

Poyang Lake's Eutrophication and Its Treatment

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Abstract. Evaluated the formation and underlying causes of general lake eutrophication. Studied how eutrophication is formed in Poyang Lake according to its hydrological characteristics. Compared different treatments for Poyang Lake's eutrophication and recommended several improvements for current Poyang Lake's eutrophication strategy.

Keywords: Poyang Lake; Eutrophication; Treatment.

1. Introduction

As an essential part of organisms' survival, water resources management is becoming more noticeable in countries. Since daily water usage is provided by neighboring lakes, lakes' water quality screening shouldn't be ignored. With increasing anthropogenic activities and climate change, water quality in lakes is decreasing over these decades. Induced lake pollutants include eutrophication, organic contamination of water, dramatic decrease in lakes' surface area and water level, change in biodiversity, and swamp formation. This paper specifically discusses the dangers and impacts of lake eutrophication and treatment of eutrophication among countries. In order to gain a deeper understanding of eutrophication, the definition of eutrophication should be known. Eutrophication occurs when a body of water receives excessive nutrients (such as phosphorus and nitrogen, which are commonly regarded as the cause of lake eutrophication) from neighboring water sources, causing the number of primary producers (plankton and algae) in the lake to surpass the threshold, which is known as algal bloom. Not every algal bloom induced by lake eutrophication is harmful, some algal blooms will diminish overtime naturally, but some algal blooms have negative impacts on both biodiversity and human health. In marine water bodies red tide is one classic example of harmful algal bloom, and blue-green algae is common in fresh water bodies. Both of them release toxins (hepatotoxic microcystins or monocyclic heptapeptides) to surroundings, causing respiratory symptoms if people are exposed with cyanotoxins. Long-term exposure to cyanotoxins may be damaging to the liver, colon, kidneys, and brain in animals and humans [1]. If the mass of cyanotoxins inhaled is high enough, it can be fatal to life. As for organisms, the harm of eutrophication can also be irreversible: decrease of coral population, and accumulation of red tide's cyanotoxin in shellfish species, which influence organisms in a high food chain. There are many factors that can influence the toxin production of cyanobacteria: light intensity, macronutrients (N&P), micronutrients (iron and other trace metals), and temperature [2]. When considering the formation of eutrophication, Nitrogen input and Phosphorus input should be carefully examined because they serve as the major food source for algae. As for Nitrogen input, atmospheric deposition and groundwater discharge are becoming more important as the cause of the eutrophication due to increasing anthropogenic activities [2]. Anthropogenic sources include urban and rural wastewater, nonpoint source agricultural, atmosphere deposition of fossil fuel and other combustion products and agricultural emissions and N-enriched groundwater [2]. These sources can also be considered as the source for phosphorus input. According to relevant research, high levels of temperature and nutrients coupled with stationary waterflow generally encourage algal bloom. In Africa, over 80% of the wastewater produced in large cities in sub-Saharan Africa are untreated and are either discharged in the soil via on-site sanitation systems or directly discharged into rivers and lakes [3]. Since municipal waste water contains large amounts of inorganic phosphorus and nitrogen (from phosphorus containing detergents and human excrement), lakes that are exposed to these waste water have higher probability to experience eutrophication. Algal blooms caused by eutrophication can also be found in Asia: In China, Lake Taihu, the third largest fresh water lake of China, eutrophication happens yearly. Black spot (oxygen depleted zone

