Journal of Civil Engineering and Environmental Technology
Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 1, Number 5; August, 2014 pp. 18 – 23

http://www.krishisanskriti.org/jceet.html

Eutrophication and its control measures: A study on lakes and Reservoir

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Abstract : **The present study deals with the studies conducted on the impact of phosphorus on growth of aquatic plants causing eutrophication in well-known water bodies the world over. This study covers the concept of eutrophication and ecosystem functioning. The eutrophication of several water bodies leads to significant changes in the structure and function of the aquatic ecosystem. Several activities of human interest, including navigation and power generation, are hampered. A large number of lakes in the United States, Europe, and Asia have recently been found to be highly eutrophic. Water, the precious fluid, is not uniformly distributed throughout the surface of the earth. Most of the water bodies' worlds over are surrounded with densely populated human settlement areas and agricultural fields. The size of smaller water bodies in human settlement areas is on the decrease with rise in population. After treatment, a large quantity of sewage from the households is regularly discharged into the water bodies. The runoff brings down fertilizers and other chemicals from agricultural fields. The phosphorus contained in these effluents is known to promote excessive growth of plants. The natural phosphorus cycle originating from the weathering of phosphate rock is now a two-way operation, due to significant addition of phosphorus from anthropogenic sources. Several environmental factors have also been found to add to the problem of eutrophication in addition to nutrients. Eutrophication not only results in algal bloom but also affects wetland plants and activates early onset of natural succession at a relatively faster rate. Some of the plant species reported and studied world over are the best indicators of the level of eutrophication. In several countries adequate control measures have been adopted in to control eutrophication. But these measures were found to be only partially effective in controlling the phosphorus unloading in water bodies. In this review some control measures are suggested, with emphasis on biological control. The study concludes by taking into account the ecological prospective of the water the precious fluid and a basis of life on the earth.**

Keywords: Eutrophication, ecological, nutrients, algal bloom, measures.

INTRODUCTION

Water, a precious natural resource, is essential for a multiplicity of purposes. Water constitutes the major bulk (70%-90%) of all living cells. Water is an essential, life-supporting factor in every cell (microcosm), individual organism, ecosystem, and cosmos. Freshwater is utilized in drinking, several domestic and household purposes, industrial cooling, power generation, agricultural irrigation, and waste disposal. Since time immemorial, water bodies (river, lakes, and oceans) have been the cheapest route of transportation. Nature has not provided any alternative or replacement of water (essential for all life forms). Today, in almost all spheres of human activity, a far larger amount of water is drawn out than what is actually required. Due to careless and excessive uses, a major bulk of water is drained out in an impure state as waste. At many places in India, clean water is no longer available for domestic uses. The rapid rise in demand for freshwater is a manifestation of an equally rapid growth in the number of consumers.

However, reckless overconsumption, misuse, pollution, eutrophication, and depletion of the underground water table, not simple population growth, are the actual causes of degeneration of freshwater. Beeton (2002) predicted that climate change and pollution are global problems that will affect all lakes, large or small. Diversion of water out of or away from large lakes will become more of a threat as global human population growth continues and water supplies from rivers and groundwater become depleted. Most of the aquatic ecosystems of varying characters worldwide receive regular inputs of a range of nutrients in varying quantities. High amounts of nutrients are unloaded into water bodies from human settlements via sewage. These nutrients result in the extensive growth of aquatic flora. Eutrophication is a kind of nutrient-enrichment process of any aquatic body, which results in an excessive growth of phytoplanktons. This undesirable overgrowth of aquatic plants and their subsequent death form a greenish slime layer over the surface of the water body. The slime layer reduces light penetration and restricts reoxygenation of water through air currents. The death and decay of aquatic plants produces a foul smell and makes the water more turbid (Beeby, 1995; Rao, 1998). Eutrophication, or the promotion of the growth of plants, animals, and microorganisms in lakes and rivers, has been a very slow, natural process. If this is allowed to occur uninterrupted, it results in an excessive deficiency of oxygen in the water. Thus organisms that thrive under anaerobic conditions are favored more and more at the expense of aerobic organisms (Mengel & Kirkby, 1996). In surface waters, phosphorus concentrations exceeding 0.05 mg may cause eutrophic conditions (Hinesly & Jones, 1990). Eutrophication of drainage ditches by over fertilization with nitrogen and phosphorus causes a shift mainly from submerged aquatic vegetation to a dominance of floating duckweeds. This results in anoxic conditions, loss of biodiversity, and hampering of the agricultural functions of such ditches (Janse & Puijenbroek, 1998). The change in eutrophic conditions is reflected in the occurrence, pattern of distribution, and diversity of the biotic community (Tiwari, 1998). Many natural water bodies are described as oligotrophic, for they have clear-water ecosystems in which primary and secondary productivities are limited by a shortage of major nutrients (Beeby, 1995). These oligotrophic water bodies, if brought under natural succession, require thousands of years to become eutrophic. The enrichment of aquatic ecosystems through the discharge of human wastes from settlements and excessive fertilizers from agricultural lands brings down the water bodies under an undesirably increased rate of eutrophication. Nitrogen and phosphorus are essential elements required by plants and animals for maintaining their growth and metabolism. Small amounts of nitrates and phosphates occur in all aquatic ecosystems and maintain a balanced biological growth in such ecosystems. In wastewater, these nutrients are abundant as phosphates, nitrates, and ammonia or combined organic nitrogen. These compounds often enter the water bodies directly from the fertilizer manufacturing and processing units or from the agro ecosystems having excessive applications.

