

The background of the cover is a photograph of a pond. The water is covered with a thick layer of green algae, indicating eutrophication. A tree branch with green leaves hangs over the water from the right side. The overall color palette is dominated by various shades of green.

Abid A. Ansari  
Sarvajeet Singh Gill  
*Editors*

# Eutrophication: causes, consequences and control

Volume 2

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# Eutrophication: Causes, Consequences and Control

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Abid A. Ansari • Sarvajeet Singh Gill  
Editors

Eutrophication: Causes,  
Consequences and Control  
Volume 2

 Springer

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## Preface

Anyone who can solve the problems of water will be worthy of two Nobel Prizes—one for Peace and one for Science

John F. Kennedy

Water is an indispensable resource and essential life supporting factor. On the hydrological map of the world, eutrophication is one of the great issues causing degradation of these freshwater ecosystems. The excessive nutrient enrichment of waters results in change of oligotrophic water bodies to mesotrophic, eutrophic and finally to hypertrophic. The major nutrient sources for enrichment of aquatic ecosystems are sewage, household detergents, industrial discharges, runoff from agriculture, construction sites, and urban areas. Eutrophication is a threat for water used in fisheries, recreation, industry, and drinking as it causes the increased growth of cyanobacteria and aquatic macrophytes resulting in low oxygen, death, and decomposition of aquatic flora and fauna. Thousands of lakes and reservoir estuaries and wetland around the globe near the large population centers has been deteriorating due to rising nutrient levels and other chemical pollutants causing changes in their ecological structure and function. Eutrophication can be minimized by reducing nutrient use in fertilizers and household detergents. The economic analysis is urgently required and devising some policies to make desired changes in agricultural practices is needed to control the eutrophication. The improved soil management practices, treatments of water, mathematical models, and bioremediation are some of the effective tools to combat eutrophication in aquatic ecosystems. The public awareness and education on eutrophication also play an important role in preventing the eutrophication of water bodies.

The consequence of man-made eutrophication of freshwaters is severe deterioration of water quality which is now a big matter of interest for the scientific community. The research in this field has suddenly increased in last few years and many books, research papers, reviews, and articles which dealt with eutrophication and related management issues have been published so far. In this series of publications, we have taken the task to publish the second volume of the book “Eutrophication: Causes, Consequences and Control” after the successful publication of its first volume in 2011. Eutrophication: Causes, Consequences and Control Volume-II covers a collection of 18 chapters written by 44 experts. The book presents the latest literature and research findings on eutrophication. The chapters from this book provide complete information on the topic of eutrophication and its related areas. It can be a resourceful guide suited for scholars and researchers. Chapter 1 will give general information including definitions, drivers, environmental conditions, and the control measures of eutrophication. Chapter 2 highlights the changes in the delicate balance between seasonal, spatial, and littoral dynamics, and the resulting biogeochemical changes in the eutrophic water bodies. Chapter 3 deals with impacts of eutrophication on the structure and functioning of aquatic ecosystem. Chapter 4 focuses on the economics related to eutrophication and its control measures. Chapter 5 covers the cultural eutrophication in lakes leading to the degradation of water quality and depletion of aquatic biodiversity. Chapter 6 deals with the structure and components of the food webs and trophic links between them in eutrophic lakes.

Chapter 7 focuses on anthropogenic perturbations on freshwater ecosystems as a consequence of tourism. The lakes, ponds, and other freshwater reservoirs are the places of attraction for the public which causes touristic impacts on the reservoirs especially in terms of

eutrophication. Chapter 8 gives information about the eutrophication in the Great Lakes of the Chinese Pacific Drainage Basin. The changes, trends, and management strategies are elaborated in this chapter. Chapter 9 discusses the changes in photoautotrophic productivity of lakes, reservoirs, rivers, and streams under the direct threat of eutrophication. Chapter 10 deals with nutrient dynamics in the inner Saronikos gulf and the changes occurred over the last 25 years due to the sewage discharges releasing from the Sewage Treatment Plant of Athens in Psittalia Island. The environmental status of the inner Saronikos gulf is also presented in this chapter. Chapter 11 sheds light on eutrophication and its associated changes in salt marshes which have an important role in biogeochemical cycles. Chapter 12 covers research work to evaluate the role of phosphate-containing household detergents in the eutrophication and deterioration of fresh water ecosystems.

Chapter 13 deals with the hypothesis of the trophic cascade relations especially between fish trophic guilds, limnology, and application of morphoedaphic index studied in the Itaipu Reservoir (Brazil). Chapter 14 describes the eutrophication status in seven coastal estuaries of southeast Australia where phytoplankton species diversity and their ecological characteristics were found as strong indicators of eutrophication. Chapter 15 deals with the biogeochemical indicators of eutrophication in wetlands. Chapter 16 deals with role of mineral nutrients in eutrophication. Chapter 17 is about the development of sustainable phytoremediation systems and the most suitable environmental conditions to recover the nutrients from eutrophic waters. Chapter 18 covers the eutrophication studies on King Abdullal Canal in Jordan Valley, Mujib dam, Wadi Rajil dam in the eastern desert of Jordan, and Muwaqqar dams in the eastern highlands of Jordan. The study reveals the significant role of ultraviolet radiation and bromide as limiting factors of eutrophication processes in the context of semiarid climate zones. The editors and contributing authors hope that this book will update the knowledge of eutrophication and its related fields on a global scale. This book will lead to new researches, methodologies, discussions, and efforts to overcome this global problem of eutrophication with minimum economic loss.

We are highly thankful to Dr. Ritu Gill, Centre for Biotechnology, MD University, Rohtak for her valuable help in formatting and incorporating editorial changes in the manuscripts. We would like to thank Springer Science+Business Media, LLC, New York, particularly Judith Terpos at Springer, for his patience and continuous encouragement during the preparation of this volume.

Abid A. Ansari  
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## Abstract

On the hydrological map of the world eutrophication has become the primary water quality issue. The excessive enrichment of waters with anthropogenic sources of nutrients especially nitrogen (N) and phosphorus (P) lead to the transformation of oligotrophic water bodies to mesotrophic, eutrophic, and finally hypertrophic. Mesotrophic and eutrophic phases exhibit intermediate and rich levels of nutrients and show increasing and serious water quality problems, respectively. Eutrophication restricts water use for fisheries, recreation, industry, and drinking because of increased growth of undesirable algae and aquatic weeds and the oxygen shortages caused by their death and decomposition. Associated periodic surface blooms of cyanobacteria (blue-green algae) occur in drinking water supplies and may pose a serious health hazard to animals and humans. Anthropogenic activities are the worst culprit of nutrient enrichment and root cause of eutrophication of water bodies. Excess nutrient inputs to water bodies usually come from sewage, industrial discharges, agricultural runoff, construction sites, and urban areas. Eutrophication can be minimized by regulating the nutrient sources, reducing the use of fertilizers, proper soil management practices, implementing mathematical models, phytoremediation etc. Among these, public awareness of eutrophication can play an important role in preventing the eutrophication of water bodies.

## Keywords

Eutrophication · Fertilizers · Livestock intensification · Nitrogen · Phosphorus · Phytoremediation · Wastewater flow

## 1.1 Introduction

During the early stages of formation, water bodies are in the state of *oligotrophy* and support a pitiful of aquatic life because of nutrient deficiency. Enrichment of water with mineral nutrients, such as nitrogen (N) and phosphorus (P) causes transformation of water bodies from oligotrophic to mesotrophic, eutrophic, and finally hypertrophic stage (Fig. 1.1).