caused by excessive planktons take up all of the oxygen throughout the water column) is one of consequences of lake eutrophication, and these black spots can last more than a week [4]. Aquatic organisms will not be able to live in black spots because of lack of oxygen, so they decrease biodiversity. In order to prevent eutrophication from bringing more harm to the ecosystem and humans, researchers have been studying the treatment of algal blooms ever since. There are various ways to deal with harmful algal blooms: algacides (copper sulfate), sediment capping agents, barley straw, ultra-sonification, increasing grazing pressure, hexavalent chromium removal, and sediment phosphorus inactivation. Sometimes eutrophication treatment can be both time and financially consuming. For example, the United States costs about 2.4 billion dollars on harmful algal blooms each year, so it is very crucial for the water bureau to determine which method fits the best to treat eutrophication. Some strategies are required to distinguish the suited method for eutrophication: appropriate sampling strategies are required to minimize the experimental errors, presence of water flow, water volume, operational parameters, secondary contamination by the release of cyanotoxins from collapsed algal cells, combination with remote sensing technologies [5]. Besides controlling eutrophication after it happens, reducing P loading has been a cost-efficient means of controlling lake eutrophication, which is widely accepted and implemented [2]. Although there are many methods to recover algal bloom brought by eutrophication, full recovery to the previous ecosystem is impossible and the treatment process is slow. Since every natural phenomenon is interconnected, the presence of lake eutrophication has a direct relationship with river eutrophication. Rivers, as one of the major water sources of a lake, make eutrophication assessment more difficult because different rivers have different nutrient limitation characteristics [2]. Besides specific treating method to solve eutrophication, governments are also trying to propose effective policies that prevent eutrophication from happening. For example, controlling sewage disposal has always been the U.S. government's prior strategy, and the purpose of it is to protect citizen health and water environment [6]. The government also acted to reduce the phosphorus loading capacity of point source such as prohibition of phosphorus containing detergent. Overall, this report aims to analyze the underlying causes of lake eutrophication, and how China and other countries protocol policies that mitigate the threats of eutrophication.

2. Research status

With ongoing rapid urbanization, nutrient loads in Yangtze River, the longest river in China, are increasing over these decades. Excessive nutrients from waste disposal allow planktons to grow out of control. During the past fifty years, dinoflagellates increased from less than 1% to over 25% [7]. Researchers in China have been analyzing major fresh lakes (Lake Poyang, Lake Chao, Lake Taihu, and Lake Dongting) in order to find the cause of eutrophication and the best fit method to solve this issue. Among the parameters that are used to measure a lake, amount of nitrogen, phosphorus load, phytoplanktons, and transparency of water body are essential in determining whether a lake is having eutrophication [8]. According to Chinese lake eutrophication evaluation criterion, the threshold of total nitrogen is 0.80 mg/L, and for total phosphorus is 0.02 mg/L; data shows that the phosphorus loads of Lake Taihu and Lake Xihu – their eutrophications are observable – have surpassed the threshold one to ten folds [8]. Forming 1g of phytoplankton needs about 0.063g N and 0.009g P: the ratio of N & P is approximately 7:1 [8]. Once eutrophication occurs, water blooms will form in a short time, and aquatic plants will die because of lack of dissolved oxygen. This is triggered by a vicious cycle that is driven by the increase of phytoplanktons: the death of these phytoplanktons will cause organic aggregate to increase, and adherent organisms can utilize these nutrients to reproduce; finally, rapid metabolism of these microorganisms consume a considerable amount of dissolved oxygen in waterbody, and thus causing underwater aquatic plants to die [9]. Adherent organisms produce two major threats to plants: limiting photosynthesis of plants and decrease transparency of waterbody [9]. Comparing to plants without disturbances of phytoplanktons, the photosynthesis efficiency of aquatic plants live in eutrophication is 60% - 90% less than healthy plants. Eutrophication

