A review of the current status of water quality and eutrophication in Dhaka's water bodies

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Abstract

Purpose of the study: The study aims to provide an overview of urban water quality and the degree of eutrophication in Dhaka's freshwater systems, and to discuss control strategies to combat eutrophication.

Methodology: The paper systematically reviews available scholarly and non-scholarly materials, and summarizes the findings from recent field investigations. This review paper is based on data and information collected from sixty-four previously published papers on the subject matter.

Main Findings: Owing to rapid urbanization and increased industrialization, Dhaka faces various water resource management challenges and struggles to provide adequate water for its residents. Nutrient enrichment (e.g., phosphorus and nitrogen) of Dhaka's water bodies is a serious threat to overall water quality. Future climate conditions are expected to create favourable conditions for algal and potentially toxic cyanobacteria growth in water bodies.

Applications of this study: The findings of the review may be used to identify in situ treatment technologies for the remediation of Dhaka's water bodies. The gathered information may also aid in implementing and enforcing water pollution regulations, and provide a coordinated focus for environmental policy.

Novelty/Originality of this study: The study highlights the potential consequences of changing climate on the water environment of Dhaka, with a specific emphasis on water quality and nutrient pollution. The paper summarizes the current knowledge of the possible effects of changing climate in Dhaka's water bodies and presents measures to control eutrophication.

INTRODUCTION

Eutrophication is defined as an unwanted growth of plants and algae from the accumulation of nutrients [e.g., phosphorus (P) and nitrogen (N)] in lakes or other water bodies. Eutrophication occurs due to a combination of environmental factors, including nutrient availability, temperature, sunlight, ecosystem disturbance, hydrology along water chemistry (Smith, 2003; Paerl, 2014). Sources of nutrients to inland and coastal water bodies come from a variety of sources, including agriculture runoff, septic tanks, urban wastewater, urban storm-water runoff, industry along fossil fuel combustion (Chislock et al., 2013). Globally, rapid population growth coupled with intensive agriculture is the leading cause of eutrophication related water quality degradation in many water bodies (Withers et al., 2014). In many emerging economies, direct drivers of eutrophication include increased energy consumption and application of chemical fertilizer and changes in land use/land cover (Boesch et al., 2001; Khan and Ansari, 2005; Haque, 2021).

Eutrophication can cause dense algal bloom, reduction in water clarity and water quality deterioration, and cause serious damage to biotic components of the natural ecosystem (Chislock et al., 2013; Dorgham, 2014). Harmful algal blooms, hypoxic zones or dead zones**,** and fish kills are also the results of eutrophication (Sonak et al., 2018; Haque, 2021). Harmful algal blooms are the rapid growth of algae or cyanobacteria that produces toxins, which are harmful to humans and other organisms. When the dense algal blooms die, subsequent microbial decay severely lowers the levels of dissolved oxygen (DO). In lakes and the world's oceans, DO levels less than 2 $mg.L^{-1}$ leads to the formation of a hypoxic or 'dead zone' that lacks a sufficient amount of DO to support most aquatic lives (Diaz & Rosenberg, 2008; Campbell et al., 2019). Excessive growth of algae and photosynthetic bacteria can limit light penetration and oxygen absorption essential for aquatic organisms. Additionally, prolific algal blooms can lower the success of predators, which need light to chase and capture prey (Lehtiniemi et al., 2005; Turner & Chislock, 2010). Moreover, eutrophication can strongly impact the survival and development of mosquitoes (Johnson & Townsend, 2008; Schrama et al., 2018). Globally this has important consequences for the spread of mosquito-borne diseases such as cholera, West Nile fever and malaria (Johnson & Townsend, 2008).

Bangladesh is scheduled to officially become a developing country in 2026, and Dhaka, the capital of Bangladesh, is a major beta-global city with a population of over 18 million residents. In recent decades, the natural increase of population and internal mass migration from rural areas across the country have been the main forces behind the city's booming population. As such, Dhaka City has emerged as one of the fastest-growing cities in the world. It is predicted that by 2025, Dhaka will become one of the top-ranking megacities worldwide with a population of 22.9 million (Dewan

& Corner, 2014). The rapid growth in population coupled with increased urbanization have created enormous stress on the city and have serious implications for freshwater usage, sanitation and drainage issues, and water management (Haque, 2020). Over the past few decades, numerous surface water bodies in and around the city have been subjected to increased pollution due to indiscriminate disposal of untreated or partially treated waste by municipal, industrial and agricultural sources (e.g., Karim et al., 2015; Haque et al., 2020; Sarker, et al., 2020). Eutrophication is a leading cause of impairment of many of its surface water bodies. Future climate conditions will potentially create more favourable conditions for the growth of algae and potentially toxic cyanobacteria.

