ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 14, Issue, 04, pp. 65362-65369, April, 2024
https://doi.org/10.37118/ijdr.28143.04.2024

REVIEW ARTICLE

OPEN ACCESS

A REVIEW ON EFFECTS OF EUTROPHICATION IN AQUATIC ECOSYSTEM

Panchakarla Sedyaaw[1*], Dr. V.R. Bhatkar. V[2] and Apurva Nikhil Sawant[3]

[1]Ph.D Scholar. Department of Fish Processing Technology, College of Fisheries, Ratnagiri; [2]Assistant professor. Department of Aquaculture, College of Fisheries, Ratnagiri; [3]Senior Research Assistant.Department of Aquaculture, College of Fisheries, Ratnagiri

ARTICLE INFO

Article History:
Received 20th January, 2024
Received in revised form
27th February, 2024
Accepted 12th March, 2024
Published online 30th April, 2024

Key Words:

Algal, Eutrophication, Nutrition, Quality and water.

Corresponding author:
Panchakarla Sedyaaw

ABSTRACT

Eutrophication is the process of addition of nutrients to water bodies, including lakes, rivers, estuaries and oceans resulting in changes to the primary production and species composition of the community. The long-time spans involved in this natural eutrophication process are typically geological time scales. Geological time scales are often used to describe the lengthy periods involved in this natural eutrophication process. However, since the industrial revolution, eutrophication of many aquatic bodies has risen as a result of anthropogenic fertiliser consumption. Cultural eutrophication is a process that has a lot of negative effects on ecosystems around the world. Cultural eutrophication has also had detrimental effects on human society, such as decreased seafood productivity, problems with drinking water, and the presence of phytoplankton poisons in both seafood and drinking water. Many of the problems related to eutrophication are primarily caused by the development of algal blooms, which have the potential to be harmful or lead to severe changes in the ecology of water bodies. This essay addresses the biological effects of eutrophication, its physical and chemical causes, and its effects on human society. Water bodies are typically categorised differently depending on their trophic status. Algal blooms, for instance, have been proven to develop with varying nitrogen levels depending on location.

Citation**: *Panchakarla Sedyaaw, Dr. V.R. Bhatkar. V and Apurva Nikhil Sawant, 2024.*** *"A review on effects of eutrophication in aquatic ecosystem". International Journal of Development Research*, 14, (04), 65362-65369.

INTRODUCTION

The word "eutrophic" comes from the Greek words "eu" for "well" and "nourishment" to describe lakes and estuaries that accumulate a lot of plant nutrients. The term "eutrophication" refers to the combined effects of excessive phytoplankton growth, which results in an imbalance in primary and secondary productivity and a quicker rate of succession from existence to higher serial stages. The modern use of the word eutrophication is related to inputs and effects of nutrients in aquatic systems (Eslamian *et al*., 2013). This nutrient enrichment is brought about by runoffs that carry down excessive fertilisers from agroecosystems and/or human waste that has been dumped into settlements (Khan and Ansari, 2005). The word "eutrophic" comes from the Greek words "eu" for "well" and "nourishment" to describe lakes and estuaries that accumulate a lot of plant nutrients. The term "eutrophication" refers to the combined effects of excessive phytoplankton growth, which results in an imbalance in primary and secondary productivity and a quicker rate of succession from existence to higher serial stages. This nutrient enrichment is brought about by runoffs that carry down excessive fertilisers from agroecosystems and/or human waste that has been dumped into settlements (Khan and Ansari, 2005The term "eutrophication" refers to the combined effects of excessive phytoplankton growth, which results in an imbalance in primary and secondary productivity and a quicker rate of succession from existence to higher serial stages. This nutrient enrichment is brought about by runoffs that carry down excessive fertilisers from agroecosystems and/or human waste that has been dumped into settlements (Khan and Ansari, 2005). Due to increased urbanisation, industrialization, and intensifying agricultural output, human activities that increase the rate of nutrient intake in a water body can significantly speed up water eutrophication (Yang *et al*., 2008). The rates at which nitrogen (N) and phosphorus (P) enter the biosphere are accelerating, and these rates are expected to continue to rise in the ensuing decades, which is one of the causes of the growing human population and its effects on the environment (Glibert, 2017; Sutton *et al*., 2013). Due to their effect on water quality, HABs have attracted a lot of attention lately. Although there has been tremendous development in the methodologies for predicting HAB events, there are still information gaps and a need for technology advancements, which will improve the early identification of HABs (Stauffer, 2019). In order to comprehend and improve the mitigation of HABs plans, variables addressing climate change need to be integrated, which will further increase the complexity of the current framework.Wells *et al*. 2020 presented collective deliberations from a symposium on HABs and climate change.). A water body's eutrophication process can be greatly sped up by human activities that raise the rate of nutrient intake due to growing urbanisation, industrialization, and escalating agricultural output. Increased nutrient turnover, poor resistance, high porosity of nutrients and sediments, extinction of dominant species and functional groups, and decreasing productivity in lake aquatic ecosystems are all effects of human activities in the watershed (Liu and Qiu, 2007). For instance, aquaculture is one of many human activities causing the global collapse of fisheries populations and the environmental degradation of coastal waterways (Alongi *et al*., 2003). Large quantities of nitrogen, phosphorus, and other nutrients are introduced to water bodies including lakes, reservoirs, embouchures, and bays as a result of human activities. This might encourage the rapid growth of algae and other plankton and decrease water quality, as well as have negative ecological consequences on the structures, functions, and processes of aquatic ecosystems (Western, 2001). Numerous facets of HABs, including 36odeling, molecular alterations, and their effects on fisheries, were investigated. Understanding future HAB trends through new research avenues and advancement was also thought to be crucial for the growth of this difficult field of study.