In their model, Welch and Crooke (1987) predicted the decline in phosphorus loading by diverting effluents away from Lake Washington, which became eutrophic as the city of Seattle expanded. Eutrophication is one of the serious kinds of water pollution directly affecting the fauna due to the loss of dissolved oxygen. It leads to an early and relatively faster mortality rate of fish and thus spoils the desired water qualities of ponds and lakes. Fishing and navigation in eutrophic water become difficult due to enmeshed and heavy growth of plants. Hydroelectric generation from such water storage is adversely affected as nutrient rich water acts chemically upon the turbines. At the end of an algal bloom, the decomposing debris also spoils the desired water characteristics and may result in the growth of disease-causing bacteria. Uncontrolled eutrophication leads to a rapid upwelling of a water body. The limited storage and water-recharging capacity of smaller freshwater bodies is reduced by silting. Small lakes and many ponds steadily lose their aquatic entity and become permanently terrestrial in nature. Eutrophication leads to significant changes in water quality. It lowers the value of surface waters for the industrial and recreational uses. Overpopulation of algae makes water unfit for swimming. Algae growing in long strands often twine around boat propellers and make boating difficult. Eutrophic waters tend to be scummy, cloudy, or even soupy green. The rapidly growing aquatic plants may wash onto the shore in storms or high winds. Where these plants die, decay produces a bad smell all around such water bodies (Penelope & Charles, 1992).