Globally, Bangladesh is one of the most vulnerable countries to climate change owing to its flat geography and low-lying topography, high population density; dependence of numerous occupations on climate-sensitive sectors (e.g., agriculture and fisheries) and institutional challenges (Huq, 2001; Rahman and Alam, 2003; Huq and Ayers, 2007). According to the Intergovernmental Panel on Climate Change (IPCC), the global average surface temperature has undergone warming of 0.85°C between 1880 and 2012 (IPCC, 2013). A warmer climate is expected to influence the hydrological cycle and change patterns of precipitation, temperature and evaporation rates (IPCC, 2007), and subsequently influence water quality by intensifying various types of water pollution (Park et al., 2014; Haque, 2021). Water temperatures over 25°C, 17-27°C and 17-22°C are optimal for the growth of cyanobacteria, dinoflagellates and diatoms, respectively (Paerl, 2014; Giannuzzi, 2018). Additionally, higher water temperatures in tropical regions may cause cyanobacteria blooms, which persist year-round.

Dhaka has numerous interconnected canals and rivers that are highly susceptible to the amalgamated effect of urbanization, environmental degradation and climate change. In particular, due to the projected changes in temperature and precipitation patterns, Dhaka's water bodies are expected to experience increased eutrophication and water quality issues (Alam and Duti, 2012; Hossain et al., 2020). Further, the impacts of climate change may cause increased water demand due to rising temperatures and evaporation while decreasing water quantities. Climate-induced severe flooding events (Hossain et al., 2020) have already hindered many of Dhaka's development projects as well as several occupations considerably. In addition, the negative impacts of changing climate on rural areas have caused increased migration to Dhaka in search of non-agricultural employment, creating further pressure on its already stressed water resources. Dhaka attracts between 300,000 and 400,000 new migrants annually (The World Bank, 2009). The shrinking freshwater resources and growing demand will have an impact on water supply sustainability (Alam and Duti, 2012).

In recent years, the breadth and depth of eutrophication research have grown steadily. A large body of both scholarly and non-scholarly materials is available on the effects of eutrophication on Dhaka's surface water bodies. The primary goal of this paper is to systematically review available literature and summarize the findings from recent field investigations and discuss the environmental impacts and consequences of eutrophication on the city's freshwater systems. The paper also includes a discussion on the influence of changing climate on the eutrophication of Dhaka's urban water bodies. Further, the paper also highlights possible eutrophication control strategies to combat the problem.

GEOLOGICAL SETTING

Bangladesh is located at the lowermost reaches of the Ganges-Brahmaputra-Meghna river basin. Bangladesh lies between 20˚34' and 26˚38' N latitude, and between 88˚01' and 92˚41' E longitude (Figure 1). As a mega delta, the country covers the greater part of the current Bengal Basin with a huge thickness of fluvio-deltaic sediments, being formed by the merging deltas of the rivers Padma, Jumuna and Meghna (Islam, 2016). Most parts of Bangladesh are geologically built up of sediments deposited by these river systems, which originate from the Himalayan Mountains to the north and Burmese hills in the east.

Dhaka lies between latitudes of 23˚43' and 23˚54' North and longitudes of 90˚20' and 90˚30' East. The city covers an area of 336 km^2 (Siddhartho et al., 2019) and consist of alluvial terraces of the southern portion of the Pleistocene uplands known as the Madhupur tract (Alam, 1998). The land surface represents uniform geomorphic features and the topography is flat. Central Dhaka is 6 to 7 m above mean sea level, whereas the neighbouring floodplains are at 4 m above mean sea level. The peripheral rivers are Tongi Khal (north), Buriganga River (south), Turag River (west) and Balu River (east; Figure 2).

CLIMATE

Bangladesh is located on the edge of the tropical region and experiences some of the wettest monsoons in the world. Dhaka has an annual average temperature of 26°C. The city experienced an average temperature rise of 1.03°C since 1900 (The World Bank, 2021). The maximum of 33°C usually occurs in March; the average annual rainfall is 2076 mm (Ahammed et al., 2014). The majority of the rain occurs during the monsoon season (i.e., May till the end of September).