Types of eutrophication

Natural eutrophication: Natural eutrophication is recognised as the accumulation, flow, and addition of nutrients to water bodies that cause initial alterations in the production and community species. It has been occurring for thousands of years (Knight, 2021). The runoff of nutrients in storm water causes an increase in nitrate and phosphate levels in receiving water bodies, such as lakes, estuaries, and slow-moving streams. Due to this enrichment, the levels of biological activity in young water bodies—which are often oligotrophic due to low nutrient concentrations—and old water bodies—which are typically eutrophic because of a high concentration of nutrients—are correspondingly low and high(Sonargharee*t al,*.2020). Some naturally occurring bodies of water, like lakes, eventually lose their capacity to purify themselves. This results in substantial volumes of solid materials being forced into the sediments of these water bodies by floods and runoff, where they can subsequently absorb a lot of nitrate and phosphate while also filling the basin. This interaction between the nutrients in the sediment and the aquatic plants encourages eutrophication, which degrades water quality and draws attention to the mechanisms involved in eutrophication (Sonarghare *et al*., 2020).

Cultural eutrophication: Eutrophication due to human activity that causes phosphate and nitrate runoff into lakes and rivers as a result of land runoff is known as cultural eutrophication, also known as anthropogenic eutrophication. As a result of human anthropogenic activities like the usage of fertilisers and detergents, as well as the disposal of untreated sewage and aquaculture effluent, the level of nutrient loading into water bodies has significantly grown. Cultural eutrophication is the end outcome of these human activities, which continuously increase the amount of nutrients (nitrate and phosphate) in the water body to a level above the capacity of these water bodies to purify themselves.Therefore, eutrophication that is accelerated beyond what occurs normally results in undesirable changes to the natural biological system(Sonargharee*t al* ., 2020 ; Knight, 2021).

Stages of eutrophication

I. Inalake, the water is cold and clear (oligotrophic stage), supporting little life.
II. With time, streams draining into the lake introducenutrients such as nitrates and phosphates, which encourage the growth of aquaticorganisms. Aquaticplants and animal life grow rapidly, and organicremains begin to bedeposited on the lake bottom (mesotrophicstage)
III. Pollutants from anthropogenicactivities like effluents from the industries and homes can radically acceleratetheaging process. This phenomen on is known as Culturalor Accelerated Eutrophication.

Causes of Eutrophication: Natural events: The seasonal occurrence of rainfall and storms that produce flooding have been recognised as the main factor that delivers extra nutrients from the land into the receiving water bodies. Additionally, as lakes get older, organic waste builds up in the substrate of aquatic systems, which encourages phytoplankton and cyanobacteria blooms to proliferate quickly (Knight, 2021; Yang, 2022).

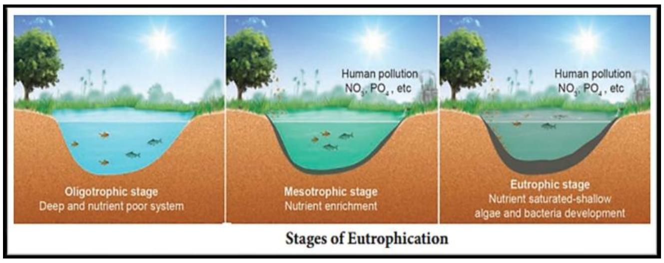


Fig. 1. Stages of Eutrophication (Prasana, 2023)

Nutrient enrichment: Because of the over-reliance of the human population on nitrate and phosphate fertiliser for agricultural production, agricultural fields' runoff has enriched aquatic bodies (Knight, 2021; Zhang, *et al*., 2022; Yang, 2022). People are consequently the main source of eutrophication due to the buildup of nitrate and phosphate brought on by human activities associated with agriculture. The buildup of nitrate and phosphate fertiliser in agricultural runoff has allegedly been the cause of a dense development of aquatic plants (like hyacinths) and algal blooms (Knight, 2021; Qi *et al*., 2022). Eutrophication, or the increase in nutrients in water bodies, has been linked to the movement of animal feeds and manure via runoff from agriculture, as well as phosphate mining and the production of industrial nitrate fertilisers (Sonarghare *et al*., 2020). The most important factors that cause water eutrophication are N and P input and enrichment. Based on the chemical makeup of algae, "$C_{106}H_{263}O_{110}N_{16}P$" is the "experienced molecular formula" for algae. The two elements that make up the least amount of an algae's molecular formula are N and P, with P serving as the primary limiting element for algal development in water (Mainstone and Parr, 2002). According to studies, phosphorus controls 80% of lake and reservoir eutrophication, nitrogen controls 10%, and other factors control the remaining 10% of eutrophication. (Zhao, 2004).