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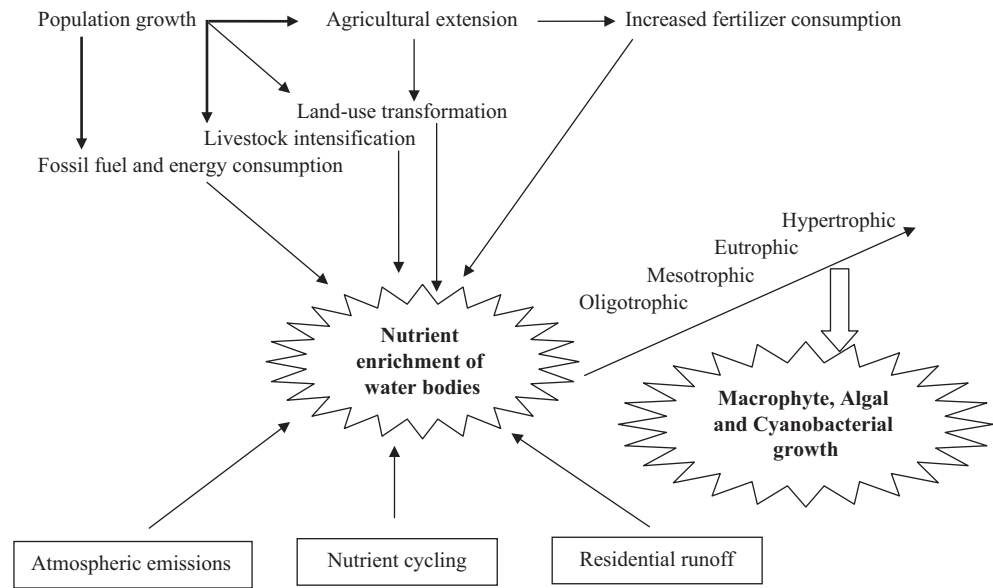
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Mesotrophic and eutrophic phases exhibit intermediate and rich levels of nutrients and show increasing and serious water quality problems, respectively. Whereas, hypertrophic phase is the excessive enrichment of aquatic and terrestrial ecosystem with anthropogenic sources of nutrients is termed as *eutrophication* which has been identified as the main cause of impaired surface water quality. Eutrophication restricts water use for fisheries, recreation, industry, and drinking because of increased growth of undesirable algae and aquatic weeds and the oxygen shortages caused by their death and decomposition. Associated periodic surface blooms of cyanobacteria (blue-green algae) occur in drinking water supplies and may pose a serious health hazard to animals and humans (Fig. 1.1).

**Fig. 1.1** Simplified illustration of eutrophication driven by synergistic action of direct and indirect drivers



Eutrophication of water bodies occurs due to overenrichment by nutrients, principally phosphorus (Schindler 1977), followed by uncontrolled growth of primary producers and episodes of oxygen depletion owing to decomposition of algal organic matter. Excess phosphorus inputs to water bodies usually come from two types of nutrient sources, point sources such as sewage, industrial discharges, and nonpoint sources such as runoff from agriculture, construction sites, and urban areas. Nonpoint sources of nutrients have replaced point sources as the driver of eutrophication in many regions (Carpenter et al. 1998). An important driver of nonpoint nutrient input is excessive application of fertilizer or manure, which causes phosphorus to accumulate in soils (Bennett et al. 2001). Phosphorus-rich soils are washed into lakes, where some of the phosphorus dissolves and stimulates growth of phytoplankton and aquatic plants.

Prevailing eutrophication by anthropogenic nutrient inputs is a relatively recent environmental problem. Intensive fertilization of agricultural soils and associated nonpoint inputs of phosphorus increased through the middle of the twentieth century (Carpenter et al. 1998; Bennett et al. 2001). It could take 1,000 years or more to recover from eutrophication caused by agricultural overenrichment of soils (Carpenter 2005).

## 1.2 Causes of Eutrophication

There are a number of sources of nutrients causing eutrophication of water bodies. All activities in the entire drainage area of a lake or reservoir are reflected directly or indirectly in the water quality of water bodies. A lake or reservoir may, however, be naturally eutrophied when situated in a fertile area with naturally nutrient-enriched soils. In many

lakes and reservoirs wastewater is the main source since untreated wastewater or wastewater treated only by a conventional mechanical–biological methods still contains nitrogen (25–40 mg/l) and phosphorus (6–10 mg/l). In fact, agriculture (including livestock agriculture) is the largest source of nonpoint water pollution. Drainage water from agricultural land contains phosphorus and nitrogen. It usually has much more nitrogen because phosphorus is usually bound to soil components. Extensive use of fertilizers results in significant concentrations of nutrients, particularly nitrogen, in agricultural runoff. If eroded soil reaches the water bodies, both phosphorus and the nitrogen in the soil contribute to eutrophication. Erosion is often caused by deforestation which also results from unwise planning and management of the resource.

Nitrates, because of their water-soluble nature, move readily with surface runoff into rivers or with water percolating through the soil profile into the groundwater below. A 1998 assessment of nonpoint sources of N and P to waters in the USA (conducted by the Ecological Society of America) determined that only about 18% of the nitrogen that is applied to fields as fertilizers leaves the fields in the form of produce and the remaining 82% is left behind as residue or in soils, where it either accumulates, erodes with the soil (often to surface waters), leaches to groundwater, or volatilizes into the atmosphere.

Unlike nitrate, however, phosphate is not water soluble, so it moves only with soil movement as it adheres to soil particles. When it erodes on soils from agricultural fields, it is essentially nonrecoverable, washing into sediments in oceans. The global P budget concludes that P is accumulating in the world's soils (that is, inputs, largely from fertilizers, animal feeds, and animal wastes, are greater than removals in harvested crops and meat). The result of this imbalance

between input and output is that the net P storage in soil and fresh water ecosystems of the world is estimated to be about 75% higher than during preindustrial times. A large portion of this P accumulation is in agricultural soils, as might be expected. A major problem associated with this increased P content of soils is that any factors that increase soil erosion will also increase runoff of P with soil to streams, rivers, lakes, and coastal regions.

Nutrients entering waterways come from a variety of sources and originate from two main categories, direct and indirect sources.

---

### 1.3 Drivers of Eutrophication

Drivers of the ecosystem often interact with one another in synergistic ways in causing increased occurrence of eutrophication. Direct drivers of eutrophication include higher energy consumption, increased fertilizer consumption, land-use change etc. Population growth, economic growth, structural change, and globalization are the most commonly identified indirect drivers that impact consumer consumption and the growth of intensive agriculture.

#### 1.3.1 Direct Drivers of Eutrophication

Direct drivers are usually associated with intensive agriculture and discharges at a particular point. These include pigeries, sheep holding yards, dairies and horticulture, meat processing plants, vegetable processing plants, fertilizer factories, and other industries. Intensive animal industries often produce large quantities of wastewater and nutrients. Nutrient concentrations in these wastes are often much higher than those leaving indirect sources. Many of these industries currently combine ponding, irrigation, and diversion to waterways to dispose of nutrient-rich wastewater. Humans discharge the equivalent of 1 kg of phosphorus annually as a result of domestic activities. Detergents make up approximately 50%. Disposal in septic tanks or improperly constructed or sited sewerage works can lead to nutrient contamination of both ground and surface waters.