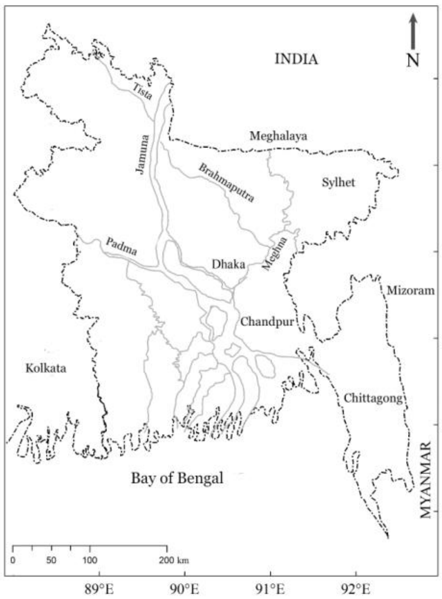

Figure 1: Map of Bangladesh.

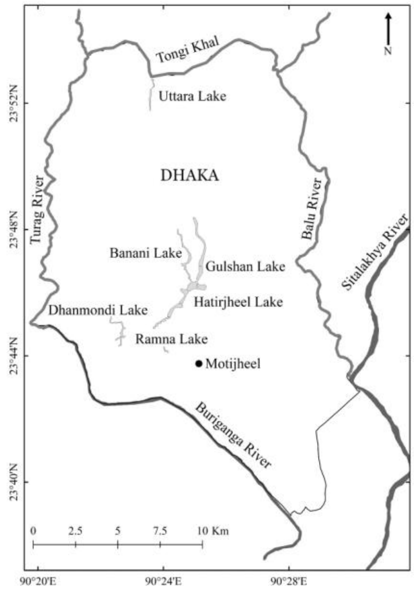

Figure 2: Map showing the leading lakes and rivers of Dhaka.

MAJOR FINDINGS

A review of the existing literature reveals a severe water pollution problem in numerous water bodies in Dhaka. High population density coupled with a poor and vulnerable population, unsanitary conditions, indiscriminate discharge of untreated and partially treated wastewater have increased pollution levels. The sewerage and sanitation network of the city covers 25% of the total urban area (Whitehead et al., 2018). Due to the lack of an appropriate waste management system, over 50% of municipal waste is disposed into the water bodies (MoEF, 2010). Additionally, industrial effluent and large agrochemicals make their way into Dhaka's surface water bodies untreated.

Consequently, pollutant levels in numerous freshwater bodies and adjoining areas are increasing at an alarming rate (Whitehead et al., 2018). Dhaka's water quality and eutrophication have been the subject of many research works (Table 1). In the following sub-sections, the water quality and eutrophication problems of some significant water bodies within Dhaka have been discussed.

Table 1: Summary of Some Recent Studies on Dhaka's Water Quality and Eutrophication

Study	Study Area	Focus	Major Findings
Sarker et al., 2020	Shitalakhya River	Investigated phytoplankton abundance, DO, pH, total dissolved solids (TDS), phosphate (PO_4-P), NO_2-N, and NO_3-N.	The results indicate that the sampled river water is moderately polluted. The pH values were within the acceptable range for fish survival. Dissolved oxygen levels were in the field of 5-6 mg.L^{-1}. High PO_4-P, NO_2-N, and NO_3-N indicate suitable conditions for phytoplankton growth.
Tahmina, et al., 2018	Turag River	Parameters studied are temperature, pH, salinity, TDS, total alkalinity, electrical conductivity (EC), chloride content, free CO_2, DO, NO_3 and sulfate.	The majority of the analyzed physicochemical parameters exceeded the relevant allowable limits of Bangladesh and the World Health Organization (WHO). The bacterial count indicated the presence of faecal matter in the water. The water quality index value suggested that the waters were polluted. Further, the observed low DO values are likely due to the presence of organic and inorganic substances discharged from nearby industries. Nitrate levels were found to be lower than WHO's allowable limit. Overall, the results indicate that the lake was more polluted during the dry season.
Zerin, et al., 2017	Buriganga River	Comparative study of water quality data using findings of numerous investigators between 1972 and 2013.	Alkalinity, conductivity, pH, PO_4-P, Chlorophyll a, and total zooplankton concentrations exhibited an increasing trend during monsoon and summer. Further, the results indicate enhanced eutrophication in the study area. Changes in phytoplankton diversity were observed over the years.