is the main reason that the biodiversity of aquatic plants decreases. As the causes of eutrophication of lakes in China have been discovered, researchers have come out several methods that can mitigate the impacts of eutrophication. Physical treatments include filtration, precipitation, direct covering of lake surface, ultraviolet radiation to kill phytoplanktons, and ultrasonification method [10]. Chemical treatment is using algicide to kill planktons directly. Common algicides include sulphate, permanganate, liquid chlorine, chlorine oxide, ozone, and hydrogen peroxide [10]. Biological treatment is taking advantages of algae's natural enemies and their excreted materials to restrain the growth of algae. Biomanipulation technique, phytoallelopathic algal inhibition technique, and biogenetic inhibition technique can be counted as biological treatments [10]. As for now, using microorganisms to reduce algae is regarded as the most promising method to control eutrophication because of its fast reproduction, high efficiency, and host specificity [10]. Aquatic plant is also a good method to treat algal bloom. Researchers found water hyacinth as an effective plant to remove nutrients in Lake Taihu [11]. Research reflected that water hyacinth can effectively control water eutrophication 2.1 times better than water bodies that do not have treating plants [11]. Although it is a good method for lake eutrophication, it has its own disadvantages: excessive water hyacinth will cause secondary pollution if they are not timely taken and how to turn water hyacinth into a financial product is also a question for researchers. Other than controlling point source nutrients, countries beside China, such as the U.S., are also using methods to treat endogenous sources: deepwater aeration, removing deepwater that contains excessive nutrients, covering lake bottom with cobbles to prevent extra release of phosphorus, and lowering water level in during spring to stimulate the growth of submerge plants [12].

3. Analysis of the causes of lake eutrophication

This paper takes Lake Poyang as an example to examine the cause and measuring parameters of lake eutrophication. Poyang Lake, the largest fresh water lake in China, is located at Jiangxi, China, which is in middle and low reaches of Yangtze River. Not only Poyang Lake is connected to Yangtze River, but also Gan River and Xiu River. Since many rivers and lakes are intersecting in this region, Poyang Lake has abundant biodiversity. Poyang Lake has flooding season (April to September) and droughting season (October to March in the following year); flooding season happens during spring and summer, and droughting season occurs during fall and winter. Average surface area of Poyang Lake is $2.24 \times 10^8 \text{ m}^2$; annual rainfall is about 1350 – 2150 mm [13]. Poyang Lake has been a great habitat for migratory birds during winter because of its complex biodiversity, wetland biological environment, and relatively moderate weather. For different regions in Poyang Lake, trophic level behaves differently: North part has relatively good water quality, but South part bears a considerable amount of wastes because 5 major inflow rivers contain many waste waters. Poyang Lake plays a very important role in adjusting run-off of Yangtze River and maintaining regional hydrologic budget. High level of nitrogen and phosphorus of Poyang Lake can be attributed to industrial waste water disposal of Lean River - a tributary of Rao River – where is located in the Southern region of Poyang Lake. Nutrient levels change significantly with time and seasons (nutrient concentrations were peaked at 2014). Poyang Lake's winters usually have higher nutrient levels because of water shortage. In contrast, Poyang Lake's summers have the lowest nutrient levels since flooding seasons bring fresh water to the lake, thus diluting the water body.

As a shallow fresh water lake (average depth is 8.4 m), lake eutrophication is a common problem for Poyang Lake. This is because shallow lake has more frequent nutrient exchange between upper water and sediments at the bottom of the lake, causing phytoplanktons to have more nutrients. Phytoplanktons have always been an important field to study in order to understand oceans, lakes, and rivers. Two profound effects of lake eutrophication is abundant reproduction of phytoplanktons and change of phytoplankton's population structure. Therefore, phytoplanktons can be used as a parameter to measure eutrophication of Poyang Lake. According to comprehensive trophic level index, chloroplast – a, total phosphorus, total nitrogen, transparency, and total permanganate are