The ratio of N: P in the water body (referred to as the "Redfield ratio") is an important indicator of which nutrient is limiting eutrophication. If theRedfield ratio is 16:1, P is most likely the limiting factor for algal growth; lower ratios indicate that N is of great importance (Redfield *et al*., 1963; Hodgkiss and Lu, 2004). P has been shown to be the principal limiting nutrient for primary production of phytoplankton in many freshwater environments (Phlips, 2002), while N is commonly limiting in marine ecosystems (Cloern, 2001). In water bodies with high P levels, the growth of phytoplankton is restricted by the amount of available N. Phosphorus turns into the limiting element in water bodies with low phosphate levels or those with blue-green algae that grow quite well and fix enough nitrogen from the atmosphere. This is because some P is used to balance out the high nitrate content (Reynolds, 2006). In such cases, it can be demonstrated that substantially eutrophicated water bodies with high levels of both N and P are unlikely to experience a paroxysmal algal boom. In order to address the issue of water eutrophication, it is crucial to reasonably control the amounts of both N and P (Yang, 2008).

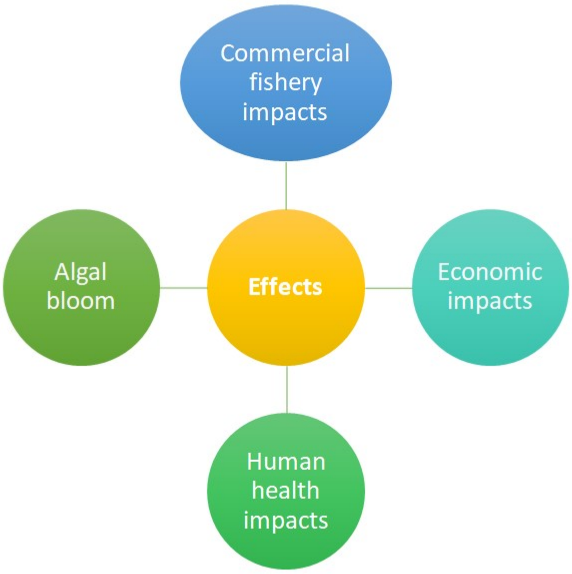
A) Point-sources of nutrients—Efforts to control point sources of nutrient loading to waterways have been successful in developed countries, especially for P. Aggressive removal of P from laundry detergents and sewage effluent has hastened this change (Litke, 1999). van Puijenbroek, Beusen, and Bouwman (2018) estimated that by 2010, tertiary or quaternary treatment to remove P was employed in 56% of North American treatment plants, and 75% of those in Western and Central Europe. However, advanced treatment is uncommon in developing nations; for instance, barely 10% of plants in Latin America have advanced nutrient removal, and almost no nutrients are removed in sub-Saharan Africa. When discharges from major metropolitan cities affected lakes and estuaries, nutrient removal from point sources has been most effective in reducing eutrophication.

B) **Nonpoint loading—**It has proven to be significantly more challenging to control nonpoint pollution from agriculture and other sources. Because these sources account for 82–84% of the P and N that enter our rivers, the limited success in nonpoint management has hampered the overall control of eutrophication (Carpenter *et al*., 1998; 1990s estimate). The variety and dispersion of sources contribute to the challenge in addressing nonpoint pollution. In the United States, agriculture is responsible for around 53 and 48 percent, respectively, of the N and P pollution, and hundreds or thousands of farms and ranches along a canal frequently contribute to loading. When fertilisers are applied to fields, over 80% of the nitrogen and 25-75% of the phosphorus fertilisers are lost and reach the environment (Sutton *et al*., 2013). Accelerating use of N and P in fertilizers since the 1950s has exacerbated this problem (Carpenter *et al*., 1998; Glibert&Burford, 2017). Again, hundreds or thousands of sources contribute significantly to urban runoff into storm drains. Control of nonpoint pollution has also advanced more slowly than that of point sources since governments have primarily relied on voluntary compliance for the former, whereas point-source compliance is typically mandated by law (Boesch, 2019).

