JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2021, 22(5), 156–165
https://doi.org/10.12911/22998993/135863
ISSN 2299-8993, License CC-BY 4.0

Received: 2021.02.26
Accepted: 2021.04.14
Published: 2021.05.01

Nutrient Determinant Factor of Causing Algal Bloom in Tropical Lake (Case Study in Telaga Menjer Wonosobo Indonesia)

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ABSTRACT

Nutrients are substances that are used by living organisms in the growth and survival of organisms. On the basis of this background, the aim of this study was to assess the concentration of nutrients (macro and micronutrients) and chlorophyll in the Menjer lake and to examine the relationship between nutrient concentration and algal biomass to identify the determinants of algal development in tropical lakes (Menjer Lake Wonosobo, Indonesia). The research was conducted using a survey method at Menjer Lake Wonosobo. Observations and sampling were carried out 3 times with intervals of 1 month at 7 locations in the photic zone. The concentrations of macronutrients and micronutrients in the Menjer Lake were spatially even in all locations and the temporally slightly increased concentrations were relatively the same during the measurement period. The Cu, NO_2, Si, and Na macronutrients are the determining factors for algal blooming in Menjer Lake Wonosobo. The effect of Cu, NO_2 and Si concentrations was inversely related to the algal abundance, while the Ca, Na and Mo concentrations were in line with the abundance of algae.

Keywords: algae bloom, eutrophication, Nutrient, Menjer Lake.

INTRODUCTION

The phenomenon of eutrophication is threatening many lakes around the world, leading to major challenges connected with drinking water supply, food security and public health. The blooming of algae can consist of one or more algae species which is characterized by an increase in cell abundance far above the average for a particular area or body of water. In oligotrophic lakes, the chlorophyll concentration ranges from 20 mg Chl m^3 and can exceed 100 $mg.m^3$ in eutrophic lakes, which can cause fish death due to the toxins produced by these algae (Ghorbani et al., 2014).

The occurrence of algal blooms is influenced by physical factors (e.g. wind, temperature) and environmental chemistry (nutrients and trace elements). In sub-tropical climates, the occurrence of blooming is triggered by temperature stratification during winter, which allows the accumulation of nutrients in the hypolimnion layer and when winter starts to end and temperatures begin to warm (spring), there is a reversal (spring overturn); then, the algal biomass will develop very fast so that blooming occurs. In tropical climates, temperature and light intensity are relatively constant throughout the year, so they do not become a limiting factors for the algal growth (Prasetyo, 2013). Algae can still grow even under minimum nutrient conditions as long as their needs are still fulfilled; the blooming is more related to the dynamics of nutrients in the lake (Piranti, et al, 2012a; Elfiza & Dharma, 2019).

Nutrients are substances that are used for the purposes of living organisms for growth and survival such as metabolic processes or organism's physiological processes. Nutrients in the waters are grouped into macro nutrients and micro nutrients. The nutrients in macro form consist of carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, potassium, magnesium, potassium, sodium, chlorine. Carbon, hydrogen and oxygen are macronutrients that must be available because they play a role in the photosynthesis process carried out by phytoplankton (Firdaus & Wijayanti, 2019). Nitrogen and phosphorus can be said to be the main nutrient requirements for phytoplankton because they can be utilized by phytoplankton and must be available in the environment, while the amount in the environment is also limited so that it affects the growth of phytoplankton, becoming a limiting factor for the life of phytoplankton.

Micronutrients are needed in very small but still decisive amounts. Micronutrients consist of ferrum, cobalt, zinc, boron, silicates, manganese, and copper (Horn & Goldmann, 1992). The potential micronutrient limitations of phytoplankton productivity in freshwater are often overlooked. In order to investigate the response of lake phytoplankton to micronutrient enrichment, it is necessary to undertake the research to monitor the concentrations in fishing lakes as representative of tropical lakes. Downs (2008) states that the prevalence of micronutrient restriction is not related to lake size or trophic status, so enrichment and micronutrient types can significantly increase the productivity of phytoplankton in various types of lakes. Therefore, the effect of the potential contribution of micronutrient enrichment to eutrophication should not be ignored. On the basis of this background, the purpose of this study was to assess the concentration of nutrients (macro and micronutrients) and chlorophyll in the Menjer Lake and to study the relationship between the nutrient concentration and algal biomass to identify the determinants of algal development in tropical lakes (Telaga Menjer Wonosobo, Indonesia).

