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Techniques for Controlling Lake Eutrophication

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Abstract: Lake Eutrophication is a global environmental issue used to express the ageing of a lake. It occurs naturally in the environment and the associated time span can be measured in the geological timeframe. Recently, man has rapidly increased his use of nutrients especially in agricultural fertilizers and detergents, many of which end up in waterways and accelerate the process of Eutrophication. Population increase, industrial growth, intensification of agricultural production, river-basin development, recreational use of waters, and domestic and industrial exploitation of shore properties have made the problem of Lake Eutrophication more crucial. This review seeks to review literature on eutrophication process, types of Lake Eutrophication, Lake Eutrophication sources/causes, role of agriculture and wastewater in eutrophication, effect of eutrophication and techniques for controlling eutrophication processes.

Keywords: Lake Pollution, Eutrophication, Agriculture, Wastewater, Remediation techniques.

INTRODUCTION

Water is one of the basic necessities required for the sustenance and continuation of life. It forms the major constituent (70%-90%) of all living cells. The importance of freshwater includes drinking, industrial cooling, power generation, agricultural irrigation, waste disposal, source of transportation etc. There is high demand for this valuable resource due to increasing population, industrial growth, and intensification of agricultural production, river-basin development, recreational use of waters, domestic and industial exploitation of shore properties. However, the pressure on this valuable resource has resulted in reckless overconsumption, misuse, pollution, eutrophication among others.

Beeton[1] predicted that climate change and pollution are worldwide environmental problems that will affect all lakes whether large or small. Also, 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 groundwater become depleted. Beeton[1] hinted that most of the aquatic ecosystems of varying characters worldwide receive regular inputs of a rate of nutrients in varying quantities. These nutrients result in the extensive growth of aquatic flora called eutrophication. 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 result in 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 [2,3].

In aquatic ecosystems, eutrophication is caused by excessive inputs of nutrients (nitrogen and phosphorus). Generally, freshwaters are said to be P limited whiles coastal estuarine waters are N-limited. The two nutrients (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. However, in wastewater, these nutrients are abundant as phosphates, nitrates and ammonia or combines 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[4].

Eutrophication is considered to be one of the serious kinds of water pollution directly affecting the fauna due to the loss of dissolved oxygen[4]. 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. In addition, hydroelectric generation from such water storage is adversely affected as nutrient rich water acts chemically upon the turbines and 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. Thus 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 which makes small lakes and many ponds to 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 as water over populated with algae becomes unfit for swimming. Moreover, 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 and when these plants die, their decay produces a bad smell all around such water bodies[5].

The problems of Lake Eutrophication and ecological damage are becoming more and more critical and it is therefore imperative to devise techniques to avert this menace. There have been a considerable research on nutrient dynamics, eutrophication and pollution control of lake water bodies. The importance of freshwater resources necessitates that they should be well managed ecologically for meeting good water quality standards. It is along this line that this report seeks to review literature on eutrophication process, types of Lake Eutrophication, Lake Eutrophication sources/causes, role of agriculture and wastewater in eutrophication, effect of eutrophication and techniques for controlling eutrophication.

DEFINITION, TYPES AND CAUSES OF EUTROPHICATION

Definition Of Lake Eutrophication: Lakes accumulating large amounts of plant nutrients are called 'eutrophic' (from the Greek word *eu* meaning 'well' *trophe* meaning 'nourishment'). Eutrophication can be defined as the sum of the effects of the excessive growth of phytoplanktons leading to imbalanced primary and secondary productivity and a faster rate of succession from existence to higher serial stage as caused by nutrient enrichment through run-offs that carry down overused fertilizers from agroecosystems and/or discharged human waste from settlements[5]. Eutrophication is a process in which water bodies (That is lakes, ponds, and rivers) receive excess nutrients that stimulate excessive growth of algae. It is a natural process which is very slow and can be greatly accelerated by human activities to increase the rate of nutrient in a water body due to rapid urbanization, industrialization and intensifying agricultural production.