Environmental factors: Numerous factors contribute to water eutrophication; however, it is unknown how these factors impact algal blooms. Many moderately eutrophicated water bodies can have an algal bloom when the environmental conditions are ideal during particular seasons or years. The following is an explanation of how some of these factors are impacted by nutritional intakes: The two key factors that contribute to an algal bloom are temperature and salinity. The concentration of nutrients also affects the change in salinity. Research shows that salinity is negatively related with NO_3^--N, and PO_4^{3-}-P, but positively related with NH_4^+-N, and however, it is not very related with NO_2^--N. One of the key elements influencing water eutrophication is the quantity of carbon dioxide. Cyanophytes are better equipped to use low levels of CO_2, and they float more readily at low CO_2 and high pH levels. Yin (2002) reported that monsoons served as a flushing mechanism in two ways: (1) They reduced seasonal eutrophication by nutrient enrichment in summer, and (2) they prevented long-term (annual) accumulation of organic matter in the sediments due to nutrient enrichment in the region. Aquatic flora's development, diversity, and density are significantly influenced by light. According to reports, algal growth increases with light intensity, and 4000 lux was shown to be the most suitable level (Shen, 2002) probably due to low light intensity caused by algal blooming. Due to interactions with nutrient loading and physical circulation, eutrophication in an estuary is a complex process that will likely have a distinct impact on each estuary as a result of climate change. In order to effectively control eutrophication, it is crucial to take climate change effects into account in the context of each specific estuarine function (Howarth *et al*., 2000). There are other factors like pH and dissolved oxygen affecting water eutrophication (Khan and Ansari, 2005). The availability and absorption of nutrients from solution are closely tied to pH changes. Changes in pH have an impact on the ionisation of electrolytes or the valence numbers of various ion species (Yang *et al*, 2008). Wastewater discharge, agriculture and other anthropogenic activities generally override natural processes and substantially increase N and P concentrations (Moss *et al*., 2013). Production of P has increased over 18-fold since 1940 (U.S. Geological Survey, 2014), and that of N over sixfold (Millennium Ecosystem Assessment, 2005a). A portion of these additional nutrients inevitably enters the aquatic environment. Consequently, the annual flux of N to the oceans has nearly doubled from backgroundconditions and the flux of P has tripled (Millennium Ecosystem Assessment, 2005b). The N: P ratio entering waterways is useful as a measure of which nutrient may limit algal growth limitation (Redfield, 1958). When TN:TP in the environment is >14:1 (by mass), N may be present in excess and P often limits algal growth:

When N: P< 14, N is often the limiting factor (Downing & McCauley, 1992). However, the bioavailability of each nutrient and the nutrient needs of different algal taxa makes this relationship far from precise, and some authors have suggested using different ratios to assess nutrient limitation (Morris & Lewis, 1988; Tank &Dodds, 2003). Understanding which nutrient(s) limit algal growth help managers decide what control measures should be implemented to reduce eutrophication.

Effects of eutrophication



Economic impacts of Algal Blooms : Harmful Algal Blooms (HABs) episodes represent a natural freshwater and marine risk and their manifestations are correlated to a significant impact on socio-economic systems and human health Episodes of harmful algal blooms (HABs) provide a natural freshwater and marine risk, and the effects of these events on human health and socioeconomic systems are enormous. Millions of people around the world rely on freshwater or marine water for goods and services that are only accessible as long as waterbodies are preserved. The physical, chemical, and biological characteristics of the water environment are altered as a result of anthropogenic influences and climate change. Public health, commercial fishing, tourism, recreational activities, monitoring, and management are the main industries affected by these changes, and they could have significant socioeconomic effects (Anderson 2000). HABs are increasingly being recognized as one of the most negative aspects of cultural eutrophication (Paerl & Otten, 2013b In lakes and reservoirs, estuaries, and coastal waterways, excessive nutrient loading causes a surge in toxin-producing algal blooms such as cyanobacteria and dinoflagellates, and it encourages the growth of undesirable associated algae in streams and rivers (Dodds, Carney, & Angelo, 2006; Lewis *et al*., 2011). HAB toxins can make waters unsafe and unusable for drinking, irrigation, and recreational purposes (Koreiviene, Anne, Kasperoviciene, &Burskyte, 2014), rendering them dysfunctional from ecologic, economic, and aesthetic perspectives (Figure 2).

Commercial fishery impacts: Economic losses in the seafood market are closely tied to instances of harmful algal blooms (HABs). Fish death from an oxygen deficit in waterbodies brought on by the growth of algae may cause the closure of the fish trade during HABs due to fish absorption of algal-released toxins. The resultant increase in fish prices and the decline in consumer demand as a result of consumers' reluctance to purchase fish at a high price, particularly during HABs manifestations, are just a few of the economic effects of HABs on the commercial fisheries industry. The producers are directly impacted financially if commercial fishing is stopped, and the cost of harvesting fish that cannot be sold because of high toxicity levels must also be taken into account. HABs may also have an effect on aquaculture facilities that must make large financial investments to safeguard the lucrative sector. Due to the high level of public interest in the safety of seafood, the economic impact of commercial and recreational fishing is essential to understanding how people will respond to the problems caused by HABs. However, economic studies on how HABs affect the commercial fishing industry usually contrast freshwater and seawater (pretty 2003).