Karim, et al., 2015	Gulshan Lake	Review of previously published work.	Bacteria count in the studied water were higher than tolerable limits. Levels of DO and BOD indicate poor water quality and human activities are likely responsible for the contamination.
Islam, et al., 2012	Dhanmondi, Ramna, Crescent, Baridhara-Gulshan, Gulshan-Banani, Uttara lakes	Water quality in the studied lakes was assessed based on fieldwork, government reports and satellite images.	An overall increase in BOD and COD along with increasing DIN (Dissolved Inorganic Nitrogen) and DIP (Dissolved Inorganic Phosphates) levels indicated deteriorating water quality.

BANANI LAKE

Banani Lake is a shallow lake, situated in the densely populated Banani Residential Area close to the city centre. Alom (2019) found the average pH, conductivity, DO and BOD_5 values of the lake water to be 7.4, 262 µS/cm, 3.56 $mg.L^{-1}$ and 23.3 $mg.L^{-1}$, respectively. The permissible limits for DO, BOD_5 and chemical oxygen demand (COD) are presented in Table 2. This study found that sewage disposal along with lack of awareness is primarily responsible for the lake's pollution. Khondker et al. (1994) investigated the eutrophication status of the lake considering 18 limnological variables and phytoplankton community structures. The DO levels were low and found to be lethal for fish survival. Further, concentrations of total P and N along with chlorophyll exceeded the ranges that indicate hyper-eutrophication. The investigators also detected the presence of a large number of euglenoid and chlorococcoid algae together with the dominance of *Rhodomonas lacustris* Pascher and *Cryptomonasovata Ehr*. Cryptomonads are one of the major groups of microalgae. Further, Jewson et al. (1993) identified Banani Lake to be hypereutrophic and found *Aulacoseira herzogii* in association with *Eichhornia crassipes* (i.e., water hyacinth). A study conducted by Poribesh Bachao Andolan found that DO levels to be 0.44-2.44 $mg.L^{-1}$ and that no aquatic organisms can survive in the lake water due to indiscriminate disposal of toxic wastes (Mallick, 2015). Additionally, Poribesh Bachao Andolan observed fish kill events during their study period.

Table 2: Water Quality Parameter Permissible Limits

Water Quality Parameter	The Environment Conservation Rules (1997) Standard for Drinking Water ($mg.L^{-1}$)
DO	6
BOD_5 at 20˚C	0.2
COD	4

Changing temperature, precipitation and wind patterns due to seasonal and climatic changes appear to influence the concentrations of various pollutants and nutrients in the lake (Khondker et al., 1994; Mallick, 2015; Alom, 2019). Recent field visits indicate that the lake continues to receive storm-water runoff, domestic waste, plastic and other pollutants from the neighbouring area. Additionally, the waters are visibly green with observable floating chunks as well as surface scum.

GULSHAN LAKE

Gulshan Lake is one of the eight Ecologically Critical Areas declared by the Department of Environment, Bangladesh (Islam, 2005). The lake has a length of 3.8 km and covers an area of 0.016 km^2. The average depth and volume are 2.5 m and 12×10^5 m^3, respectively. The peripheral sides are Baridhara (north), Tejgaon-Hatirjheel (south), Gulshan-Banani (west) and Badda area (east). Dhaka Water Supply and Sewerage Authority has identified that storm sewers and waste disposal from drains and sewerage pipes are the major contributors to the pollution of Gulshan Lake (Sabit and Ali 2015; Karim et al., 2015). Sabit and Ali (2015) identified a total of 102 outfalls in the lake, including 24 major outfalls (diameter 61 cm or significant flow). The outfall discharges were characterized by elevated levels of BOD_5 (56-160 $mg.L^{-1}$), COD (129-188 $mg.L^{-1}$), ammonia (16-28 $mg.L^{-1}$), and PO_4 (3.55-13.4 $mg.L^{-1}$). Further, the lake water is characterized by low DO levels (<2 $mg.L^{-1}$), high concentrations of faecal coliform bacteria, BOD_5 (up to 46.0 $mg.L^{-1}$) and COD (up to 130 $mg.L^{-1}$), demonstrating faecal and organic pollution of the lake water. The DO levels are well below the permissible limit for drinking water (Table 2). Karim et al., 2015 found the bacteria count of the lake water to be 1,200. Sabit and Ali (2015) also report that the water sample collected during the dry season contains elevated nutrients (10-20 $mg.L^{-1}$ ammonia; up to 8.55 $mg.L^{-1}$ PO_4). The findings suggest that the elevated cadmium (Cd) and lead (Pb) levels in the lake sediments are associated with a high potential sediment oxygen demand. High metal concentrations are of concern given that elevated levels of various dissolved metals (Cd, Cr, Pb, etc.) have been identified in the city's groundwater (e.g., Karim et al., 2015; Haque et al. 2020). It is important to note that Gulshan Lake is considered a dominant source of underground water recharge in the area (Rahman and Hossain, 2019).