EUTROPHICATION STUDIES ON LAKES

Lakes can be synthetically characterized as plain lakes, very shallow, polymictic, eutrophic, or hypereutrophic. During the peak of the growth season three types of the large lakes are distinguished: 1) lakes with relatively low phytoplankton biomass and abundant rooted macrophytes; 2) lakes with high inorganic turbidity, scarce macrophytes population, and low phytoplankton biomass; and 3) lakes clearly limited in their productivity by light availability and are the result of direct human action on their drainage basins (Quiros et al., 2002). Linmological studies on lakes, rivers, and streams have been emphasized owing to deterioration of water quality due to eutrophication (Saxena et al., 1988). Lake Erie is a fitting example of eutrophication due to human made problems. This lake is surrounded by four American states and one Canadian province. It is approximately 240 miles long and 57 miles wide. The lake has a shallow western basin (average depth of 24 feet), a deep eastern basin (maximum depth of 210 feet) and a central basin (average depth of 60 feet). The lake is biologically the most productive of the Great Lakes because it is the shallowest and warmest, and it is excessively rich in nutrients (Reutter, 1989). The human activities around the lake have enhanced the nutrient input rate and accelerated the natural aging process known as eutrophication. This aging process brought down the lake under a faster cycle of succession. This succession is the process by which a water body becomes a marsh, then a bog, and finally a drier terrestrial body (Reutter, 1989). According to an estimate, more than 80 tons of phosphates were added daily in the lake in 1965, and each 400g of phosphate induces an algal bloom to add about 350 tons of algal slime (Sharma, 1998). Nutrient (such as phosphorus) enrichment in the Lake Erie has resulted in huge blooms of floating blue-green algae and the attached green alga, *Cladophora* spp. These blooms have rolled onto beaches in large mats resembling green steel wool. The blooms impaired the light penetration in the lake, reduced photosynthesis and oxygen production. When the bloomed algae died, the decomposers further depleted the dissolved oxygen (Reutter, 1989). Interestingly, all forms of phosphorus entering Lake Erie were not biologically available to phytoplanktons. Therefore, reducing total phosphorus input is not as important as reducing the input of usable phosphorus (bioavailable or soluble reactive form). These models helped to demonstrate that phosphorus was the key nutrient in the eutrophication of the ecosystem (Welch & Crooke, 1987). Lake Apopka is another large, shallow lake in Florida. The lake was made hypereutrophic by phosphorus loading from floodplain farms and has high levels of nutrients, phytoplankton, and suspended matter (Coveney et al., 2002). Field investigations were conducted on Jaroslawieckie Lake, in Poland, during the summer of 1996. The lake had several plant communities in corresponding variable environments. Most habitats of this lake were eutrophic. Analysis of the phytoplankton samples and bottom sediment showed a succession of algae, corresponding to the increasing trophic levels (Pelechaty et al., 1997). Most freshwater lakes in the northern and western portions of the Netherlands are very shallow (<2 m). These lakes vary in area from a few hectares to a few thousand hectares. The input to the lakes of phosphorus and nitrogen and of polluted waters from the rivers and canals have been the major cause of eutrophication (Gulati & van Donk, 2002). Based on soil-erosion levels, population settlements, and fertilizer-use data, the water bodies were phosphorus sensitive in the three zones of the country; namely, central south, western zone, and the eastern rice fields (Sommaruga et al., 1995). The majority of Danish lakes are highly eutrophic due to high nutrient input from domestic sources and agricultural activities. Several factors--reduced nutrient retention, more rapid removal in catchments, and channelization of streams--also play a role in eutrophication (Jeppesen et al., 1999). Control measures have resulted in 73% reduction in total phosphorus concentration of point-source-polluted streams since 1978, but reduction of the total nitrogen concentration has not been significant (Jeppesen et al., 1999). Surface runoff rich in agricultural wastes and underground seepage from urban and rural areas enriched the Lake Kastoria in Greece with nutrients and intensified eutrophication (Koussouris et al., 1991). The Lake Lammijarv part has some eutrophic features, and the Lake Phikva part is a typically unstratified eutrophic. The mean concentrations of total phosphorus and nitrogen in the surface water were 42 and 767 mg/m^3, respectively. The biomass of phytoplankton fluctuated between 1 and125 mg/m^3; that of zooplankton, from 0.088 to 6.344 g/m^3, with a summer average of 3.092 g/m^3. Lake Taihu, in China, is in the mesoeutrophication stage owing to the nutrients unloading from local industries and agricultural areas. The main eutrophic area of this lake is Meiliang Bay. The chemical oxygen demand was 4.63 mg/l in 1993. Total nitrogen and total phosphorus contents were 3.93 mg/l and 0.107 mg/l respectively, in 1995. Eutrophication is one of the main factors causing increased growth of green algae and turbid waters in Donghu Lake, also in China (He et al., 2002). Excessive growth of *Eicchornia crassipes* and *alternanthera pheloxirodes* has been noted in the shallow, eutrophic Donghu Lake. *Alternanthera pheloxirodes* showed the beginning of bloom in September; *E. crassipes*, in October (Liu et al., 2004). City Park Lake is a shallow, urban, hypereutrophic lake in Baton Rouge, Louisiana. The lake has become highly eutrophic and suffered from frequent algal blooms and fish kill (Ruley & Rusch, 2002). Garg et al. (2002) studied three lakes of Bhopal (Upper Lake, Lower Lake, and Mansarovar Lake) in India, to assess the potential fertility of lentic waters and to analyze the floral ecology. The highest level of eutrophication was found in Mansarovar Lake. The nutrient unloading into the lake initially promoted the growth of phytoplanktons. But the higher nutrient levels eliminated the sensitive phytoplankton due to competition with other species (Garg et al., 2002). Bellandur Lake is one of the major lakes of Bangalore, India. The addition of effluents from urbanized Bangalore city has changed the characteristics of the lake from a natural, oligotrophic lake to an artificial reservoir of domestic sewage and industrial effluents (Chandrashekar et al., 2003). Singhal and Mahto (2004) studied the characteristics Robertson Lake in the urban area of Jabalpur, India and found low species density, dominance of detritus food webs, and water unsuitable for human consumption. To gain more insight into the gravity of damage caused by eutrophication to our depleting water resources, a brief account of the ecological aspects of distribution and water cycle is given herewith.