RESEARCH METHODS

The research was conducted using a survey method at Menjer Lake Wonosobo. Telaga Menjer is a lake that occurred due to the volcanic eruption of Mount Pakuwaja which is located in Maron Village, Garung District, 12 kilometers north of Wonosobo City. Telaga Menjer is located at an altitude of 1300 meters above sea level; this lake occupies a basin area of 70 hectares with a water depth of 45 meters. The area of the Menjer catchment area is 2.27 km^2 while the area of Menjer Lake is 0.61 km^2. The activities of the chactment area being carried out by residents are agriculture, and animal husbandry. Menjer Lake is used by local residents for tourism, fishing, irrigation and hydropower (PLTA). This will increase the nutrients that enter the lake. There has not been much research on water quality in the fishing pond. The research on plankton diversity and abundance has been carried out but the potential for eutrophication that can cause blooming has not been investigated.

The presented research to determine the occurrence of blooming was carried out with a quantitative approach, namely by taking water samples and measuring the required parameters according to the research objectives. Observations and sampling were carried out 3 times with intervals of 1 month at 7 locations in the photic zone. The schematic of the sampling location at the Menjer Lake is presented in Figure 1.

The main parameters were nutrient status and algal biomass. The research variables were macro/micronutrient concentrations and chlorophyll concentrations. The considered macronutrients included: Si, NO_2, NH_3, Ca, Mg, NO_3, Na, SO_4, Fe, and PO_4, while micronutrients comprised: Se, Zn, Cu, Co, Mn, and Mo. The supporting parameters involved water volume, rainfall, light penetration, temperature, oxygen, and depth.

In order to assess the status of macro and micronutrients and the biomass of algae, a descriptive analysis based on spatial and temporal was applied. In order to study the relationship between micro/macro nutrient concentrations with algal biomass (chlorophyll) and to identify the determinants of algal blooming, a multivariable correlation-regression analysis was carried out using the Minitab version 14 software.

Figure 1. Sampling location at Menjer Lake

RESULTS AND DISCUSSION

Increasing nitrogen supply to waters is mainly due to human activities in water catchment areas, industrialization activities, and agricultural intensification (Piranti et al., 2015b). The use of agricultural fertilizers, sewage disposal, animal waste, atmospheric input, and raising fish using cages contribute to increasing nutrient concentrations in lake and reservoir waters. The increase in nutrients has led to an increase in the phytoplankton biomass (Abell et al., 2010). The initial indicator of biota that is affected by aquatic eutrophication is phytoplankton, which is indicated by adaptation or tolerance to water instability conditions and continues to bloom events (Dewi et al., 2018; Gatz, 2020).

The chlorophyll concentration ranged from 33.0–42.9 $mg \cdot m^3$ (eutrophic) and horizontally the concentration was almost the same in all locations (Figure 2). However, in the areas close to the greenbelt which are planted with agricultural crops, the concentration tends to increase compared to other areas. At the time of the observation, the stock of agricultural fertilizers was in bags placed on the edge of the lake, which probably means that when it rains or an increase in the water level of the lake occurs, fertilizers will infiltrate the lake.

Temporally, the chlorophyll concentration tended to increase during the sampling period (Figure 3). In July, the concentration is lowest and increases in August and September. August - September is the peak of the dry season and during that period the hydroelectric gate was not operated, so there was a chance for microalgae to develop so that its biomass increased.

The accumulation of sediment due to erosion results in the accumulation of nutrients that are bound to sediment particles (Kiani et al.; Bashagaluke et al., 2018). If this condition occurs continuously, it is feared that it will cause the phenomenon of nutrient enrichment or "eutrophication". In the process of utilizing macronutrients, there are two categories of phytoplankton, namely: productive phytoplankton which functions as natural food or as the main producer in the food chain, so as to indicate the level of water productivity. The condition that is reflected in the high productivity of primary waters is very dependent on the ability of the waters to synthesize inorganic material into organic material through photosynthesis by phytoplankton as the primary producer. On the other hand, there is a type of phytoplankton that