##### 1.3.1.1 Wastewater Flow

Municipal wastewater treatment plants and industrial wastewater discharges, nitrogen leaching from below-ground septic tanks, and storm water runoff are some of the urban and industrial sources of nutrient losses. They are typically the most controllable sources of nutrients and are often regulated in developed countries. The most prevalent urban source of nutrient pollution is human sewage, although its importance varies by region and country. Sewage is estimated to contribute 12% of riverine nitrogen input in the USA, 25% in

Western Europe, 33% in China, and 68% in the Republic of Korea (MA 2005). Urban wastes are processed in sewage treatment plants that work on the principle of bacterial oxidation of organic matter. In this way, all the major elements from the wastes are oxidized. These elements therefore become soluble and drain in high concentration in the effluent from the treatment plant. Such effluents are point sources of nitrogen and phosphorus.

Storm water runoff is another significant source of nutrients from urban areas. Rainfall events flush nutrients from residential lawns and impervious surfaces into nearby rivers and streams. In some cities, combined sewer overflow (CSO) systems worsen storm water runoff problems. CSOs are designed to collect rainwater, domestic wastewater, and industrial wastewater in the same pipe. During heavy rain or snowmelt, wastewater volume can exceed the capacity of the CSO system, as well as that of the wastewater treatment plant receiving the flow. As a result, the excess wastewater, including raw sewage, is discharged directly into nearby streams and rivers.

For industrial sources of nutrient pollution, certain industries are larger sources than others. Pulp and paper mills, food and meat processing, agroindustries, and direct discharge of sewage are some of the larger sources of industrial nutrient pollution. Industrial wastes and domestic sewage together are the major urban sources of nutrient overload, responsible for 50% of the total amount of phosphorus unloaded into lakes from human settlements (Smith et al. 2006). Approximately 15% of the US population contributes phosphorus-containing wastewater effluents to lakes, resulting in eutrophication (Hammer 1986). By 1970, nearly 10,000 public lakes had been affected by excessive human-influenced nutrient enrichment (Knud-Hansen 1994).

##### 1.3.1.2 Livestock Intensification

The rapidly changing nature of raising livestock has also contributed to a sharp increase in nutrient fluxes over the last century. Animal production is intensifying with increasingly more production occurring further away from feedstock supplies. The large quantity of manure produced by these operations is applied to land as fertilizer, stacked in the feedlot, or stored in lagoons. The consequence is that livestock units become point sources of nutrients runoff rather than diffuse sources, and under improper management practices they may pose serious problems. They may contribute to organic pollution of the receiving body of water as well as nutrient enrichment. Frequently, the rate and timing of land application of manure is dictated by the volume and availability of manure and not by crop needs. This leads to ill-timed application or overapplication of manure, further exacerbating nutrient runoff and leaching.

In China, meat production rose by 127% between 1990 and 2002 (FAO 2009), but fewer than 10% of an estimated 14,000 intensive livestock operations have installed pollution controls (Ellis 2007). In the Black Sea region, one swine operation, which subsequently closed, had over 1 million pigs and generated sewage equivalent to a town of 5 million people (Mee 2006).

Aquaculture is one of the growing sources of nutrient pollution. Annual aquaculture production worldwide increased by 600%, from 8 million tons in 1985 to 48.2 million tons in 2005. Nearly 43% of all aquaculture production is within marine or brackish environments, with the remainder in freshwater lakes, streams, and man-made ponds (FAO 2007). Marine fish and shrimp farming generate concentrated amounts of nitrogen and phosphorus from excrement, uneaten food, and other organic waste. If improperly managed, aquaculture operations can have severe impacts on aquatic ecosystems as nutrient wastes are discharged directly into the surrounding waters. For every ton of fish, aquaculture operations produce between 42 and 66 kg of nitrogen waste and between 7.2 and 10.5 kg of phosphorus waste (Strain and Hargrave 2005).

### 1.3.1.3 Fossil Fuel and Energy Consumption

Coal-fired power plants, cars, buses, and trucks consume fossil fuels, which is also a contributor of nutrients. On combustion fossil fuel releases nitrogen oxides into the atmosphere. These oxides of nitrogen contribute to the formation of smog and acid rain. Nitrogen oxide is redeposited to land and water through rain and snow, or can settle out of the air in a process called dry deposition. Fossil fuel combustion contributes approximately 22 Tg of nitrogen pollution globally every year, approximately one-fifth of the contribution of synthetic nitrogen fertilizers (MA 2005). In the Baltic Sea, atmospheric deposition, primarily from burning fossil fuels, accounts for 25% of nitrogen inputs (HELCOM 2005). Similarly, in the Chesapeake Bay, atmospheric deposition accounts for 30% of all nitrogen inputs. In some areas, such as in the US North Atlantic, atmospheric deposition of nitrogen can exceed riverine nitrogen inputs to coastal areas (Spokes and Jickells 2005).

Increasing demand of energy for the increasing population across the globe is one of the direct drivers of eutrophication. Total worldwide energy consumption rose by 33% between 1990 and 2005. Currently, more than 86% of the world's energy needs are being met by fossil fuel sources (EIA 2008). Experts estimate that per capita energy consumption will increase by approximately 18% between 2005 and 2030, while total global energy consumption will rise by 50%; the developing world is projected to account for the majority of increased energy consumption (EIA 2008). Fossil fuels are expected to continue meeting approximately 86% of global energy needs (EIA 2008).

### 1.3.1.4 Increased Fertilizer Consumption

The increasing population forces to increase the agriculture production that is accompanied by the additional use of fertilizers. It is expected that between 2002 and 2030 fertilizers consumption will increase by 40% (FAO 2000). The majority of the projected increase in global fertilizer consumption is attributed to the developing world where food production and adoption of intensive agricultural practices are expected to increase (FAO 2000). At present, two sources of fertilization commonly used are slurry and synthetic compounds. Nitrogen and phosphorus losses in surface runoff from fertilized soils depend upon the quantity of transporting water and the time and rate of fertilizer application. When fertilizers are applied before a wet period or snowmelt, or on frozen ground, losses are higher than when fertilization is done in the spring. Excessive application of fertilizers and bad management practices increase nutrient loss from the soil. Lesser amounts of nitrogen and phosphorus are lost to the surface water of judiciously fertilized and well-managed soils.

### 1.3.1.5 Land-use Transformation

Enhanced food production is coupled with the transformation of forest to crop land. Cropland has experienced a net global increase of about 3 million ha per year from 1995 to 2002, with over 90% of the total cropland gains coming from forests (Holmgren 2006). Agriculture is also the single largest cause of wetland loss. Approximately 50% of the world's wetlands have been lost since the 1950s. The majority of wetland loss occurred as a result of drainage for agricultural production (OECD/IUCN 1996). According to the prediction of FAO, land-use conversion for agriculture will continue, but at a slower pace than in the past (FAO 2002). Natural landscapes such as forests and wetlands are important for capturing and cycling nutrients. Increasing land-use conversion reduces the ability of these landscapes to intercept nutrients and leads to greater nutrient losses to local waterways.

## 1.3.2 Indirect Drivers of Eutrophication

### 1.3.2.1 Population Expansion

Although population growth is an indirect driver of eutrophication but it is also the root cause for all types of the drivers of eutrophication. The global population is predicted to grow from 6.5 billion in 2005 to nearly 9.2 billion in 2050 with the majority of population growth occurring in developing countries (United Nations Population Division 2008). Population growth will increase the demand for food, land, energy, and other natural resources, ultimately leading to greater agricultural production and increased burning of fossil fuels to heat homes, power cars, and fuel industry.