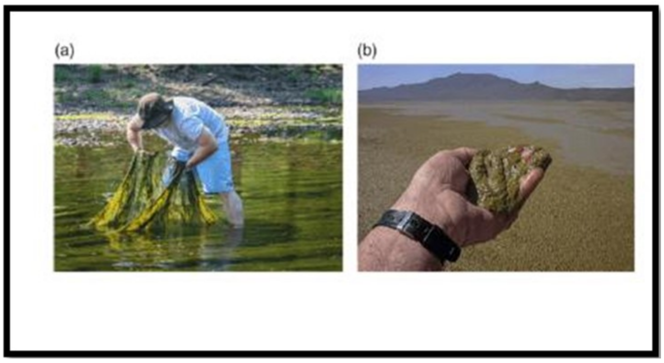


Fig. 2. (a) Filamentous algae (Cladophora) in a nutrient impacted Greenbrier River, West Virginia. (b). Bloom of cyanobacterium, *Nodulariaspunigena* in Farmington Bay of the Great Salt Lake (Utah, USA). This toxic species creates dangerous blooms in saline estuaries such as the Baltic Sea and Gippsl and Lakes, Australia. (Source): a) West Vargina Department of Environmental protection; b) Wayne Wurtsbaugh

Neurotoxins and Methanol: According to reports from the Florida coast in the United States, red tides were caused by large concentrations of the dangerous dinoflagellate Karenia brevis, which produced the neurotoxins brevetoxins and led to massive fish kills as well as the deaths of marine mammals, sea turtles, and sea birds. (Pierce and Henry, 2008). The primary mode of action of brevetoxins is the attachment to voltage-gated sodium channels, which depolarizes nerve cells and impairs neuronal signalling. Additional effects include bronchial constriction, immunological suppression, and hemolysis.

Shellfish Poisoning: When shellfish eat poisonous blooms as a food source, they absorb poisons to levels that are dangerous for humans and other consumers. Amnesic shellfish poisoning (ASP), neurotoxic shellfish poisoning (NSP), paralytic shellfish poisoning (PSP), Ciguatera fish poisoning (CFP), diarrhoeic shellfish poisoning (DSP), and cyanobacterial toxin poisoning are some of the poisoning syndromes brought on by these toxic occurrences. There are several other species that contaminate water in addition to these, some of which are poisonous to humans but not to invertebrates. Marine microalgae are essential for the early life stages of the local fauna, which includes fish, protozoans, crabs, mussels, clams, oysters, and scallops. However, more than 5000 distinct types of these microalgae have been discovered (Sournia 1991), and out of these, only 300 contribute to the formation of red tides in marine ecosystems (Hallegraef 2003).

Effects on Aquaculture Food Production and Water Supply: HABs have negative effects on aquaculture and shellfish aquaculture because theshellfish have the ability to accumulate phycotoxins in their body by filtering during feeding, which also impacts their survival, life, history, and body structure (Shumway 1990). Despite the extensive geographic distribution and negative impacts of HABs on aquaculture, accurate estimations of the estimated loss are difficult to quantify; nonetheless, only a few detailed studies have provided insights on this subject. According to FAO (2006), several HABs pose substantial dangers to aquaculture food production and are linked to diminishing wild fish stocks, which have increasingly become an important source of protein for coastal human populations. The most effective strategy to protect humans from seafood poisoning caused by HABs in farmed and wild shellfish harvest is to monitor HAB species and biotoxins and enforce periodic closures of recreational, harvesting, growing, or commercial regions (Berdalet 2016). Additionally, the gathering and development of shellfish as well as some types of finfish aquaculture may suffer financial losses as a result of contaminated seafood goods and things. Other losses in auxiliary businesses could include those related to the distribution, processing, retailing, and wholesale of seafood (Larkin, 2007).

Ecological and Economic Impacts of HABs: Understanding the significant and diverse effects of HAB species on animals and ecosystems can be challenging due to the complex phenomenon of chemical signalling from HAB species. The diverse toxic, noxious, or allelochemical properties of HAB species enable them to avoid some negative consequences and predators (Turner 2006). The poisonous HAB species could not typically be consumed by micro- and meso-zooplankton members; however, these deterrent qualities may be extremely species- or condition-specific (Davis 2011). Particularly when grazing pressures are low, the toxins and allelochemicals of HABs may have potential effects on the communities of creatures further along the food chain or food web, such as altering the microbial food web (Weissbach 2011). Such large-scale ecological problems of HABs have been notoriously difficult to evaluate and quantify.