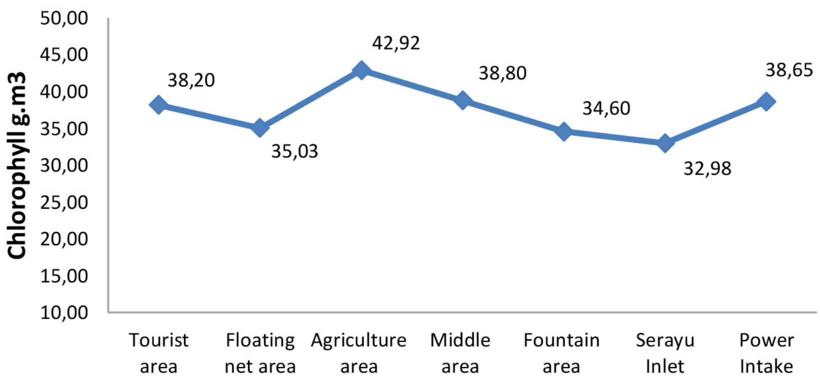

Figure 2. Distribution of chlorophyll in Menjer Lake spasially

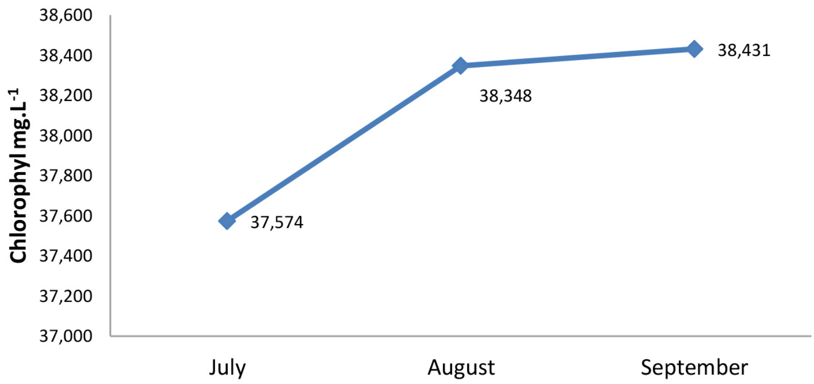

Figure 3. Temporal distribution of Chlorophyll

is capable of producing toxins (HAB). In general, the term HAB refers to the growth of high levels of phytoplankton with the toxins that cause anoxia, namely decreased oxygen loss in water bodies, and mass death of fish as well as result in negative biomagnification processes in the food chain. Therefore, it is considered dangerous (Ji et al., 2017).. The influence of natural factors (freshwater flow input, sedimentation) and anthropogenic activities of land use change, supported by fluctuations in environmental changes during the rainy season. Ecological conditions are of concern to support the occurrence of eutrophication phenomena which affect the composition and abundance (blooming) of phytoplankton, affect aquatic organisms as well as decrease the dissolved oxygen content (anoxia) and the average value of primary productivity.

Macronutrients

The results of spatial and temporal measurements of macronutrient concentrations (Si, NO_2, NH_3, Ca, Mg, NO_3, Na, SO_4, Fe, PO_4) are presented in Figures 3–9. There was a slight trend of increasing or decreasing at several observation points, but it can be said that in the ponds the distribution of macronutrients is even. The distribution of macronutrient silicates (Si), nitrite (NO_2) and ammonia (NH_3) is presented in Figure 3. Silicates are the compounds required for diatom growth. Silicates come from weathering dissolved rock and sediment. These silicates then flow into the catchment area by rivers and groundwater to the lake and finally to the sea. Diatoms are the main contributor to phytoplankton in waters and support fisheries. According to Umiatun et al., (2017), the diatom abundance is significantly influenced by the silicate concentration of 38% and the rest is determined by other factors. Spatially, the silicate concentration in the lake keeps the distribution even, but there is a tendency to increase the concentration in the area near agriculture which is carried out in the green belt (Figure 4). The average concentration of silicates during July – September was around 0.03–0.04 $mg \cdot L^{-1}$ and tended to increase in September (Figure 5). The increase in silicate concentrations was due to the fact that in September the hydropower plant was not operated, resulting in accumulation in the lake.

Calcium (Ca) is one of the essential macro minerals that are beneficial to aquatic animals (Terech-Majewska et al., 2016). The calcium concentration tends to increase in the cage area, which comes from fish feed in the form of pellets which are usually made from shrimp shells. Calcium also tends to increase in spring water areas