used to measure water quality. When researchers were using single factor index method to evaluate monitoring point in different lake sections, they found that the essential indicators are total nitrogen and total phosphorus, which means that they possess a positive relationship with comprehensive trophic level [14]. Total nitrogen of Poyang Lake has been increasing over this decade: nitrogen level was decreasing from 2011 to 2013, but it was rapidly changing after 2015; nitrogen level peaked at 2018 (1.44 mg/L), which is three times bigger than the threshold (0.5 mg/L). Similar to total nitrogen, total phosphorus is also increasing from 2011 to 2019: it peaked at 2018 (0.083 mg/L) and slightly decreased at 2019. The change of total phosphorus in flooding seasons and drought seasons is more obvious than that of total nitrogen in Poyang Lake. Phosphorus concentration in drought season is much higher than flooding seasons after 2015 [15]. Nitrogen and phosphorus are primary nutrients for phytoplanktons. When Poyang Lake undergoes eutrophication, phytoplanktons utilize these inorganic nutrients for reproduction, so that transparency decreases and chloroplast – a concentration increases. Bacillariophyta (50 species, which are 26.88% of total phytoplanktons) and chlorophyta (72 species, which are 38.71% of total phytoplanktons) are two major phytoplanktons in Poyang Lake during both flooding season and drying season; protozoans (33 species, which are 44% of total zooplanktons) and rotifera (29 species, which are 38.7% of total zooplanktons) are two major zooplanktons during both seasons that are mentioned above [16]. Concentration and biomass of phytoplanktons are much more different between hydrologic seasons: during flooding season, concentration of phytoplanktons is higher than that of drought season [16]. According to research, seasonal change doesn't alter phytoplankton's species composition and dominant species, but it changes the diversity and bearing of phytoplanktons significantly. Conductivity is also an effective measurement of total ion concentration in water body: terrestrial plants, inorganic material in soil, and dead leaves will be flushed into rivers during flooding season, directly affecting conductivity of water body because of the decomposition by microorganisms [16]. During eutrophication, the amount of phytoplankton species will decrease, but the total amount of phytoplankton's cells will increase. Not only does eutrophication influences phytoplankton structure of Poyang Lake, but aquatic plants are also affected. Aquatic plants grow rapidly during flooding season because water level has a negative relationship with the level of lake eutrophication: the higher the water level, the lower the eutrophication level. Looking at annual change of Poyang Lake, July has the lowest trophic level: this is because high water level and short lake residence period, so excessive nutrients are diluted to prevent severe eutrophication. However, during winter, which is drying season for Poyang Lake, water level is low, so concentration of nutrients increases, sediments in bottom of lake will release nutrients again and be floating on watersurface [17]. Due to large scale sand minning in recent years, Poyang Lake basin has changed dramatically. This caused lake water channels to become deeper and wider, so lake's ability of aerial drainage is greatly increased, causing water level to decrease during drying season. Outflow of Poyang Lake during drying season has nearly doubled after sand minning [14]. *Cynodon* communities has stable biodiversity in different seasons, but its stability is significantly lower during flooding season; *Phragmites* communities' biodiversity is high during flooding season, but its stability is high in droughting season [18]. This phenomenon can be attributed to water level change between the two seasons. Overall, low water level for shallow lake increase possibility of Poyang Lake eutrophication and decrease in biostability of aquatic plants.

Among all the nutrients that cause eutrophication, nitrogen and phosphorus are the most important nutrients for the growth of algae. there are multiple sources of these nutrients: exogenous source (point source and nonpoint source) and endogenesis source. Point source indicates that excessive nutrients come from industrial waste water and city waste water. For Poyang Lake, point sources include agricultural waste, poultry breeding, organic pollution (very severe), industrial production (waste from electroplate factories), and domestic wastage [19]. As reported, 78% or above of industrial waste water in Jiangxi will be directly discharged into Poyang Lake, bringing nitrogen & phosphorus and heavy metal into waterbody [19]. Nonpoint source is a nutrient source that comes from external river inflow, lake precipitation, and fodder. Endogenesis source comes from phosphorus that is released from lakes' sediments. These sediments are biological deposits that formed in a long-time. Phosphorus' endogenesis source is composed of organisms' dead bodies and

