through nutrient loading. This nutrient loading results in harmful planktonic bloom in freshwater and thus it hampers the health of aquatic ecosystem and finally human health. Hence, environment friendly sustainable green technologies are required for management of freshwater ecosystem health as it is directly related with human health. Phyto-remediation, microbial remediation or use of agro-waste biomass can be the green approaches to remove excess phosphorus from freshwater ecosystem.

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