### 1.3.2.2 Financial Boom

Increasing economic growth and per capita income indirectly contributes the nutrient pollution in developing parts of the world. Increasing incomes will lead to changes in dietary choices, increasing energy use, and increasing consumption of consumer goods. Worldwide increase in purchasing power is moving dietary trends toward greater meat consumption especially in the case of lower to middle income populations (FAO 2002). The increased livestock production that will be necessary to meet growing global demand for meat is expected to have significant implications for the severity of nutrient pollution worldwide. It is estimated that only 20% of the nitrogen used in swine production is actually consumed by humans, the remainder is excreted as manure or lost to the environment during the production of animal feed (UNEP and WHRC 2007). On the contrary, one study of the Mississippi River Basin estimated that if feed cultivation for meat production were switched to crops that would support a lacto-ovo-vegetarian diet, nitrate exports to the Gulf of Mexico would decrease by 50% (Donner 2006).

### 1.3.2.3 Agricultural Extension

In order to fulfill the food demand of increasing population across the globe, the way in which we grow food has changed dramatically. Significant advances in agriculture production have been made, the widespread use of agrochemicals such as synthetic fertilizers and pesticides to improve crop yields. These chemicals and modern machinery allowed the intensification of agriculture, which has led to significant unintended environmental impacts such as nutrient pollution. In fact, agriculture (including livestock agriculture) is the largest source of water pollution. Fertilizer leaching, runoff from agricultural fields, manure from concentrated livestock operations, and aquaculture are the largest agricultural nutrient sources. Between 1960 and 1990, global use of synthetic nitrogen fertilizer increased more than sevenfold, while phosphorus use more than tripled (MA 2005). The excess nutrients are lost through volatilization, surface runoff, and leaching to groundwater. On average, about 20% of nitrogen fertilizer is lost through surface runoff or leaching into groundwater (MA 2005). Synthetic nitrogen fertilizer and nitrogen in manure that is spread on fields is also subject to volatilization. Volatilization is where nitrogen in the form of ammonia ( $\text{NH}_3$ ) is lost to the atmosphere. Under some conditions, up to 60% of the nitrogen applied to crops can be lost to the atmosphere by volatilization (University of Delaware Cooperative Extension 2009); more commonly, volatilization losses are 40% or less (MA 2005). A portion of the volatilized ammonia is redeposited in waterways through atmospheric deposition. Phosphorus, which binds to the soil, is generally lost through sheet and rill erosion from agricultural lands.

## 1.4 Impacts of Fertilizers on Eutrophication

It is evident that eutrophication is related with a number of anthropogenic activities in urban and rural areas including agricultural practices. Phosphorus and nitrogen input owing to excessive use in agricultural practices, their cycling in the water bodies and seasonal variabilities (temperature, water level, depth, irradiance, and winds) are the main causes of eutrophication (Khan and Ansari 2005). Nonpoint sources of nutrients are often of greater concern than point sources because they are larger and more difficult to control. Fertilizer application on land remains a major contributor to nonpoint nutrient pollution, and this source is still increasing at an alarming rate in many geographic regions (Vitousek et al. 1997). Both industrial and developing nations are using significantly higher loadings of fertilizer in agriculture with global N and P fertilizer usage increasing eightfold and threefold, respectively, since the early 1960s (Constant and Sheldrick 1992; Caraco 1995; Matson et al. 1997; Smil 2001). In addition to compost, several brands of chemical fertilizers containing macro and micronutrients are being excessively used. The fertilizer industry recognizes its crucial role in meeting basic human needs. It stands to meet the challenge of adopting new practices and technologies for greater efficiency and optimum crop productivity to sustain better quality of life (Fixen and West 2002).

The fluxes in nutrient concentration of a water body are the result of synergistic action of population development and fertilizer applications (Caraco 1995; Smil 2001). When these nutrients get to lower rivers, estuaries, and coastal waters, they are available for phytoplankton uptake and growth. The nitrate component of fertilizers can travel long distances. A significant relationship between traveling distance of nitrate and increased phytoplankton productivity was recorded by Mallin et al. (1993). A dramatic trend in world fertilizer production is the increased proportion of urea in world N production, especially in Third-World countries. Urea now comprises roughly 40% of all N fertilizers produced (Constant and Sheldrick 1992). This is significant because data indicate that in some areas this shift in fertilizer composition has resulted in a shift in the nutrient composition of runoff, potentially favoring some harmful algal bloom species.

In situ experiment of nutrient enrichment in a temperate region reservoir in Seoul (South Korea) revealed that algal response on P treatments were greater than on treatments with  $\text{P}+\text{NH}_4\text{-N}$  or  $\text{P}+\text{NO}_3\text{-N}$ . The response was greater during summer monsoon than in any other season (An 2003).

### 1.4.1 Effects of Nitrogen

The atmospheric reservoir of gaseous dinitrogen is the initial source of nitrogen. It must be converted by nitrogen fixation

by microorganisms living principally not only in the soil but also in aquatic environments before it is available to most living organisms. In natural water, nitrogen is present as dissolved dinitrogen, ammonia, and salts of the nitrate and nitrite ions.

The supply of both nitrogen and phosphorus from atmosphere deposition is potentially a significant source of nutrients for aquatic ecosystem. However, nitrogen deposition is of higher magnitude than that of phosphorus, it includes dissolved dinitrogen, the products of chemical fixation, and some organic compounds as well. Atmospheric inputs of nitrogen have increased a great deal more than those of phosphorus as a result of human activities. Gaseous nitrogen pollutants may be ammonia from the application of fertilizers and the decomposition of animal and human wastes and oxides of nitrogen from the combustion of fossil fuels and the use of motor vehicles. Such compounds are released into the long-range atmospheric circulation patterns and may travel very long distances, according to atmospheric wind patterns and meteorological conditions, before they are deposited onto a lake surface.

Crop and livestock agricultural systems are important contributors to local, regional, and global budgets of  $\text{NH}_3$ ,  $\text{NO}_x$  ( $\text{NO} + \text{NO}_2$ ), and nitrous oxide ( $\text{N}_2\text{O}$ ). Emissions of biologically and chemically active  $\text{NH}_3$  into the atmosphere serve to redistribute fixed N to local and regional aquatic and terrestrial ecosystems that may otherwise be disconnected from the sources of the N gases. About 50–75% of N in terrestrial ecosystems emitted from animal excreta and synthetic fertilizer applications (Mosier 2001).

Among nonpoint nutrient pollutions, fertilizer application on land remains a major contributor, and this source is still increasing at a frightening rate in many regions (Vitousek et al. 1997). There is a direct relationship between population development, fertilizer applications, and riverine N and P fluxes (Caraco 1995; Smil 2001). Both industrial and developing nations are using significantly higher loadings of fertilizer in agriculture, with global N usage increasing eightfold, since the early 1960s (Constant and Sheldrick 1992; Caraco 1995; Matson et al. 1997; Smil 2001). These nutrient supplies, after reaching lower rivers, estuaries, and coastal waters, are available for phytoplankton uptake and growth. The nitrate component of fertilizers can travel long distances. Mallin et al. (1993) demonstrated a significant relationship between nitrate, carried ca. 400 km downstream to the lower Neuse estuary (over a 2-week period), and increased phytoplankton productivity. Biological transformations of N added to ponds in the form of inorganic or organic fertilizers and formulated feeds were found to dominate the nitrogen biogeochemistry of aquaculture ponds.

One of the most rapidly increasing sources of nutrients to both freshwaters and the coastal zone is the atmosphere. Nutrient inputs from runoff are influenced by several envi-

ronmental factors and form of fertilizer in use. A dramatic trend in world fertilizer production is the increased proportion of urea in N production, urea now comprises roughly 40% of all N fertilizers produced (Constant and Sheldrick 1992). This is significant because data indicate that in some areas this shift in fertilizer composition has resulted in a shift in the nutrient composition of runoff. Nitrate derived from particulate or oxidized nitric/nitrous oxides in wet and dry deposition have long been recognized as important sources of nutrients to streams and lakes, and can be major sources especially for soft water, nutrient-poor freshwater systems (Likens et al. 1979; Kilham 1982). It has been estimated that in estuarine and coastal waters 20–40% of N inputs can be of atmospheric origin, from industrial, agricultural, and urban sources (Duce 1986; Fisher and Oppenheimer 1991; Paerl 1995; Coale et al. 1996). Interactions of N and iron (Fe) can influence the structure of plankton community (DiTullio et al. 1993) and may act as a regulator of growth and encystment of dinoflagellates (Doucette and Harrison 1991) and possibly in the toxicity of diatoms.