For lake aquatic ecosystems which is the focus of this review, human activities in the watershed can lead to loss of dominant species and functional groups, high nutrient turnover, low resistance, high porosity of nutrients and sediments and the loss of productivity [6]. For example, aquaculture is one of many human activities contributing to the environmental decline of coastal waters and the collapse of fisheries stocks worldwide [7]. Because of the influence of human activities, excessive nitrogen, phosphorus and other nutrients are loaded into water bodies like lake, reservoirs, embouchure and bay which could cause negative ecological consequences on aquatic ecosystem structures, processes and functions. This results in the fast growth of algae and other plankton which deteriorate water quality [8].

TYPES OF LAKE EUTROPHICATION

There are two types of eutrophication namely natural and human-induced (cultural).

Natural Eutrophication*:* For many lakes, as they age, there is a gradual buildup of nutrients, sediments and organic material which slowly fill the lake basin. Eventually, the process ends and the basin become colonized by terrestrial vegetation [9]. The timing of natural eutrophication **(Figure 1)** is highly variable and depends on the characteristics of the basin, watershed and climate [10].

Human-induced (Cultural) Eutrophication: The alteration of nutrient input to water basins by human activity can dramatically increase eutrophication leading to major ecological changes in decades rather than centuries. Human-induced eutrophication of freshwaters is also called cultural eutrophication (See figure 1), is largely as a result of increased phosphorus inputs from sources such as agricultural fertilizers or partially treated sewage. Phosphorus has been found to be one of the strongest stimulators of algae growth. Besides, man-caused sedimentary eutrophication is primarily from soil erosion which is caused by the removal of trees and vegetation. Thus, the health of aquatic habitats is directly tied to the human activity that takes place throughout the entirety of their watersheds, requiring effective land management and environmental policy.

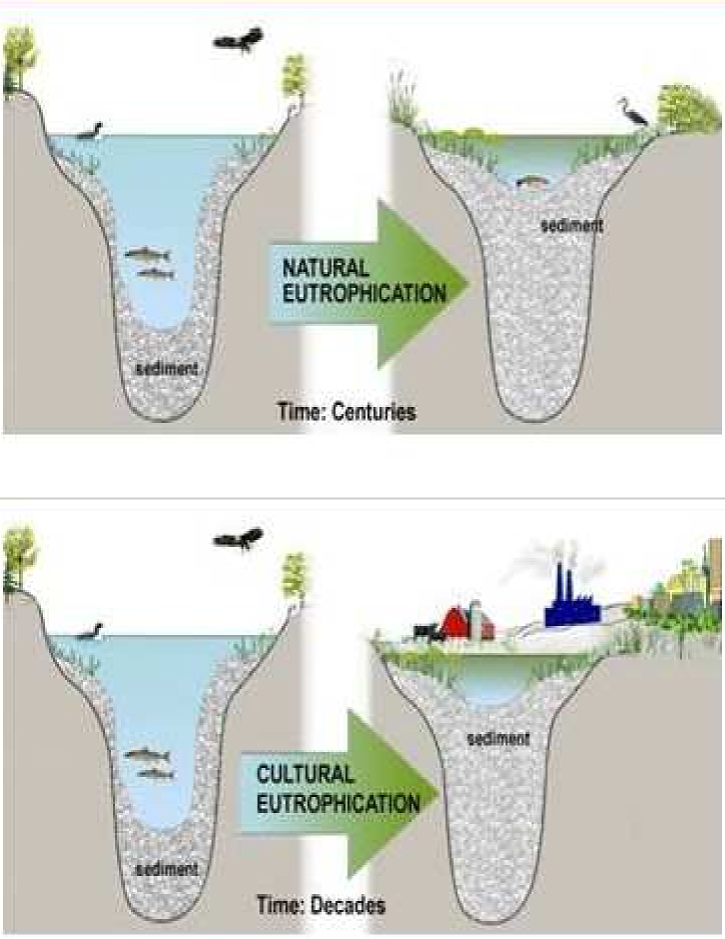

Figure 1: Natural and human-induced eutrophication (Adapted from Mack, 2012)

Sources/Causes of Lake Eutrophication: The types of sources for nutrients and sedimentary materials are point and nonpoint. The point sources are definitive, localized sources of nutrients and sedimentary pollution and a primary point source is municipal and industrial wastewater runoff. Additionally, point sources include runoff and leaching from waste disposal systems, animal feedlots, hog and chicken farming operations and industrial sites. Large construction sites are also a frequent point source for sedimentary runoff. The nonpoint sources are diffuse sources of nutrients and sedimentary pollution while the primary nonpoint source of eutrophication is run-off from agriculture and pastures. Other possible nonpoint sources include runoff from urban areas without sewer systems and abandoned mines leaching from septic tanks and atmospheric deposition.