Recent site visits and field interviews indicate that increasing population growth coupled with rapid urbanization, land-use changes and nutrient pollution are significant threats to the lake's water quality (Sabit and Ali, 2015; Karim et al., 2015). Over the years, the lake has experienced accelerated cultural eutrophication along with adverse effects on its natural ecosystem (Figure 3). The findings are particularly alarming as neighbouring slum dwellers continue to use the lake water for drinking, cooking and bathing purposes.

(a) **(b)**

Figure 3: Water quality of (a) Gulshan Lake and (b) Hatirjheel Lake (Pictures taken on 15 October 2021)

HATIRJHEEL LAKE

Hatirjheel Lake is the most prominent lake designed to store rainwater in Dhaka (Hossain et al., 2017; Tariquzzaman et al., 2016). The lake is 4.1 km long covers an area of 0.79 km^2, with an average depth of 2.6 m (Chowdhury and Chowdhury, 2018). Chowdhury and Chowdhury (2018) found the measured carbon dioxide (CO_2) levels in the lake water to be 29 mg.L^{-1}, which indicates that these waters are acidic. These researchers also report BOD (2 mg.L^{-1}) and COD (27 mg.L^{-1}) levels to be well above the permissible limits (Table 2). Siddika et al. (2015) found that P levels increased substantially over two decades, and the lake is hypereutrophic due to its high P content. The neighbouring low-lying areas receive storm-water discharges primarily through major storm sewer outfalls. During the dry months of the year, storm sewers primarily carry domestic sewage and industrial wastewater, causing further pollution of the already polluted water (Sohail-Us-Samad, 2009). Devnath (2020) reports that the lake has become a sewage pond due to a lack of an appropriate sanitary system in the surrounding area. Recent field investigation indicates that the lake's water level declines during the dry months of the year and result in intensified pollution. Recent field visits found a foul smell coming from the visibly green lake waters (Figure 3). In addition, a substantial amount of debris, scum and floating mats of water hyacinth were observed.

BURIGANGA RIVER

Buriganga River, one of the most polluted rivers in Bangladesh, originates from Dhaleswari from the north of Dhaka and flows past the southwest outskirts of the city (Haque et al., 2020). The river's average depth is 7.6 m, and its maximum depth is 18 m (Majumder, 2009). Field visits and review of past research indicates that the primary point sources of river pollution are untreated or partially treated industrial effluents, municipal wastewater and sewage treatment plants (Haque et al., 2020). Diffuse sources of pollution to the river include solid waste and human waste disposal along the river banks and oil leakage from various types of water vehicles. Saila (2020) assessed different point and non-point sources of pollution of Buriganga River and found that BOD_5 and COD values meet the ECR (1997) permissible limits, unlike the DO and ammonia nitrogen levels. In a separate study, Bhuiyan and Khondker (2018) assessed the water quality and potamoplankton of the river. They found that the mean values for pH, CO_2, conductivity, TDS, SRP, and NO_3-N to be 8.34, 8.49 mg.L^{-1}, 686 µS.cm^{-1}, 155.17 mg.L^{-1}, 493 µg.L^{-1} and 810.28 µg.L^{-1}, respectively. Since the early 1970s, many scientists have studied the water quality of the Buriganga, and found severe eutrophication and water pollution with an increasing trend in chlorophyll and declining biodiversity of pelagic plankton (e.g., Ahmed 1993, Raknuzzaman 2006, Bhuiyan and Khondker 2018). Ferdous et al. (2012) identified 27 genera of Phytoplankton belonging to Cyanophyceae, Bacillariophyceae, Chlorophyceae, Euglenophyceae and Cryptophyceae in Buriganga River water. In addition, merismopedia of Cyanophyceae was the most abundant and frequent genera. More recently, Bhuiyan and Khondker (2018) found *Fragillaria virescens* Ralfs was the dominant diatom of the river Buriganga, with levels ranging from 6.5 x10^5 to 11.09x10^5 ind.L^{-1} which was the highest compared to the population of all other groups of potamoplankton.

Buriganga River is crucial for providing drinking water supply, transportation, cleaning, washing, recreation, groundwater recharge, and flood control (Kibria et al., 2015). Large quantities of groundwater are extracted from the underlying Dupi Tila sand aquifer to meet the water demand of Dhaka's growing population. Overexploitation of the aquifer has led to a progressive drop in water levels in many areas under the city. The resulting cone of depression is likely causing surface water infiltration, mainly from the polluted Buriganga River (Darling et al., 2002).