waste water. When shallow lakes' capacity decreases, phosphorus that is stored in nutrients will be released, which explains shallow lakes will still have eutrophication when exogenous sources have been cut. The amount of phosphorus released from nutrients is different depending on the size of the shallow lake. Smaller shallow lakes have faster phosphorus circulation and shorter releasing period. There is a circulation between overlying water and bottom sediments. The exchange of phosphorus happens between them. Therefore, even when point sources are correctly controlled, lake eutrophication may still happen due to the presence of nonpoint sources. Exogenous input and environmental conditions influence nitrogen distribution to an extent in Poyang Lake [20]. Southern region of Poyang Lake has higher total nitrogen, total nitrate nitrogen, and total amount of phytoplanktons. Western region of Poyang Lake has less nitrogen comparing to that of other parts. Eastwestern region faces higher probability to eutrophication. Affecting by phytoplanktons' growth, seasonal change, and change of temperature, nitrate nitrogen has the highest variable coefficient than ammonia nitrogen and total nitrogen. Amount of phytoplanktons is also different in each region: Weste > East > South [20]. Regional change has influenced amount of phytoplanktons, and this may attribute to phytoplanktons' absorption to nutrients and nutrients distribution in different regions.

Currently Poyang Lake is still lacking an effective emergency monitoring management system of water pollution in drainage basin, sewage pipe network, and wastewater treating plants, so it needs a complete water resource management system. Controlling exogenous sources (such as anthropogenic waste water) is one of the expedients to prevent further increase of nutrient levels of Poyang Lake in the future, thus mitigating eutrophication. As the research indicates, industrial waste water disposal of Poyang Lake has large discharge and low reuse rate. Industrial waste water includes production sewage, equipments cleaning water, terrace cleaning water, and sanitary wastage. At a certain period, 12 districts of Poyang Lake have disposed over 100,00,000 tons of industrial wastewater: Hukou county, Lushan district, and Poyang country etc. Industrial wastewater damages Poyang Lake more than bringing nutrients directly into waterbody: large demand for oxygen, high emission load of heavy metal and petroleum pollutants which kill aquatic organisms directly, create oil slick on water surface that depletes oxygen, and accumulate in organisms' bodies that consumed by human. Local government suggests several plans to solve this issue. First, wastewater pipeline should be built; hydrological stations are required 2 kilometers away from Poyang Lake's section downstream, monitoring water level, quantity of outflow, sediments composition, water quality and water quantity. These data can be used to study Poyang Lake, hydrological cycle, and the construction of Poyang Lake's ecological economic region. Also, Poyang Lake's ecological hydro-junction construction can utilize these data to prepare for preliminary work [21]. Policy protocol is also an important method in controlling exogenous waste sources. Poyang Lake region's waste disposal regulation should strictly follow national standards, and a economic value threshold should be set in order to build factories around Poyang Lake. All waste water should be distributed to water treatment plants first for purification in order to minimize nutrient input. Chemical industry and domestic water waste are the main source of eutrophication in Poyang Lake. Heavy metal pollution majorly comes from contingent factories and mines waste [21]. These are all exogenous sources of lake eutrophication, and more regulations should be installed to protect Poyang Lake. Moreover, penalty for illegal wastewater disposal need to be enhanced and rules for industrial wastewater disposal licence needs improvement. These regulations can indirectly prevent waste water from exogenous sources.

Endogenesis source is another major source of nutrients. Endogenesis source comes from phosphorus that is released from lakes' sediments. These sediments are biological deposits that formed in a long-time. Phosphorus' endogenesis source is composed of organisms' dead bodies and waste water. When shallow lakes' capacity decreases, phosphorus that is stored in nutrients will be released, which explains shallow lakes will still have eutrophication when exogenous sources have been cut. Multiple treatments have been implemented to remove endogenesis nutrients: deep water aeration, deep water extraction, using pebbles to cover the bottom of lake, and lowering water level in spring to boost the growth of submerged plants [12]. Deep water aeration mixes upper and lower water, which lowers upper water's temperature and oxygenates upper water. This method accelerates