The main causes of Lake Eutrophication are increased nutrients or build-up, sediments, thermal stratification and dissolved oxygen. The details of the causes of Lake Eutrophication are presented below.

Nutrients: There is clear evidence that nutrient loading to lakes, estuaries and coastal oceans has greatly increased through human activities over the past few decades and that this has caused or enhanced many of the symptoms of the aquatic ecosystem transformation known as eutrophication [11]**.** Nitrogen and Phosphorus input and enrichment in water are the most primary factors to induce water eutrophication. These two elements account for the least proportion in the molecular formula of algae ($C_{106}H_{263}O_{110}N_{16}P$), especially P is the main limiting factor to control the growth of alga in water [12]. It was reported that 80% lake and reservoir eutrophication is restricted by phosphorus, about 10% lake and reservoir eutrophication is relative to nitrogen, and the rest 10% lake and reservoir eutrophication is relative to other factors [13]. In many ecosystems, phytoplankton biomass is correlated with the availability of N or P [14,15] and the composition of phytoplankton species is also affected by the concentrations of N and P [16]. The ratio of N: P in the water body (referred to as the "Redfield ratio") is an important indicator of which nutrient is limiting eutrophication. It is believed that if the Redfield ratio is 16:1, P is most likely the limiting factor for algal growth and lower ratios indicate that N is of great importance[17]. P has been shown to be the principal limiting nutrient for primary production of phytoplankton in many freshwater environments [18] while N is commonly limiting in marine ecosystems [14]. However, there are many exceptions to this general pattern. In some freshwater environments, particularly in the tropics and subtropics, N has been found to be the primary limiting nutrient for phytoplankton production due to large part to excessive P load and long growing seasons.

In phosphate-deficient water bodies or those having reasonably good growth of blue-green algae, which fix enough of the atmospheric nitrogen, phosphorus becomes the limiting element, because a portion of P is used to counterbalance high nitrate content [16]. Such circumstances can be seen that no paroxysmal algal boom may break out in heavily eutrophicated water bodies with both high N and P. Thus, it is the key point to control the concentrations of both N and P reasonably for solving the problem of water eutrophication.

Sediments: Sediments such as sand, silt, and clay also add to eutrophication. As sediments are eroded, the particles are carried in suspension reducing light penetration and photosynthesis. Phosphorus may attach onto these particles and they become disturbed by erosion. They are however released into the water making phosphorus a long term problem [19]. Thus, sediments provide a major reservoir of phosphorus, as they can be transported through great distances furthering their role in Eutrophication.

Thermal stratification: Another major contributory factor is the annual temperature cycle of the lake. This determines its physical, chemical and biological behaviour. In temperate climates, most lakes stratify thermally in the summer months into a deep, dark, stagnant, cold layer (the epilimnion). This thermal stratification gives rise to the chemical stratification of the water body, with oxygen concentrations declining rapidly with depth and sometimes reaching zero at the level of the sediment.

Dissolved oxygen: Eutrophication brings about increased dissolved oxygen consumption in lakes progressively lowering dissolved oxygen concentrations. Eutrophic lakes covered with ice and snow, wetlands and northern rivers receiving large quantities of organic matter from their ice and snow, exhibit substantial dissolved oxygen losses during the winter[20]. At higher temperatures, water can hold less oxygen when saturated. This result in less oxygen directly available and a lower percentage of the metabolic demand being satisfied since the metabolic rate of organisms increases with increasing temperature[20].

ROLE OF AGRICULTURE AND WASTEWATER IN EUTROPHICATION

Agriculture: Nutrients from agricultural systems enter natural water systems in three main ways namely through drainage water, in eroded soil and through animal waste products. Drainage plays a critical role in agriculture as the moisture content of soil is very important in crop propagation techniques because it is the nutrient transport medium from the soil to the crop[21]. More importantly, most of the soluble nutrients that get into lakes and streams from rural areas are first dissolved in water and then moved in solution to the waterways [17]. This dissolved form comes from the release of phosphorus from soil and plant material. Some nutrients may also be suspended in particulate matter and later converted to soluble forms in the water system but most dissolved phosphorus is immediately available for biological uptake [21]. In water that percolates through the soil the soluble phosphorous concentration is usually very low because the phosphorous precipitates in the subsoil. Therefore, most of the soluble phosphorous should reach the waterways via surface runoff [21].