BALU RIVER

Balu River originates from Paruli River and Sutia River in Gazipur District. The river flows through extensive swamps of Beel Belai and eventually meets the Sitalakhsya River at Demra (Hasan et al., 2014; Bhuiyan et al., 2020). The 44 km long Balu River is a drainage channel and a small tributary of the Sitalakhsya River (Bhuiyan et al., 2020). Balu River is also connected with the Turag River through Tongi Khal. Balu River carries floodwater from Sitalakhsya and Turag Rivers (Chowdhury, 2012). Hasan et al. (2014) found that the maximum levels of EC, DO, BOD and TDS during the dry season were 715.1µS.cm^{-1}, 1.04 mg.L^{-1}, 8.06 mg.L^{-1} and 87.3 mg.L^{-}1, respectively. These investigators found that the primary sources of pollution of the river include untreated sewerage inputs from both Dhaka and Tongi, domestic wastewater, effluents from power plants, tannery and battery industries, and agricultural runoff.

Bhuiyan et al. (2020) investigated the water quality of the Balu River and found that the pH values ranged between 7.1 and 7.5. Dissolved oxygen and CO_2 levels ranged from 0.2 to 4.47 $mg.L^{-1}$ and 0.07 to 2.90 $mg.L^{-1}$, respectively. Chlorophyll levels ranged from 6.77-32.60 $\mu g.L^{-1}$. Phytoplankton density ranged between 1178×10^3 and 7409×10^3 $ind.L^{-1}$, and the maximum value of SRP was found to be 1247.62 $\mu g.L^{-1}$. The study's findings indicate that air and water temperature and alkalinity correlated considerably with the phytoplankton biomass of the pelagic zone. Whitehead et al. (2018) applied various models to evaluate hydrochemical processes in Balu River to assess alternative strategies for policy and the management of the pollution issues in the polluted Turag-Tongi-Balu river system. These investigators concluded that with DO levels close to zero in the river system, there is a solid need to substantially improve the DO levels to bring them back to internationally permissible limits. Balu River is still being used for domestic, agricultural and residential purposes.

MEASURES TO CONTROL EUTROPHICATION

Globally, human-induced eutrophication has negatively influenced the water quality of inland water bodies and coastal waters. Specifically, urbanization coupled with rapid population growth, industrialization and excessive use of agrochemicals has resulted in disproportionate quantities of nutrients in urban water bodies stimulating plant and algae overgrowth. Nutrient pollution is not a new problem; it is among the most persistent. Measures to control eutrophication are crucial as nutrient accumulation renders controlling eutrophication more complex with time. The following criteria can be vital to reverse eutrophication trends and to develop robust strategies to control eutrophication in Dhaka's water bodies:

- Composting can be used as a preventative solution to Dhaka's eutrophication problem. Composting converts organic matter into compost manure, which is deficient in high levels of NO_3 and PO_4.
- Municipal wastewaters containing large quantities of nutrients play an essential role in water trophic state deterioration. Nutrient removal via wastewater treatment technologies is vital to minimize nutrient pollution in these waters.
- Instead of regulatory guidelines, scientific guidelines should determine whether high quantities of nutrients exist in water bodies.
- Dissolved PO_4 should be removed from water bodies using techniques such as precipitation.
- Oxygenation of water bodies can also reduce the negative impacts of the eutrophic process and restore ecological condition.
- The general public does not sufficiently understand eutrophication and its influences. Public awareness campaigns, environmental education programs, and targeted outreach are vital.
- Integrated research and monitoring efforts are necessary to pinpoint the nature and extent of the eutrophication problem, provide essential information to identify specific policy, programs and legislation, and establish cost-effective measures for managing and reducing nutrient loading.

CONCLUSION

It is evident from the review that over the past few decades, increased urbanization and industrialization has caused numerous primary indicators of poor water quality to rise sharply. Implementing and enforcing water pollution regulations is crucial in providing a coordinated focus for environmental policy. Strengthening laws and regulations against non-point water source pollution can significantly control eutrophication; however, in many countries, even with existing legislation to regulate point source of nutrients, eutrophication remains widespread in surface water bodies. Furthermore, due to the influences of changing climate, impacts of nutrient pollution is expected to increase in the coming decades, leading to increased eutrophication and more severe effects on aquatic environments; policymakers must begin taking decisive actions now.

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