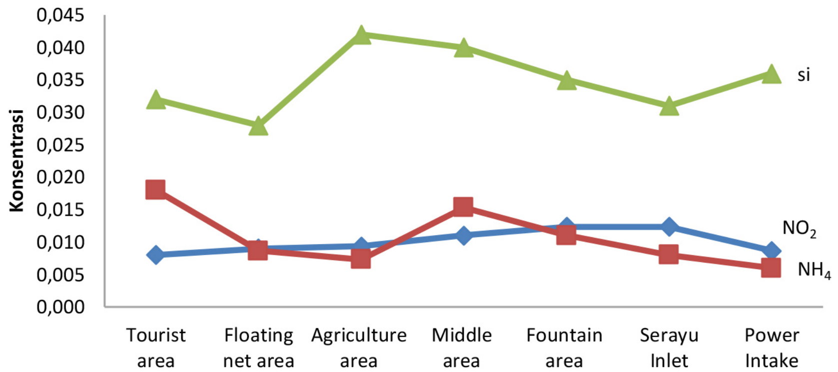

Figure 4. Spatial distribution of Si, NO_2, NH_3 macronutrients in Menjer Lake

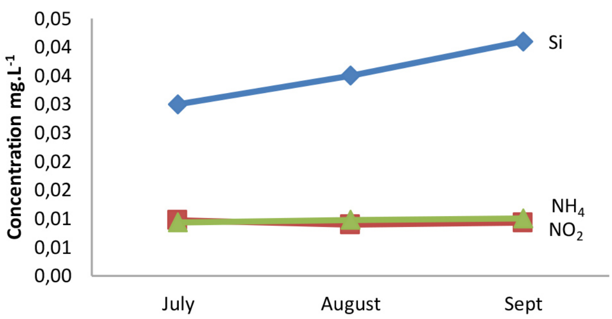

Figure 5. Temporal distribution of Si, NO_2, NH_3 macronutrients in Menjer Lake

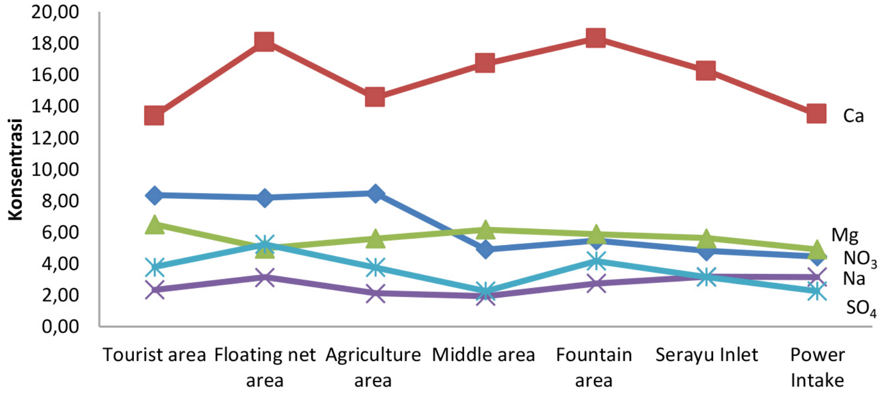

Figure 6. Spatial distribution of Ca, NO_3, Mg, SO_4, and Na during the study

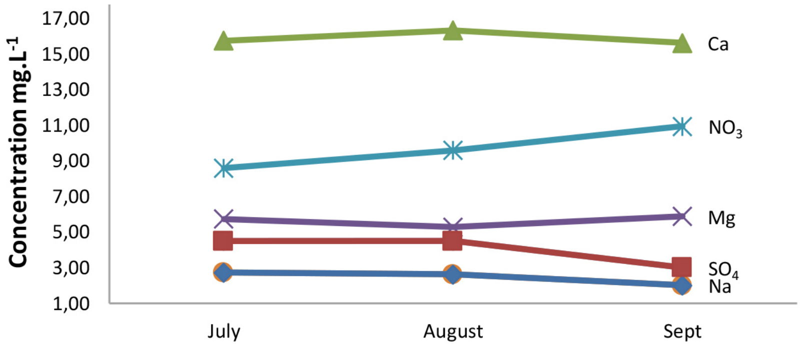

Figure 7. Temporal distribution of Ca, NO_3, Mg, SO_4, and Na during the study

because this element is a result of rock weathering and is carried away by spring flow (Figure 6). Temporally, the Ca concentration did not fluctuate (Figure 7).

Nitrate (NO_3) is a form of dissolved ion produced from the complete oxidation of nitrogen compounds. NO_3 – this is a form of available nutrient that is ready to use for algal growth. The level of nitrate is very dependent on the dissolved oxygen content. When the oxygen levels are low, the balance moves towards ammonia, while when the oxygen levels are high, the balance moves towards nitrate. The concentrations of nitrate in the Pemeraga ranged from 4.45 to 8.34 $mg \cdot L^{-1}$ and were evenly distributed at all sampling points – see Figure 6. Temporally, there was an increasing trend during observation (Figure 7). According to Piranti (2012a), the nitrate content will cause a bloom to a eutrophic condition in the Mrica Banjarnegara reservoir, when the nitrate concentration is > 11 $mg \cdot L^{-1}$.