ROLE OF PHOSPHORUS IN EUTROPHICATION

The average concentration of total phosphorus (inorganic and organic forms) in wastewater has been reported to vary in the range of 10-20 mg/l (Bitton, 1999). Approximately 15% of the U.S. population contributes phosphorus-containing wastewater effluents to lakes, resulting in eutrophication of those water bodies (Hammer, 1986). Phosphorus concentration in clean waters is generally very low. Phosphorus is used extensively in fertilizers and other chemicals and commonly accumulates in higher concentrations in the water bodies around agricultural fields or densely populated areas. In water bodies, the phosphorus may be present in various forms. All forms of phosphorus are not readily available to plants. Total phosphorus is a measure of all forms of phosphorus (dissolved or suspended) found in any water sample. The soluble reactive phosphorus is a measure of orthophosphate. The soluble inorganic (a filterable fraction) phosphorus is the form directly taken up by plant cells. While monitoring the water bodies, the latter form of phosphorus would be of special significance to determine the stage of eutrophy and oligotrophy. Natural waters are normally deficient in phosphorus and other plant nutrients. Such natural water bodies support only a limited growth of algae and higher aquatic plants. An additional loading of phosphorus in any of the various forms orthophosphate, pyrophosphate, metaphosphate, mono- and di-hydrogen phosphate, etc. results into an undesirably extensive growth of algae and/or other aquatic plants like water hyacinth (Ambasht & Ambasht, 1992). The death and decay of the bloomed aquatic flora further deteriorate the natural water bodies. The organic form of phosphorus is decomposed by bacteria in the bottom of the eutrophic water bodies and converted into inorganic form, which readily diffuses upward to the photic zone. The inorganic form of phosphorus is recycled again by the aquatic flora via absorption, photophosphorylation, growth, death, and decay. Notestein et al. (2003) suggested that phosphorus rather than nitrogen was implicated as the nutrient that potentially limits periphyton growth in the coastal stream of Florida. Clastic sediments were found to act as a sink of phosphorus in a German lowland river, especially in summer months. The particulate iron was reported to be the sorption site of phosphorus. The organic river substrate was, however, found to be a source of phosphorus rather than a sink (Schulz & Herzog, 2004). England and Wales were found vulnerable to the transfer of sedimentary phosphorus from agriculture to river. Estimates of phosphorus transfer risks were carried out on a larger grid size of resolution of 25 km 2 (Chapman et al., 2003). The phosphorus concentration in the River

Stour exceeded the standard limit of the Environment Agency (Kelly & Wilson, 2004).

BIOLOGICAL CONTROL MEASURES

Partial recovery from an algal to a macrophyte-dominated state in a eutrophic freshwater system requires managed phosphorus limitation and unmanaged macrophyte growth (Perkins & Underwood, 2002). Aquatic macrophytes like *Eichhornia crassipes* and *Salvinia auriculata* cause significant reduction of nitrogen and phosphorus compounds in the water. This information was thought to be helpful in developing adequate management strategies for aquatic macrophytes, intended to check the eutrophication process in Imboassica Lagoon, in Brazil, by Petrucio and Esteves (2000). Some aquatic weeds, such as *Typha, Phragmites,* and *Glyceria*

spp., in ditches was expected to be useful in removing nutrients from the eutrophic water body (Beltman et al., 1990). Wychera et al. (1990) studied macrophytes of the New Danube River flowing through Vienna and suggested that the constant harvesting of macrophytes would be necessary to manage the process of eutrophication if a power plant were built on its bank. Potential removal of particulate matter and nitrogen through water hyacinth *(Eicchornia crassipes)* roots was also reported by Billore et al. (1998), and removal of water hyacinth may prove beneficial in controlling eutrophication. Alternatively, water hyacinth may be used in the formation of compost. Some aquatic macrophytes are capable of purifying eutrophic lake water.