precipitation of soluble phosphorus and inhibits phosphorus to release from lake sediments [12]. Adding chemical substances into Poyang Lake can increase the transparency of waterbody to some extent. However, using chemical materials chronically may accelerate lake's aging, which causes new ecological problems [22]. Endogenous sources can also be controlled by dredging: removing bottom soils and sediments remove total amount of phosphorus of the lake. Currently biological fixation method is appraised by the industry for its low cost, complete purification and no second-pollution. Adding effective microorganisms' community can mitigate eutrophication. This community includes photosynthetic bacteria, actinomycetes, saccharomycetes, and lactobacillus [22]. These microorganisms compete with phytoplanktons for excessive nutrients, so rapid growth of phytoplanktons can be inhibited. Studies also demonstrated that domesticated large cladophora zooplanktons are useful in treating algal blooms [23]. These algae-consuming microorganisms can increase transparency of waterbody, creating a suitable environment for submerged plants. Domesticated cladophora zooplanktons have increased ability to resist cyanobacterial toxins. Their main food sources are phytoplanktons and organic sediments in waterbody, and the amount of phytoplanktons they consume daily is tenfold of their volume. Using evergreen short type *Vallisneria* in shallow lakes is proved to be useful in purifying water [23]. Evergreen short type *Vallisneria* endures pollutants and low light level; it also has high purifying efficiency, fine landscape, and undemanding maintenance. It effectively solves the issues of seasonal succession of submerged plants: utilizing excessive nutrients released from lake's sediments and produce oxygen with photosynthesis. Researchers combined domesticated cladophora zooplanktons and evergreen short type *Vallisneria* to treat Sanxian Lake, located in Fuliang County, Jiangxi, for its eutrophication. After three months of this project, the maximum transparency of Sanxian lake is above 3 m [23]. Therefore, cultivating short type aquatic plants and algae-consuming zooplanktons in Poyang Lake can be an effective method to decrease endogenous nutrients and the number of algae. Other biological fixations contain cultivation of hypophthalmichthys molitrix, *aristichthys nobilis*, unionids, and snails, which eliminate phytoplanktons directly [28].

Algal blooms create black spots which deplete oxygen in water columns, causing submerged plants dying because of oxygen shortage. Restoration of aquatic plants in Poyang Lake is essential for environmental sustainability: submerged plants create oxygen, provide shelters for organisms, consume nutrients that cause eutrophication. Although original ecosystems cannot be restored completely, cultivating aquatic plants that are easy to breed and has high resistance to pollution is an expedient method: producing economic values while purifying waterbody of Poyang Lake. Researches indicate that *Eichhornia Crassipes* (water hyacinth) are useful in removing excessive nutrients and creating benefits with large-scale processing [11].

4. Conclusion

This paper utilizes previous researches' hydrological data (water quality, water level change, climate impacts, biodiversity change, nutrient levels etc.) of Poyang Lake to study the cause and effects of Poyang Lake's eutrophication. Mitigation of lake eutrophication and deficiencies in current regulations with regard to wastewater disposal are also discussed in this paper. New water regulations of Poyang Lake should learn from other successful projects that deal with lake eutrophication: a complete wastewater pipeline should be built and a complete water management system, which monitors hydrologic data and water quality of Poyang Lake consistently, should be redesigned. With these precautions, futuristic lake eutrophications will decrease and environmental mitigation will be improved with comprehensive data. As for treatments of nowadays exogenous and endogenous pollutions, unregulated wastewater disposal should be banned and biological fixation of the lake needs to be implemented. Stricter regulations and high penalties need to be issued. Local governments can add more budget in building wastewater treatment plants. Moreover, local residents should be educated about the dangers of lake eutrophication so that they can participate in the protection of Poyang Lake by avoiding over-fishing and disposing domestic wastewater into waterbody. Biological

fixation aims to prevent endogenesis sources from releasing excessive nutrients such as nitrogen and phosphorus that lead to eutrophication when there are no inputs of untreated wastewater. This method includes introduction of algae-consuming microorganisms, evergreen short type plants that uses excessive nitrogen and phosphorus as nutrients, aquatic organisms such as unionids and hypophthalmichthys molitrix (silver carps) that feed on phytoplankton. Biological fixation restores biodiversity and environmental sustainability in a long term, creates economic benefits for fisherman, reduces nutrients that cause eutrophication, and create recreational values for Poyang Lake indirectly. Controlling eutrophication is not an easy and fast project, both of government and residents should take their responsibility in this process.

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