Commercial fertilizers provide the major portion of the common plant nutrients - nitrogen, phosphorus, and potassium used in crop production. The remainder is supplied through animal manure and natural sources such as soil and legumes which are nitrogen fixing and through precipitation processes [23].

Nitrogen particularly in the form of nitrate is highly soluble in water and consequently highly mobile. Application of nitrogen at rates over and above the ability of the crop to use it results in losses of that nitrogen normally by leaching[24]. In addition, manure or organic wastes from agriculture are valuable and historic resource for improving soil structure and agriculture and can be considered a fertilizer as well. During application to the field it must be given the same amount of care because it is more labour intensive in application giving rise to compaction which may result in runoff. Thus, the water present also makes them highly mobile [24].

Good fertilizer practices including split applications, and delaying applications when soils are wet or if heavy rain is forecast can prevent excessive leaching of fertilizers[24]. The economic loss to the farmer and the consequent effect on the environment can then be predicted.

Wastewater: Eutrophication may be enhanced by nutrients contained in wastewater sources which may be deemed organic including the food industry or inorganic which concerns washing processes and detergents. Wastewater can be further separated into two main sources, which include domestic and industrial wastewater. Domestic wastewater or sewage derive majority of its nutrients from faeces and urine with food wastes and detergents also contributing significant amounts although the composition vary with regards to geographic location around the world [17].

Industrial wastewater is highly variable in quantity and quality as it may contain hazardous elements such as heavy metals. Once it is used it may be disposed of in a variety of ways including re-usage for other processes, discharge into lakes or reservoirs, for example mine tailing ponds and it may go directly to the municipal sewer system [25].

EFFECTS OF EUTROPHICATION

The effects of eutrophication on the environment may have deleterious consequences on the health of exposed animal and human population through various pathways. However, specific health risks appear when freshwater extracted from eutrophic areas is used for the production of drinking water. Severe impact can also occur during animal watering from eutrophic waters[26]. The following are the symptoms and impacts of eutrophication.

• Increase in production and biomass of phytoplankton, attached algae, and macrophytes.

• Shift in habitat characteristic due to changes in assemblage of aquatic plants.

• Replacement of desirable fish by less desirable species: Eutrophication has been shown to cause competitive release by making abundant or otherwise limiting nutrients. This causes shifts in the composition of ecosystems. For instance, an increase in nitrogen might allow new, more competitive species to invade and compete with original species [27].

• Production of toxins by certain algae since some algal blooms especially blue-green algae is toxic to plants and animals. This toxicity can lead to decreased biodiversity or can manifest itself in primary products making its way up the food chain, and marine animal mortality has been observed [28] and may pose a threat to human.

• Increasing operating expenses of public water supplies including taste and odour problems, especially during periods of algal blooms. That is, when raw water supplies contain large amounts of algae and some other aquatic plants, the cost of treatment increases and the quality of the product may decrease as planktonic algae can shorten filter runs. They can also release organic compounds that cause tastes and odors and in some instances, serve as trihalomethanes (THMs) and halo acetic acid (HAA) precursors [29]. The compounds react with chlorine during the disinfections process and are considered as human carcinogens.

• Deoxygenating of water especially after collapse of algal blooms usually results in fish kills. Thus, when a body of water experiences an increase in nutrients, primary producers reap the benefit first which means that species such as algae experience a massive population bloom and the increase in algae bloom would increase the amount of oxygen present in the water because oxygen is a product of photosynthesis. On the contrary, under eutrophic condition, dissolved oxygen is reduced by the dense population. But too much algae block sunlight from reaching deep in the lake and these algae die and become food for bacteria which use up the oxygen while eating the dead algae. Additionally, when dissolved oxygen levels decline especially at night when there is no photosynthesis hypoxia occurs and fish or other marine animals may suffocate.

• Loss of recreational use of water. Excessive growth of attached algae and aquatic macrophytes can impair swimming, boating and fishing by interfering with water contact, severe odour problems can also be caused by decaying algae, water weeds and algal scum[29].