Nearly 81.7 million metric tons of commercial nitrogen fertilizer account for approximately half of all N reaching global croplands now a days and supplies basic food needs for at least 40% of the world population. The challenge is to meet the increasing food requirements and minimize the risk of negative environmental impacts through improved N-use efficiency. Current N-efficiency and crop productivity are generally lower in several parts of Asia than in North America, but they are improving (Fixen and West 2002).

The surplus nitrogen (N) from Japanese agriculture was speculated to have strongly affected the environment. In a study of N flow in agricultural production during 1980–1997 it was estimated that application of chemical fertilizer per unit area of farmland in Japan peaked in 1985 and then declined. The amount of residual N on farmland (expressed as the difference between N inputs and N outputs) was lowest in 1997 owing to the low input of chemical fertilizers and manure, although the amount of nonutilized livestock waste was highest. Therefore, the total amount of residual N in farmland and nonutilized livestock wastes in Japan were 141, 163, 158, and 148  $\text{kg N ha}^{-1}$  in 1980, 1985, 1990, and 1997, respectively (Mishima 2001).

The breakdown of dissolved inorganic and organic nitrogen from readily available compounds such as  $\text{NH}_4^+$  and urea was felt to be the important process in the nitrogen nutrient availability. The nitrogen was utilized by the phytoplanktons and bacteria in the Lake Kinneret (Israel), the River Charante estuary, and coastal water near Ile de Re the French Atlantic Coast (Berman et al. 1999).

Nonpoint sources are considered as the major nutrient contributors because they are larger and difficult to control. However, point sources can be a major source of nutrients for small watersheds. Phosphorus and nitrogen in runoff from

agricultural fields are key components of nonpoint source pollution of water bodies and can accelerate eutrophication of surface waters. In an experiment, the fertilizer input with near-surface hydraulic gradient (free drainage, saturation, artesian seepage with and without rain) tested for contribution to the water quality problems. The total  $\text{NO}_3\text{-N}$  loss from free drainage treatment was 0.01% of the applied N while artesian seepage with and without rain resulted into 16 and 11% loss of  $\text{NO}_3\text{-N}$ , respectively (Zheng et al. 2004). Sewage from New York City contributes an estimated 67% of the N inputs to Long Island Sound annually. Sewage treatment plants deliver from 40–80% of the N to Kaneohe Bay, Hawaii, and to Narragansett Bay, Rhode Island (Nixon and Pilson 1983; National Research Council 1993). It is estimated that sewage contributes only 12% of the flux of N from the North American continent to the North Atlantic Ocean (Howarth et al. 1996). Only ca. 25% of the N and P inputs to Chesapeake Bay come from wastewater treatment plants and other point sources (Boynton et al. 1995). Nonpoint source pollution of surface water by nitrate from agricultural activities is a major environmental problem in USA. An agricultural watershed in the Iowa Loess Hills with a 23 years history of annual corn production with average N fertilization has been studied. Head cut seepage was transported through a natural riparian zone and observed as weir base flow; surface runoff was measured separately. The concentration of nitrate carried from the field in basin drainage steadily increased from <1 mg/l in 1969 to >20 mg/l in 1991 (Steinheimer et al. 1998).

The groundwater protection and eutrophication are significant environmental issues on the European agenda. The main source of nitrogen in Europe is leaching from agricultural fields caused by excess fertilizer inputs. Since the late 1970s, nitrate concentrations have increased all over Europe reflecting intensification of agriculture. High nitrate concentrations in ground and surface water make it unsuitable for drinking. High nitrogen inputs in the marine environment cause eutrophication and results in increased algal growth, altered biological communities, and deoxygenation (Iverson et al. 1998). Nitrates from fertilizers account for nearly 50% of the surface water acidification in watershed. Owing to these N inputs, there is a strong need to cut in  $\text{NO}_x$  and  $\text{NH}_x$  emissions (Hessen et al. 1997a, b).

The mathematical model has shown that phosphorus and nitrogen input is likely to be reduced to the extent of 50 and 85%, respectively into the Swan and Canning Rivers (Australia) provided agricultural land is reforested. The urbanization has also been reported to be a major cause of phosphorus and nitrogen input. During the next 10 years the urbanization is likely to increase 4 and 12% of phosphorus and nitrogen loads, respectively in the estuary of those rivers (Zammit et al. 2006).

Biological transformations of N added to ponds in the form of inorganic or organic fertilizers and formulated feeds were found to dominate the nitrogen biogeochemistry of aquaculture ponds. Nitrogen application in excess of pond assimilatory capacity can lead to the deterioration of water quality through the accumulation of nitrogenous compounds (e.g., ammonia and nitrate) with toxicity to fish or shrimp (Hargreaves 1998).

#### 1.4.1.1 N-Cycle

Increased use of fertilizers in agriculture has led to the altered nitrogen cycle across the globe. The excessive use of fertilizers increased emissions and transboundary air pollution. During the 1900s, over 50% of the nitrogen deposition over Republic of Korea (South Korean Peninsula) was imported from abroad. The N inputs from atmospheric deposition, fertilizers, biological fixation, imports of food, feed and products, outputs in riverine export, crop uptake, denitrification, volatilization, runoff, sedimentation, and sea water exchange have been quantified. The nitrogen budgets were found positive with N inputs exceeding outputs. The excess N inputs in turn increased N storage in ground water. Annual accumulation of N in the Yellow Sea including inputs from South Korea and other drainage areas was 1,229 kt per year. The human-derived N inputs lead to excessive eutrophication and pollution of Yellow Sea (Bashkin et al. 2002).

Human activities have greatly altered the global nitrogen (N) cycle and accelerated the rate of N-fixation in landscapes and delivery of N to water bodies. Using data from the early 1990s, Boyer et al. (2002) quantified N inputs in 16 catchments from those of atmospheric deposition, nitrogenous fertilizer applications, biological nitrogen fixation, and imports of N in agricultural products. Net atmospheric deposition was found to be the largest N source (>60%) to the forested basins of Northern New England. However, in most populated regions of Southern New England, the net import of N in food was the largest N source. The agricultural inputs were the dominant N sources in the mid-Atlantic regions (Boyer et al. 2002).

#### 1.4.1.2 Impact of Phosphorus

Phosphorus (P) inputs are essential for cost-effective crop and livestock agriculture. However, P inputs can also increase the biological productivity of surface waters by accelerating eutrophication that is responsible for the impairment of surface water quality and restricts water use for fisheries, recreation, industry, and drinking because of increased growth of undesirable algae and aquatic weeds and the oxygen shortages caused by their death and decomposition. Phosphorus is mainly responsible for eutrophication of most fresh water around the world (Schindler 1977; Sharpley et al. 1994). Although nitrogen and carbon are also essential to the growth of aquatic biota, most attention has focused on

P inputs because of the difficulty in controlling the exchange of nitrogen and carbon between the atmosphere and water and the fixation of atmospheric nitrogen by some blue-green algae. Therefore, P is often the limiting element, and its control is of prime importance in reducing the accelerated eutrophication of fresh waters.