Case study 1: Effect of Reduced Anthropogenic Activities on Water Quality in Lake Vembanad, India.

A study was carried out by Kulkm *et al*., 2021 to analyse the short-term changes in water quality in Lake Vembanad during the nationwide lockdown in 2020.The study was conducted between February and April 2020, during the COVID-19 pandemic, when the Indian government imposed a nationwide lockdown to reduce the spread of the virus. The lockdown resulted in reduced anthropogenic activities in and around Lake Vembanad, providing a unique opportunity to study the impact of human activities on water quality. The study used remote sensing data from Sentinel-2 and Landsat-8 satellites to measure water quality indicators such as chlorophyll-a, total suspended solids (TSS), and colored dissolved organic matter (CDOM). In situ samples were also collected from 13 different locations in the lake to validate the remote sensing data. The study compared the water quality indicators before and during the lockdown period to assess the impact of reduced anthropogenic activities on water quality. The study found that the lockdown period resulted in a significant reduction in anthropogenic activities such as fishing, boating, and tourism, which led to a significant improvement in water quality indicators such as chlorophyll-a, TSS, and CDOM. The study also found that the reduction in anthropogenic activities had a greater impact on water quality in the northern and central parts of the lake, which are more heavily impacted by human activities. The study highlights the importance of reducing anthropogenic activities to improve water quality in Lake Vembanad. The findings of the study can be used to inform future management and conservation efforts for the lake, such as the implementation of sustainable fishing practices, regulation of tourism activities, and the establishment of protected areas. The study also demonstrates the potential of remote sensing data to monitor water quality in large water bodies such as Lake Vembanad.

Case study 2: Assessment of ecosystem health of a micro-level Ramsar coastal zone in the Vembanad Lake, Kerala, India

Padua *et al*., 2021 carried out a research on the assessment of ecosystem health of a micro-level Ramsar coastal zone in the Vembanad Lake, Kerala, India.This study focuses on the assessment of ecosystem health in a micro-level Ramsar coastal zone in Kerala, India. The study area is located in MulavukadGramaPanchayath, which is a coastal area in the Vembanad-Kol wetland system. The area is known for its rich biodiversity and is home to several species of fish, birds, and other aquatic animals. However, the area also facing several environmental challenges, including pollution, habitat loss, and overfishing. The study used a multivariate approach to assess the ecosystem health of the study area. The approach involved the selection of several indicators, including water quality, sediment quality, and biological indicators. The indicators were selected using a Principal Component Analysis (PCA)-based Multidimensional Scaling (MDS) approach, which ensured that the indicators truly represented the system conditions and evaluated its health or the state of affairs. The study also involved citizen scientists with proper training for regular monitoring of the ecosystem system. The citizen scientists were involved in the collection of data on the selected indicators, which were then analyzed using statistical methods. Results: The study found that the ecosystem health of the study area was poor, with several indicators showing signs of degradation. The water quality was found to be poor, with high levels of pollutants such as nitrogen and phosphorus. The sediment quality was also poor, with high levels of heavy metals such as lead and cadmium. The biological indicators, including fish and bird populations, were also found to be declining. The study recommended several measures to improve the ecosystem health of the study area. These measures included the implementation of better waste management practices, the restoration of degraded habitats, and the promotion of sustainable fishing practices. The study also suggested the involvement of local communities in the management of the ecosystem, as they have a better understanding of the local environment and can contribute to its conservation. They concluded that the assessment of ecosystem health in a micro-level Ramsar coastal zone in Kerala, India, provides valuable insights into the current state of the coastal ecosystems and offers suggestions for better management.

Case study 3: Assessment of Water Quality and Eutrophication Status of UlsoorLake, Bangalore, Karnataka, India

A study was carried out by Vyshnavi D and Shivanna 2020 for the assessment of Water Quality and Eutrophication Status of UlsoorLake, Bangalore, Karnataka, India.Water samples were collected from the sewage inlets before the bund and across the length of the lake to analyze the quality and eutrophication status. The region near the sewage inlets was found to be hyper eutrophic with algal bloom and solid waste, while the water in the lake was mesotrophic.The study analyzed various physical, chemical, and biological parameters of the lake water, including temperature, transparency, pH, nitrate, phosphate, electrical conductivity, dissolved oxygen, BOD, COD, total coliform, and chlorophyll-A. The results of these analyses were presented in different tables and figures.The study found that the water near the sewage inlets had high bacterial content, indicating the presence of coliform and E. coli bacteria. The average Trophic State Index (TSI) calculation revealed that the water near the sewer inlet was in a hypereutrophic condition, while the water after the bund was mesotrophic. The temperature of the sewage was normal and comparable to the lake water sample. The transparency of the water in the cordoned part was reported to be very.The study used the Carlson index as a measure of the trophic status of the lake, considering transparency, chlorophyll-A concentrations, and total phosphorus. The results indicated that the water near the sewage inlets had higher levels of dissolved solids, which led to higher electrical conductivity. The total dissolved solids were relatively uniform across the different stations, except for station E. The dissolved oxygen levels were lower at the inlet, indicating hypoxic conditions.Based on the assessment of water quality and eutrophication status, it is evident that the region near the sewage inlets of Ulsoor Lake in Bangalore is experiencing hyper eutrophication, while the water in the lake itself is mesotrophic. These findings highlight the need for effective measures to address the pollution sources and preserve the water quality of Ulsoor Lake.