• Violations of water quality standards. During daylight, algal photosynthesis removes CO_2 from water which increases the pH while algal respiration at the night releases CO_2 which lowers the pH and in late afternoons the pH of excessively fertile water can be found to exceed the water quality standard for pH. Generally, algae produce oxygen during photosynthesis but they consume it during respiration. Also due to bacterial and other organism respiration dissolved oxygen concentrations can be below water quality standards for the protection of fish and other aquatic life. Excessively fertile water bodies that thermally stratify often exhibit dissolved oxygen depletion below the thermocline due to bacterial respiration and consumption by dead algae. It is believed that one phosphorus atom when converted to algae which subsequently dies, can consume 276 oxygen atoms as a part of the decay process [29]. Although oxygen depletion in lakes leads to the death of fish and benthic organisms, the production of undesired chemical species (NH_3, H_2S, CH_4) accelerates cycling of pollutants from sediments especially P.

• Water clarity (water transparency). Water clarity is defined by the depth of the water body at which the bottom sediments can be seen from the surface. Water bodies with high degrees of clarity (the bottom can be seen at depths of 20 or more feet) have low planktonic algal content. In more eutrophic water bodies, the sediments can only be seen at a depth of a few feet. The greenness of water, inorganic turbidity and high level of planktonic algal chlorophyll diminish water clarity.

• Economic loss due to change in fish species, fish kills and shellfish.

TECHNIQUES FOR CONTROLLING EUTROPHICATION

As stated in this report, Lakes are used to store and supply water for industry, agriculture, domestic and fishery which have the functions of maintaining biodiversity, regulating regional climate, storing flood, modulating surface water runoff and purifying water. However, Lake Eutrophication has been one of the focus problems for environmental protection. The treatment of eutrophied lake waters should encompass three components. These are control of pollutant sources, restoration of the damaged ecosystem and catchment management. They all aim at reducing nutrient loads and restoring the lake ecosystem [30,31]. Also to control lake water eutrophication efforts should be directed at harnessing the external point discharge and the nutrients released from floor deposits and restoration of the damaged ecosystem should centre around the regeneration of vegetation along lakeshores and aquatic plants in lakes. The restored ecosystem along the lakeshore can effectively intercept pollutants originating from the catchment area before they enter the lake. Aquatic lake plants can help to reduce the amount of suspended matter and internally released nutrients and wastewater treatment plants can be employed to remove the eutrophic enhancing phosphorous and sometimes nitrogen before releasing it into the waterways. Again, agriculture nutrient management techniques can be employed to prevent run-off and erosion by timing out the deposition of fertilizer, moderating fertilizer use and maintaining drainage systems[24]. This may be beneficial to the environment but also economically viable to the farmer.

On the other hand, chemicals may also be used to help reduce and control existing eutrophic conditions. They may be sprayed over the surface of the lake or injected directly inside which are intended to precipitate nutrients or convert them into a form unavailable to aquatic life such as aluminium's effect on phosphorus. "Algaecides" such as copper sulphate may also be used to kill existing biomass but it has the disadvantage of copper remains in the system and possible health effects on aquatic life from its deposition [22]. There are many other techniques for controlling Lake Eutrophication in the world and details of such techniques are discussed below.

ENGINEERING TECHNIQUE

The engineering measures mainly include sediments dredging, deep aeration, water diversion, Lake Bottom sealing etc. Deep aeration is used to supply oxygen through aeration, maintaining an aerobic state between water and sediments so as to suppress phosphorus release from sediments while water diversion is a method used to dilute the eutrophicated lakes in order to reduce the pollutants concentrations.

Dredging: Sediments play a big role in the transfer of nutrients to the water column and their removal often forms an integral part of lake restoration programs. In addition to nutrient removal, dredging may also create further benefits such as the deepening of lakes. The major disadvantage of this process however, is the ever-looming costs it creates to implement because lakes become more eutrophic as they age over time and sediments nearest the bottom remain nutrient poor while the surface sediments become rich in organics [32]. Removal of these top sediments through dredging exposes the nutrient poor layering and curtails the nutrient cycling capacity[22].