The magnesium ion (Mg^{2+}) is a microalgae growth factor and is a key component of chlorophyll which can be found in the stoichiometric to chlorophyll ratio in photosynthetic tissue (Ben Amor-Ben Ayed et al., 2015). The chlorophyll content of microalgae is known to vary with growth conditions such as light intensity and CO_2 concentration (Larosière et al., 2014). The concentration of Mg metal in the lake water does not flow spatially or temporally (Figure 6 and Figure 7).

Inorganic sulfur is mainly present in the form of sulfate (SO_4^{2-}) which is the main form of sulfur in water and soil. Sulfur is one of the essential elements for living things, because it is an important element in the protoplasm. Sulfur is absorbed by plants in the form of SO_4^{2-}, this substance is part of the protein found in the form of cysteine, methionine and thiamine. The SO_4 concentration in the dangers lake also does not fluctuate both spatially and temporally (Figure 6 and Figure 7).

Sodium (Na) is one of the main alkaline elements found in waters and is an important cation that affects the overall equilibrium of the cations in the waters. The main source of sodium in waters comes from the waste from human activities in DTA. Sodium salts are used in industry so that industrial waste and domestic waste are sources of anthropogenic sodium. Almost all natural waters contain sodium with levels between 1 $mg \cdot L^{-1}$ liter to thousands of $mg \cdot L^{-1}$. The measurement of sodium levels is necessary if the waters are designated for drinking water and agricultural irrigation purposes. The Na concentration in the Menjer Lake was evenly distributed both spatially and temporally in the range of 2–3 mg·L^{-1} liter (Figure 6–7).

Phosphorus in waters comes from weathering rocks and the impact of human activities in water catchments. Phosphorus enters the waters in the form of particles and is deposited in sediment particles. Horne & Goldmann (1994) stated that in natural waters, only 5–10% of the phosphorus that enters the waters is in dissolved form and the rest enters waters bound in sediments and settles on the bottom of the waters as P_20_5 compounds. The presence of both organic and inorganic phosphorus compounds that are bound in the sediment can be a source of phosphorus which can be released back (resuspension) into a dissolved form in water (PO_4). Under anoxic conditions, the sediments can release phosphorus 1000 times faster than the sediments that are oxic (oxygenated) (Horne & Goldmann, 1994). Phosphorus, in the form of orthophosphate, plays a key role in the photosynthesis of phytoplankton for metabolism (Abell et al., 2010).

On the basis of a spatial study, the phosphorus concentration at each observation location was evenly distributed, only tending to be lower at Power Intake (Figure 8). Temporally, the P concentration at 3 months of observation from July, August and September tended to increase (Figure 9). During the dry season, the average TP concentration in the reservoir tends to be stable, ranging from 0.4–0.5 mg·L^{-1} (September). This observation is carried out in the dry season, the water conditions are relatively clear because the sediment resulting from erosion which is carried by the flow of water entering the reservoir tends to be small in number. With the clear reservoir water conditions the P concentration in the dry season, can increase. This is because under the relatively clear water conditions, the photic layer becomes deeper and the penetration of light can enter the water column. Under these conditions, aquatic organisms develop well, resulting in nutrient regeneration in reservoir waters or an increase in nutrients from internal input loads (in lake source).

Ferrum (Fe) is basically an element that is required for metabolic processes, but if the concentration exceeds the threshold, it will be toxic and can accumulate in microalgal cells, so that it can inhibit growth and cause the death of microalgae. The disruption of the photosynthesis process can reduce the ability of microalgal cells to multiply. In general, microalgae have self-protection mechanisms against heavy metals. The concentration of Fe in Menjer Lake ranges from 0.17 to 0.31 mg·L^{-1} and the highest concentration is in the lake inlet originating from