Agriculture is regarded as an important source of P in environment. However, the rapid growth and intensification of crop and animal farming in any areas has created regional and local imbalances in P inputs and outputs. This has created regional surpluses in P inputs (mineral fertilizers and feed) over outputs (crop and animal produce), built up soil P in excess of crop needs, and increased the loss of P from land to water. Recent research has shown that this loss of P in both surface runoff and subsurface flow originates primarily from small areas within watersheds during a few storms. These areas occur where high soil P, or P application in mineral fertilizer or manure, coincide with high runoff or erosion potential (Sharpley et al. 2001).

Phosphorus is an essential element for all life forms. A mineral nutrient orthophosphate is the only form of P that autotrophs can assimilate (Corell 1998). Phosphorus does not occur as abundantly in soils as N and K. Total phosphorus in surface soils varies between 0.005 and 0.15%. The average total P content of soils is lower in the humid southeast than in the Prairie and Western states. Unfortunately, the quality of total P in soils has little or no relationship to the availability of P to plants. Although Prairie soils are often high in total P, many of them are characteristically low in plant available P. Therefore, understanding the relationship and interactions of the various forms of P in soils and the numerous factors that influence P availability was felt essential to efficient P management (Tisdale et al. 1995).

Anthropogenic factors, viz. mining P and transporting it in fertilizers, animal feeds, agricultural crops, and other products are altering the global P cycle, causing P to accumulate in the soil. Increasing P levels in the soil elevate the potential P runoff to aquatic ecosystems leading to eutrophication of fresh water ecosystems (Schroeder et al. 2004; Djodjic and Bergstrom 2005; Vadas et al. 2005). Phosphorus generally enters aquatic ecosystems adhered to soil particles that are eroded into lakes, streams, and rivers (Daniel et al. 1994; Sharpley et al. 1994). Much of this runoff occurs during major erosion-causing storms (Pionke et al. 1997). Phosphorus-induced pollution of aquatic ecosystems is thus strongly influenced by watershed land use and the concentration of P in watershed soil. Any factor that increases erosion or the amount of P in the soil increases the potential P runoff to downhill aquatic ecosystems (Daniel et al. 1994; Sharpley et al. 1994). Most of the eutrophication is caused by water quality problems owing to phosphorus accumulation in upland soils. Accumulation of P in soil and the appearance of adverse effects in freshwater ecosystems may take a

long period of many years. Soil P accretion could lead to sudden and unanticipated changes in aquatic ecosystem productivity. It could also cause lags between management actions taken to control eutrophication and the time when results of those actions are realized (Stigliani et al. 1991).

Information regarding human impact on P cycle is meager. However, instances of human impact on the P cycle leading to accumulation of P in upland systems have been discovered. Lowrance et al. (1985) found that imports of P exceeded exports by 3.7 to 11.3 kg ha<sup>-1</sup> per year in four subwatersheds of the Little River in the Georgia Coastal Plain. Similarly, a P budget of the upper Potomac River Basin revealed that over 60% of imported P was retained within the watershed (Jaworski et al. 1992). In this case, P retention was caused by an excess of fertilizer and animal feed inputs over outputs of agricultural products. In a Florida study, Fluck et al. (1992) found that less than 20% was P output, in agricultural and other products, of P input to the Lake Okeechobee watershed in fertilizers was output. Runge-Metzger (1995) calculated net fertilization (fertilizer input minus crop removal) of 0.7–57.2 kg P ha<sup>-1</sup> per year in 25 countries of Europe. All the studies showed no country on the globe with net loss of P; all countries were P accumulators. Natural imbalance in P inputs and outputs are not the cause for P accumulation but inputs of fertilizer and animal feeds that exceeded outputs in agricultural products contribute to P accumulation (Runge-Metzger 1995). During 1950 and 1990, an eightfold increase in average available P in the soils of Ireland was recorded (Tunney 1990). In 1990, P inputs in fertilizers to Ireland were more than double the outputs (Tunney 1990). Isermann (1990) calculated the P surplus (total application of fertilizers minus net withdrawal by agricultural products) in the Netherlands and Germany to be 88 and 63 kg ha<sup>-1</sup> per year, respectively.

Bennett et al. (2001) calculated a global agricultural P budget to determine the amount of P accumulation that occurs in agricultural areas. This budget included only agricultural inputs (fertilizer and manure) and outputs (agricultural products such as meat and eggs, and runoff). Fertilizer inputs were calculated based on global estimates of fertilizer use and P content of fertilizer (FAO 1950–1997). They calculated agricultural P budget from 1958 to 1998 at 5-year intervals, which indicated that the average annual P accumulation in agricultural areas of the world was 8 Tg per year. The result of the study carried out by Bennett et al. (2001) suggest that a considerable fraction of the excess P in the current global budget is being stored in agricultural soils, which occupy 11% of the terrestrial area of the Earth (World Resources Institute 1998).

Moreover, studies predict that fertilizer demand and use will continue to increase to 208 million tons by 2020, with greater increases in developing countries, further aggravat-

ing a trend of freshwater eutrophication worldwide (Bumb and Baanante 1996).

Phosphorus, an essential nutrient for crop and animal production, can accelerate freshwater eutrophication and is considered as one of the most ubiquitous forms of water quality impairment in the developed world. Repeated outbreaks of harmful algal blooms (e.g., Cyanobacteria) have increased society's awareness of eutrophication and the need of solutions. Agriculture is regarded as an important source of P in environment. Specifically, the concentration of specialized farming systems has led to a transfer of P from areas of grain production to animal production. This has created regional surpluses in P inputs (mineral fertilizers and feed) over outputs (crop and animal produce), built up soil P in excess of crop needs, and increased the loss of P from land to water. Recent research has shown that this loss of P in both surface runoff and subsurface flow originates primarily from small areas within watersheds during a few storms. These areas occur where high soil P, or P application in mineral fertilizer or manure, coincide with high runoff or erosion potential (Sharpley et al. 2001).

## 1.5 Control Measures and Recommendations

Anthropogenic activities are the worst culprit of nutrient enrichment and root cause of eutrophication of water bodies. Several countries have come forward to address the issue by implementing a range of technologies, legislative and biological measures.

### 1.5.1 Biological Control

Phosphorus (P)-induced eutrophication leads to water quality tribulations in aquatic systems, particularly freshwater, across the globe. Processing of nutrients in shallow habitats removes P from water naturally. Periphytons are considered as one of the tools for P removal from the water column in lotic waters and wetlands. Periphytons play several roles in removing P from the water column, including P uptake and deposition and filtering particulate P from the water. Periphyton photosynthesis locally increases pH up to 1 unit, which can lead to increased precipitation of calcium phosphate, concurrent deposition of carbonate-phosphate complexes and long-term burial of P. In general, periphytons tend to increase P retention and deposition (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 (Hrbáček 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 and Litt 1982; 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).

#### 1.5.1.1 Phytoremediation

In freshwater bodies, the phytoremediation has been suggested to be effective in reducing the toxicity of waters caused by microorganisms releasing ammonia and sulfide during degradation of protein released from food industries.