It is known that before any dredging is accomplished a survey and sample test should be done so that an accidental layer of sediments rich in organic matter is not exposed and sedimentation rates assessed. Two main methods are used in lake dredging. These are hydraulic dredging and bucket dredging. In hydraulic dredging a vacuum cleaner principle is employed. The surface layer of sediment is sucked up, where it is treated and returned to the lake and the organic material used as a soil additive in some cases [22]. The second type is the bucket dredging which involves skimming the surface sediments into a bucket type device where they proceed to treatment. This method is more cost efficient than the first but it creates more ecological disturbance to the system.

Deepening: Sediment stirring can be a problem for eutrophication in shallow lakes as it enhances the release of phosphorus held in these sediments. This gives way to the process of lake deepening which may allow for a lesser degree of stirring by factors such as wind. It may also increase the amount of oxygen content through volume and reduce the impact of nutrient inputs. Deepening can be achieved by increasing the water level or lowering the lake-bed itself accomplished by dredging methods[20].

Aeration: Aeration of water bodies can be employed to counter the oxygen depleted conditions of Eutrophication where sufficient nutrient removal techniques cannot be employed. Aesthetic conditions may warrant aeration as well to restore the lake for recreation activity and quality of water may be a provision for the costs associated with this system.

There are several techniques used and wide arrays of machinery are employed. One of the most basic techniques involves the de-stratification of the lake through circulation or a bubbled air system placed on the bottom of the lake. The disadvantages of artificial circulation that can occur contain the homogenization of the water column which may impact on certain fish populations that thrive in cold water regions [20].

Lake Bottom Sealing: Lake bottom sealing can also be introduced although it only covers up the existing problem. A layer of heavy plastic is laid upon ice covered waters and covered with sediment that will eventually act as the new lake floor. In the summer when the ice melts the sediment covered "sheet" will float to the bottom and cover the existing organic sediments susceptible to eutrophic conditions [22]. This technique may be complicated on lakes that do not freeze in winter time causing disturbance and uneven deposition.

BIOLOGICAL/ECOLOGICAL RESTORATION TECHNIQUE

The essence of ecological restoration lies in the establishment of a natural, self-regulating ecosystem that forms an integral part of the entire ecological landscape [33]. Ecological restoration may be accomplished through reduction of algae via aquatic plants. As primary producers, advanced aquatic plants and micro-organisms compete with each other for ecological resources such as nutrients, light and living space. During their growth, advanced aquatic plants release chemical substances that are conducive to inhibiting algal production, in addition to directly absorbing nitrogen and phosphorus in water. Storage of these elements in the plants means that they can be effectively extracted from the water via physical removal of these plants from the lake, thus reducing the nutrient level in lake waters [34]. An added advantage of submerged aquatic plants is the suppression of resuspension of floor deposits and hence considerable improvement in water quality [35]. Ecological restoration takes advantage of this competitive relationship between aquatic plants and microorganisms. In addition, the propagation of aquatic plants in lakes helps to transform the former algae dominated ecosystem into a sound grass-dominated ecosystem.

The success of ecological restoration lies in selecting the right kind of plant species that are most suitable for growth, taking into account the uniqueness of the lake water. Because of their biological propensity, different aquatic plants require different growing environments since they differ in their ability to adsorb, eliminate and condense nutrients in water and to decompose algae. Hence, once an aquatic plant ecosystem becomes established, it will have the ability to self-cleanse water and rehabilitate lake water eutrophication.

However, caution must be exercised in selecting the right aquatic plants. Otherwise the introduction of inappropriate exotic plants could mean another environmental disaster if their growth cannot be controlled effectively.

CONCLUSION

Lake water eutrophication results from high concentration of nutrients that cannot be adequately absorbed by water. Eutrophication is the gradual accumulation of nutrients and organic material subsequently utilizing these nutrients as an energy source within a body of water. The two sources of nutrients are point and non-point sources. The former include sewage treatment plant discharges, storm sewer discharges, industrial discharges among others while the latter are atmospheric deposition, agricultural run-off (fertilizer, soil erosion), septic systems etc. Recently, increasing attention has been directed at treating point and non-point source of nutrients that causes Lake Eutrophication. The most fundamental step in tackling lake water eutrophication is to reduce the amount of nutrients in lakes through engineering/physical and biological/ecological restoration interventions. Also, heavy pollution industries should be shutdown while moderate pollution industries should be relocated away from the catchment area.

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