Management measures: Water resource managers routinely employ a variety of strategies to minimize the effects of culturaleutrophication, including (1) diversion of excess nutrients (Edmondson 1970), (2) altering nutrient ratios (Downing *et al.* 2001), (3) physical mixing (Huisman *et al.* 2004), (4) shading water bodies with opaque liners or water-based stains, and (5) application of potent algaecides and herbicides (Boyd & Tucker 1998). In general, these strategies have proven to be ineffective, costly, and/or impractical, especially for large, complex ecosystems (but see Edmondson 1970). There are several well-known examples where bottom up control of nutrients has greatly improved water clarity, and reducing nitrogen and/or phosphorus inputs into aquatic systems can frequently improve water quality. However, managing nutrient reduction can be difficult (and expensive), especially in agricultural areas where the nutrients for the algae come from nonpoint sources. Additionally, improvements in water quality where external fertiliser loading has been reduced may be constrained by internal nutrient loading from sediments in lakes (Søndergaard *et al.* 2003). The use of algaecides, such as copper sulfate, is also effective at reducing HABs temporally (Boyd & Tucker 1998). Algaecides, on the other hand, are expensive to use, don't deal with the problem's root (rich resources for primary producers), and present risks to people, cattle, and wildlife in addition to killing a range of aquatic creatures that aren't their intended targets. According to Kumar *et al*., 2018 to protect human interests in lake water management, effective management strategies and strong control measures are required. Municipalities urgently need to develop water management plans that safeguard water at the source or treat water to maintain its finest qualities as a result of urbanisation and declining water quality. Therefore, it is very valuable to evaluate public opinion and competence in the area of water and observe how that affects participation. Programmes that emphasise the environment and raise public knowledge of it can greatly contribute to the safety of water bodies, and the supported engagement of communities and non-profit organisations will significantly contribute to the preservation, protection, and safety of lakes.

Biological Control: Phosphorus (P)-induced eutrophication is the root cause of poor water quality issues in aquatic systems, particularly freshwater. Nutrient digestion normally removes P from the water in shallow environments. Periphytons are thought of as one of the tools for eliminating P from the water column in lotic streams and wetlands. Among the several roles they play in removing P from the water column are periphyton absorption, deposition, and filtering of particulate P from the water. Increased calcium phosphate precipitation, concurrent carbonate-phosphate complex deposition, and long-term P burial can occur as a result of local pH elevations of up to one unit brought on by periphyton photosynthesis. P retention and deposition are typically boosted by periphyton development (Dodds-Walter 2003). Nutrients and food webs have been recorded to have strong interactions which can profoundly alter the eutrophication level of a water body (Hrbâcek *et al.* 1961; Shapiro 1979; Mazumder 1994; Carpenter *et al.* 1995; Proulx *et al.* 1996). The sudden appearance of large populations of herbivorous *Daphnia*, during the recovery of Lake Washington from eutrophication, had profound effects on algal biomass and transparency (Edmondson 1994). *Daphnia* are efficient grazers capable of clearing the water column of edible algal cells, their appearance caused unexpectedly sharp increase in transparency of Lake Washington (Edmondson 1994).

Mechanical Control

Dredging: Dredging, which is often employed and well-recognized as an efficient means of regulating cyanobacterial blooms, aims to remove the topmost organic and nutrient-rich silt.When combined with external nutrient loading, sediment dredging has a major impact on internal nutrient loading, which causes an algal bloom. Additionally, dredging alters the rate of nutrient release at the sediment-water interface and considerably reduces the amount of nutrients in the water column. Dredging can alter the physicochemical and biological ecology of the newly formed sediment-water interface. Compared to other nutrient control methods, dredging's key benefit is that it removes polluted nutrients from the lake (Wen,2020). Therefore, dredging is recognized as one of the top strategies for removing severely polluted sediments (Liu 2015). However, the impact of dredging on aquatic health is still under observation, its effectiveness has not yet been established. In some cases, the degree of eutrophication remained high, and there was no evident reduction in internal loading. Fig. 3 shows the effectiveness and impact of external loading after dredging, as well as potential cyanobacterial bloom mitigation with other combined approaches.