Several plant species have been found to reduce the excess of nitrogen and phosphorus from aquatic system. Aquatic macrophytes such as *Eicchornia crassipes* and *Salvinia auriculata* cause significant reduction of nitrogen and phosphorus compounds in water. This information was felt helpful in developing adequate management strategy for aquatic macrophytes to check the eutrophication process in Imboassica Lagoon (Petruccio and Esteves 2000). Jiang et al. (2004) reported that *Phragmites communis* and *Zizania latifolia* have the efficiency to absorb N and P and thus these two species were found to play an important role in the purification of wetlands receiving nonpoint source pollutants. The harvesting of these species took away 463–515 kg hm<sup>-2</sup> of N and 127–149 kg hm<sup>-2</sup> of P each year. This amount of N and P is equivalent to the discharge from 2.3–3.2 and 1.3–3.0 hm<sup>-2</sup> of fields, respectively in this area. The absorption and decomposition capacity of *Z. latifolia* was higher than *P. communis* (Jiang et al. 2004). Abe et al. (2002) investigated nitrate, nitrite, ammonium, and phosphate ions removal characteristics of aerial macroalga *Trentipholia aurea*. The 1.5 times higher biomass was recorded in medium with sufficient N and P source than in ordinary medium. The macroalga had a potential of 37% of nitrite and 32% of nitrate removal from the wastewater.

Duckweeds have been reported to be promising macrophytes for wastewater treatment. They are used to treat effluent from shrimp farm and found to remove nutrients and high amounts of ammonia effectively (Ruenglerpanyakul et al. 2004). The duckweeds increase the degradation of organic material (Sabine et al. 2003).

Cedergreen and Madsen (2004) investigated the ability and relative contribution of roots and fronds of floating macrophyte *Lemna minor* for N uptake. They showed that roots and leaves of *L. minor* can acquire significant amount of inorganic N through both root and frond.

The wetlands with floating *Lemna gibba* were constructed to treat wastewater from various sources. The suspended solid and organic matter removals were the highest. The nitrogen removal increased with higher nitrogen loads. The phosphorus removal was negligible (Noemi et al. 2004).

## 1.5.2 Mechanical Control

The problems associated with eutrophication can be overcome by several mechanical means by adopting the strategy of minimum nutrient input and maximum nutrient retention.

### 1.5.2.1 Fertilizer Requirement

Fertilizers are considered as one of the important sources of nutrients causing eutrophication. Therefore, reducing fertilizer application without compromising the crop requirement by some means could be a strategy to reduce nutrient inputs, of which, use of fertilizer according to the requirements of soil rather than tradition can go far toward reducing nutrient applications in catchments. Optimized use of fertilizer requires regular soil testing so that fertilizer applications are optimized. Soil testing may indicate that some soils with a high P status may be able to do without applications for even longer. Use of an alternative source of fertilizers that could supply phosphorus in a slow release form will be more suitable to the needs of pasture in the high rainfall areas. In addition, particularly for soils with a high phosphorus status, other nutrients such as sulfur and potassium can be used to achieve the most economic level of production (Weaver and Summers 1998). A survey by the South Coast Estuaries Project showed that more than 50% of the soil samples taken in the area had a high P status and could go without extra applications for at least 1 year.

### 1.5.2.2 Eutrophication Sources and Nutrient Loading

Under natural conditions total phosphorus concentrations in lakes range from 14 to 17 parts per billion (ppb). In 1976, the Environmental Protection Agency recommended phosphorus limits of 25 ppb within lakes to prevent and control eutrophication (Addy and Green 1996). However, many lakes have nutrient levels above this limit. Therefore, to control eutrophication and restore water quality, it is necessary to check and restrict phosphorus inputs, reduce soil erosion, and develop new technologies to limit phosphorus content of over-enriched soils (Carpenter and Lathrop 2008). Methods to control eutrophication include enforcing wastewater treatment and eliminating the importation of chemical phosphorus to watersheds via fertilizers (Schindler 2006).

Hypolimnetic aeration also proved helpful to improve oxygen conditions of water of eutrophic lakes. In hypolimnetic aeration, water from the bottom of a lake is brought to the surface to be oxygenated then returned to the bottom. However, effectiveness of this process is dubious and variable. Studies have shown that this alternative is less effective in shallow lakes and there is little evidence that hypolimnetic aeration reduces algal biomass (Cooke and Carlson 1989). To alleviate eutrophication and algal biomass, regulation of nutrient control focusing on reducing phosphorus input is

the most effective way to control eutrophication (Anderson et al. 2002; Smith and Schindler 2009). Lake Washington is perhaps the most widely recognized success story of recovery from eutrophication through nutrient-input control. A considerable improvement of water quality and decrease in phytoplankton was recorded after the diversion of phosphorus-containing wastewater effluent from the lake (Schindler 2006).

Enhanced use of detergents is also one of the major sources of phosphates in enhancing the eutrophication of the water bodies. It has been recorded that phosphorus loads in wastewater fluctuates together with the consumption of phosphate in detergents. Therefore, reduction and eventual elimination of phosphates in detergents would be of prime importance in managing the eutrophication. As synthetic detergents became widespread in the USA since 1970, phosphate consumption raised to a peak of 240,000 t. Although the industries have reduced the amount of phosphate in detergents, but a complete ban would eliminate up to 30% more of the phosphates in sewage, thus reducing future loading to lakes (Litke 1999). Therefore, the need of the hour is to improve water quality by enforcing environmental technology techniques to control discharge from wastewater treatment plants, to find a phosphate substitute in detergents, to educate consumers so that they select washing products with the least amount of polluting components (Knud-Hansen 1994).

### 1.5.2.3 Nutrient Monitoring and Mathematical Models

Many eutrophication problems can be addressed by preventing the abnormal growth of blue-green and other undesirable algae. One measure for controlling eutrophication is the installation of aeration and circulation equipment, the "Current Control System" that controls the inflow of river and surface water. The efficiency of conventional aeration and circulation is boosted by controlling the vertical distribution of water temperature with this system. Field experiments were carried out on current control in a dam reservoir and the effects of current control to improve the water quality of reservoirs were examined by simulation using a modified one-dimensional model. Parameters of this model were determined by experiments in several reservoirs. The current control system was found effective but its aeration was suggested to be stopped in flood period and turbid water should not be raised to surface when resuming aeration (Niwa et al. 1997).

To control the eutrophication, the phosphorus limitation in surface runoff water may play an important role. In the wetland of Hovi, Finland, the P sorption by Al (ox) played an important role in the first phase of removal of P because wetland retained P efficiently under anoxic conditions. The fine textured mineral soil in the bottom of wetland efficiently retained the P from agricultural runoff (Liikanen et al. 2003).

Removal of harmful algal blooms by chemical treatments may also impair the eutrophication. Sun et al. (2004) used cocamidopropyl betaine (CAPB), a surfactant with high inhibition efficiency, high biodegradability and low cost, to mitigate harmful algal blooms. The half life of the surfactant in sea water was less than 1 day and 90% of the surfactant degraded in 5 days.

HEM-3D (Hydrodynamic-Eutrophic Model-3-Dimensional) Model is a general purpose modeling package for simulation of flow field, transport, and eutrophication processes throughout the water column. The excessive loadings of organic wastes have been found to significantly deteriorate water quality conditions of Korean coastal waters of Kwang-Yang Bay (Park et al. 2005).

Eutrophication, in Lago Maggiore Lake, Italy, was caused by industrial and economic development, the use of P-containing detergents and fertilizers, and the disposal of untreated human sewage into the lakes. Total P concentrations in the lake water increased to 30–35 mg m<sup>-3</sup>, and a twofold increase in the concentrations of NO<sub>3</sub>-N was recorded (Roggiu et al. 1985). More than threefold increase in phytoplankton production was observed, and nuisance blooms of cyanobacteria also occurred (de Bernardi et al. 1996). In order to assess water quality restoration strategies for the lake, Mosello and Roggiu applied the OECD (1982) modeling framework, and they concluded that a 67% reduction in external P loading would be required to return Lago Maggiore from eutrophic to oligotrophic conditions.