The water peanut, *Alternanthera philoxeroides,* improves the transparency of eutrophic lake water (Wang et al., 1999). *Hydrodictyon reticulatum* was reported to actively remove 67.3% nitrogen and phosphorus in six days under different environmental conditions (Liu et al., 2004). The dissolved phosphorus can be removed in irrigation drainage water by planted floats. The floats are designed to implement horizontally spreading water plants to the surface of irrigation drains, fields, or treatment ponds in order to eliminate dissolved phosphorus and to allow harvest of the standing crop and therefore removal of the accumulated phosphorus. The results indicated that the float technology could utilize creeping-stem water plants in order to remove soluble reactive phosphorus from the water column (Wen & Recknagel, 2002). Seaweeds can remove up to 90% of the nutrient discharge from an intensive fish farm. Mass culture of commercially valuable seaweed species is likely to play an increasingly important role as a nutrient-removal system to alleviate eutrophication problems due to fed aquaculture (Luning et al., 2002). The potential of three estuarine macroalgae *(Ulva rotundata, Enteromorpha intestinelis,* and *Gracilaria gracilis)* as biofilters for phosphate in effluents of a sea bass *(Dicentrarchus labrax)* cultivation tank was reported by Martinez-Aragon et al. (2002). Abe et al. (2002) collected the aerial macroalga *Trentipohlia aurea* from Japan, which was investigated in relation to the removal characteristics of nitrate, nitrite, ammonium, and phosphate ions. The biomass was recorded 1.5 times higher in medium with sufficient nitrogen and phosphorus source in ordinary medium. In the experiment about 37% of nitrite and 32% nitrate removal was observed. Thus T. *aurea* has the potential for use in the purification of wastewater. Some phytoplanktivorous fish can be utilized for weed management and counteracting eutrophication (Opuszynski & Shireman, 1995). Processing of nutrients in shallow habitats removes phosphorus from water naturally, and periphyton influences phosphorus removal from the water column in flowing waters and wetlands. Periphyton plays several roles in removing phosphorus from the water column, including phosphorus uptake and deposition, filtering particulate phosphorus from the water, and attenuating flow, which decreases advective transport of particulate and dissolved phosphorus from sediments (Dodds, 2003). Lake managers have opted to increase macrophyte abundance to improve water quality and transparency and thus to restore eutrophic water to the oligotrophic stage (Lau & Lane, 2002b). In freshwater bodies phytoremediation has been suggested to be effective in reducing the toxicity of water caused by microorganisms releasing ammonia and sulphide while degrading protein released from the food industry (Jones, 2001).

CONCLUSION

Water is an important resource of prime necessity in life-supporting systems. Rapid eutrophication in the past 25 years has led to significant changes in water quality. The eutrophication results in physical, chemical, biological, and ecological changes in water bodies. Studies on eutrophication have revealed that the nutrient inputs into shallower and warmer parts of lakes are more severely altered (Reutter, 1989). Enrichment of nutrients in a water body accelerates its aging process and leads to faster succession. Eutrophication of smaller water bodies reduce the water-recharging capacity in these areas, so groundwater is likely to become depleted partly due to eutrophication and partly due to exploitation through pumping. Water bodies located near large cities are likely to receive more phosphorus from domestic effluents containing detergents. However, urban water bodies also receive major quantities of phosphorus from fertilizers and other agriculture-related activities. Some effective control measures, including awareness programs pertaining to the present threat to water resources on the blue planet need to be implemented. We hereby propose that biological control through phytoremediation, together with mechanical removal of sediments from the water body, would be an effective control measure. The depletion of the water resource may be checked if efforts are made at international and local government levels to adopt legislative measures and develop an alternative phosphorus-free detergent builder. Awareness and educational programs at government and nongovernmental organization levels would be much more effective than mere legislative measures.

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