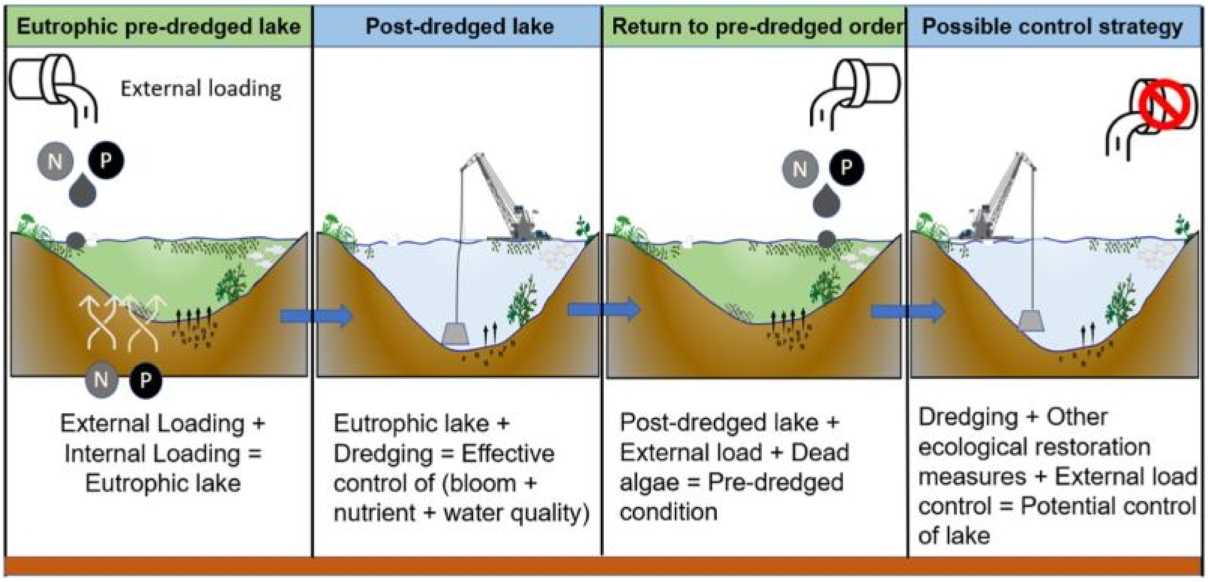


Fig. 3. Schematic representation of the potential control of eutrophication of the lake with dredging. (Source: MumtahinaRiza 2023)

Nutrient Removal: An effective mitigating method is the lowering of phosphorus (P) concentration in eutrophic lakes, particularly in shallow water bodies. In fact, the use of lanthanum-modified bentonite, also known as Phoslock in the marketplace, was able to lower the P level (sometimes temporarily) and the severity of the bloom in the water column. However, reports have also shown potentially harmful effects of lanthanum levels in fish, plants, zooplankton, and phytoplankton, a topic of grave concern (Oosterhout 2014). Dredging as a means to remove nutrients and heavy metals from the sediments was proposed and has been applied to small lakes (Bormans, 2016). The amount of nutrients in the sediments that might become available in the photic zone for phytoplankton growth may be reduced if it is done correctly. However, it might only be applicable to tiny water bodies due to the nature of the treatments needed and their current cost.

Public Awareness and Legislations: Public environmental awareness influences people's capacity to comprehend their surroundings, including the laws of the natural world, their sensitivity to all environmental changes, their understanding of the causal links between environmental factors and human behaviour, their comprehension of how the environment functions as a system, and their sense of responsibility for the Earth's common heritage, such as its natural resources. Only a concerted community effort, as in the example of Lake Washington, where a decline in detergent use was the result of public awareness, may more effectively reduce nutrient inputs to water bodies. The environmental impact of local people's understanding of their surroundings and water supplies is significant and long-lasting. Consequently, it is essential to develop a comprehensive plan that addresses both eutrophication reduction and environmental education for the general public (Jorgensen 2001).

CONCLUSION

Rising phosphorus concentrations are the primary cause of algal blooms, hypoxia, and the demise of fish and other aquatic animals in inland lakes. As a result, preventative actions are needed to reduce phosphate addition to inland waters. Additionally, these actions must lessen the flow of home waste, detergent-containing washings, and industrial effluents into inland lakes. The addition of heavy metals from industrial effluents and pesticide residues in agricultural runoff must also be reduced. It is undeniable that fertiliser loading promotes high biomass algal blooms, and research has connected increases in chlorophyll to nutrient concentration increases. The relationship between nutrient delivery and the formation of blooms of various HAB species as well as the potential toxicity of those blooms or outbreaks has been successfully linked to HAB outbreaks on numerous occasions, but more research is still needed in this area. Local, regional, and global coordinated efforts will be required to better understand the underlying direct and indirect mechanisms that interact to determine the intricacy of these interactions. Particular attention should be paid to comparison ecosystems that comprise both highly eutrophic waters and those that have had nutrient inputs changed.

Data availability: No data were created or analysed in this study. Data sharing is not applicable to this article

Conflicts of Interest: The author declares no conflict of interest.

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