To analyze point and diffuse sources of nutrients in Marne river, France over more than 10 years taking into account the role of exchangeable phosphorus, Garnier et al. (2005), applied the RIVERSTRAHLER model (Billen et al. 1994; Garnier et al. 1995; Billen et al. 1998; Garnier and Billen 2002), a generic model of the biogeochemical functioning of whole river systems. Different realistic scenarios of future reduction of phosphorus load were tested, in various hydrological conditions (dry and wet years). They reported that phytoplankton development can be slightly reduced by a further 85% decrease of phosphorus in all the wastewater treatment plants of the basin, but a reduction both of diffuse and point phosphorus sources would be necessary to further decrease eutrophication.

#### 1.5.2.4 Public Awareness and Legislations

Public awareness of the environment shapes the ability to understand the surrounding world, including the laws of the natural environment, sensitivity to all the changes occurring in the environment, understanding of cause-and-effect relationships between the quality of the environment and human behavior, an understanding of how the environment works as a system, and a sense of responsibility for the common heritage of the Earth, such as natural resources—with the aim of preserving them for future generations. The awareness

of local people to their surrounding environment and water sources has an important and lasting impact on the environment, and only a cooperative community effort can more efficiently reduce nutrient inputs to water bodies as in the case of Lake Washington, where the reduction in detergent use was the consequence of public awareness. Therefore, it is an urgent need of the hour to increase public awareness and the environmental education of citizens and also develop an integrated strategy to abate eutrophication (Jorgensen 2001).

Australia relied heavily on public education. Two public education campaigns, one within the Murray-Darling Basin in its town called Albury-Wodonga and the other within the Hawkesbury-Nepean Basin in the western suburbs of Sydney, were carried out. The results were positive and it was concluded that campaigns such as “Phosphowatch” can provide a long-term, cost-effective way of addressing eutrophication if the problem is focused at source and a community support is created for an integrated strategy (Howard and McGregor 2000).

There are a number of decision support systems (DSS) that provide advice on the application of inorganic fertilizers and organic manure to farmers. It was suggested that DSS should be based on dynamic models. However, DSS is needed to be developed particularly for organic wastes, grassland systems, and fruits (Falloon et al. 1999).

In 1998, Netherlands government introduced a new manure policy in order to combat pollution of the environment by an excess supply of nutrients in agriculture. This policy is based on a mineral accounting system (MINAS) at the farm level and is focused mainly on nitrogen. MINAS came into force by an alteration of the law on fertilizers. In MINAS, chemical nitrogen fertilizers are included because the use of these fertilizers contributes in the same order of magnitude to nitrogen surpluses as the application of animal manure. It was felt that by implementing MINAS surface waters may eventually be protected against eutrophication and the ground water quality could be improved (Van den Brandt and Smit 1998).

The European Union has taken steps toward the reduction of nitrogen and phosphorous loads in the environment notably through the adoption of several crucial pieces of legislation. A legislative framework has set out to directly tackle the problem of eutrophication through three directives: (1) The Nitrates Directive (1991) aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices. (2) The Urban Wastewater Treatment Directive (1991) aims to protect the environment from the adverse effects of urban wastewater discharges and discharges from certain industrial sectors. (3) The Water Framework Directive (2000) lays down a strategy to fight against the pollution of water, including adopting specific measures against pollution by individual pollutants or groups of pol-

lutants presenting a significant risk to or via the aquatic environment.

The regulatory and nonregulatory programs have been developed by the US Environmental Protection Agency (USEPA) to control water pollution. The Clean Water Act defined concentrated animal feeding operations as point sources and all other agricultural sources were considered nonpoint sources and thus not regulated under federal law. There is provision of Coastal Zone Act Reauthorization Amendments of 1990 for nonpoint source management of the USA. For water bodies that continue to be impaired despite the basic implementation of these laws and other programs, states are required to develop a total maximum daily load (TMDL). The TMDL process is the quantitative basis for reaching water quality standards. The USEPA is putting a new emphasis on controlling nutrient pollution sources to meet the goal of the Clean Water Act (Roberta 1998).

## 1.6 Conclusion

Eutrophication is one of the serious threats to the environment and has heavily degraded freshwater systems by reducing water quality and altering ecosystem structure and function across the globe. Population growth, industrialization, and excessive use of fertilizers are the root cause for disproportionate amounts of nutrients stimulating overgrowth of plants and algae. A solution to eutrophication is urgent since nutrient accumulation renders controlling eutrophication more difficult over time. Whereas the first and most obvious step toward protection and restoration of water bodies is to reduce the nitrogen and phosphorous load to the fresh water systems, which can be done through changes in the agricultural practices, for example, by restrictions in the use of fertilizers, optimizing nutrient use to crop requirements, planning the use of fertilizers, establishment of more sustainable agriculture farms. Moreover, reductions in atmospheric sources of nitrogen, better cleaning of sewage and wastewater, and better control of diffuse urban nutrient sources such as runoff from streets and storm sewers and introduction of wetlands as nutrient sinks can be mentioned as some of the solutions to the eutrophication issues. However, these processes alone are insufficient to produce immediate and long-lasting effects. Therefore, the modern strategies should include many other aspects such as phosphorus enrichment and food web structures to understand the changes that occur after alterations of nutrient loadings. An improved understanding of the interactive effects between grazers, nutrients, and algal production is necessary for successful eutrophication management. Governments should implement more effective policies to regulate the industrial and agricultural sectors to reduce activities that contribute to eutrophication. Finally, it can be postulated that the scientific and public

awareness and collective community efforts can play an effective role in reducing nutrient inputs to our vital water bodies.

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# Eutrophication: Global Scenario and Local Threat to Dynamics of Aquatic Ecosystems

# 2

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## Abstract

All self-regulated aquatic ecosystems maintain their structural and functional dynamics in equilibrium. Most natural oligotrophic surface water bodies maintain production: respiration ratio closer to 1 irrespective of geographical variations. The prevailing environmental gradients govern seasonal, structural and functional dynamics of aquatic ecosystem. During the past century, major socio-economic changes resulted into adverse alteration in both terrestrial and aquatic ecosystems. The terrestrial and aquatic ecosystems are not independent of each other. There is a delicate balance between the two. In the present work, changes in the delicate balance between seasonal, spatial, littoral dynamics and resulting bio-geo-chemical changes in the eutrophic water bodies have been highlighted. Seasonal environmental variables are the forcing factors behind cycling of materials in the water bodies which in turn result into structural and functional dynamics. Summer season triggers the release of orthophosphates bound in the sediments and advection brings the free nutrients to upper water surface and promotes phytoplankton abundance. The rain water input during monsoon may dilute or enrich the water bodies with nutrients subject to the quality of catchment areas. Upwelling and downwelling and surface run offs are among major drivers of the dynamics of water bodies. The hydrological characteristics of water bodies vary with the geographical location. Under extreme polluted conditions, seasonal heterogeneity in nutrient composition of water bodies may not remain maintained except on downstream scale. Phosphorus (P) in runoff from agriculture land accelerates eutrophication of lakes and streams. Seasonal variation of some selected macrophytes in a surface water body close to AMU campus has been studied. About 7.56 ha of catchment area of a nearby park forms a source of fertilizer "run off". Qualitative and quantitative seasonal estimates of density and productivity of two indicator species (*Lemna minor*, *Spirodela polyrrhiza*) and physicochemical properties indicated that the water body is under a fast rate of eutrophication process owing to chemical fertilizer inputs, variables of summer (high wind, high temperature, fast wind speed), winter (low temperature, reduced rain fall), and monsoon (excessive rainfall).

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## Keywords

Eutrophication · Fertilizers · Nitrogen · Phosphorus · Phytoremediation

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