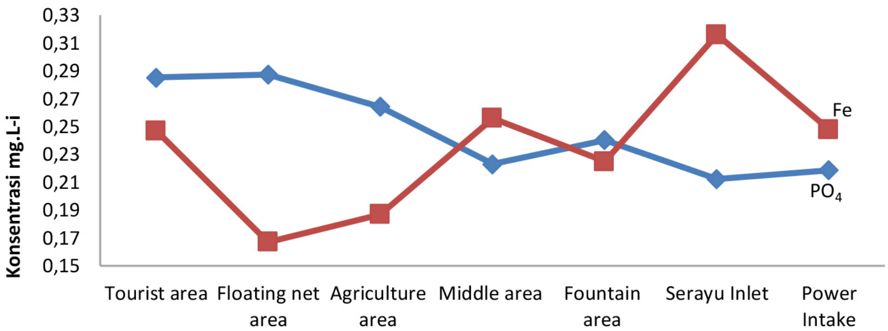

Figure 8: Macronutrient concentrations (PO_4 and Fe) during the study

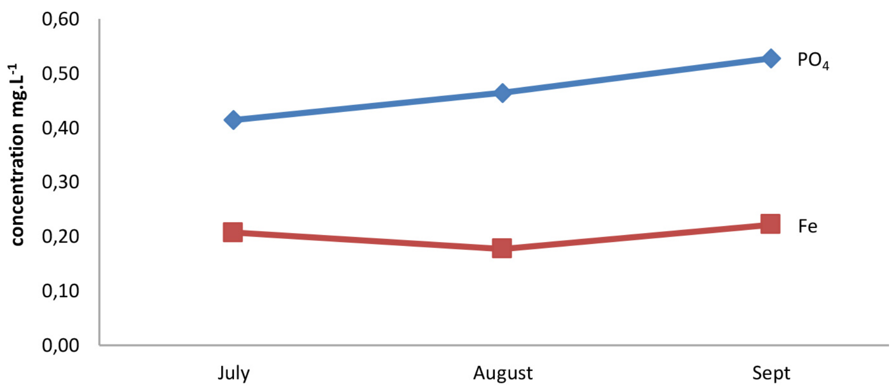

Figure 9: Macronutrient concentrations (PO_4 and Fe) during the study

the Serayu River (Figure 8), the concentration is relatively the same during the months of July – September (Figure 9).

Micronutrients

Fluctuations in the micronutrient measurements are presented in Figures 10–14. Selenium is absorbed by algae into amino acids and proteins so that algae serve as the main vector for absorption of organic selenium compounds by consumers. The Se concentration in the Menjer Lake spatially and temporally ranges from 0.02–0.03 mg·L^{-1} (Figure 10). The zinc concentration has several direct effects on increasing the algal biomass. The lower limit concentration of zinc to have a negative effect on algal growth is 0.03–0.04 mg·L^{-1}, and the growth will be suppressed once the Zn content in the media exceeds this threshold. The concentration of Zn in the fishery pond ranged from 0.03 mg·L^{-1} (Figure 10) and is still at the safe limit for macroalgae life.

The Cu content in river water ranges from 0.017 ppm to 0.54 ppm. The Cu content in the river water is 0.2 ppm, which is classified as high (Sulistyono & Rokhmah, 2012). The Cu content in the Menjer Lake is still within safe limits, not exceeding 0.2 mg·L^{-1} (Figures 10 and 12). Naturally, Cu can enter the aquatic environment from various natural events such as erosion (erosion) of mineral rock or dust or Cu particulate matter contained in the air layer brought down by rainwater which then accumulates in the sediment and body of organisms.

The Co pollution due to domestic, industrial and natural processes can contribute to the increase in metals in waters. The metals that enter the aquatic environment will experience deposition, then they will be absorbed by organisms that live in these waters. The heavy metals have properties that easily bind organic matter and can settle on the bottom of the waters and then unite with sediments, resulting in higher levels of heavy metals in the sediments than in water (Najamuddin & Surahman, 2017)estuarine, and marine. The concentration of Co in the lake waters ranges from 0.01 to 0.025 mg·L^{-1} (Figure 10). The concentration tends to increase temporally during the measurement period from July to September (Figure 13)

Manganese is also an essential nutrient, and a large number of enzymes take advantage of the redox properties of this element. For example, it is needed in cells to catalyze the oxygen evolution in photosynthesis. Increasing the concentration of manganese has a positive impact in stimulating the development of algae. Molybdenum is a constituent of several metalloflavin enzymes, including those involved in dinitrogen fixation and nitrate reduction. Molybdenum limits primary productivity and N fixation in the natural environment.

Determinants of microalgal growth in the Menjer Lake

The development of algae in waters is determined by nutrient availability, light intensity, oxygen, temperature and water retention (Soares et al., 2012). In tropical waters such as those found Indonesia, light is available all year round and water temperature is still in the optimum range for the metabolic processes of aquatic organisms (around 20–35 °C), so light and temperature are not limiting factors for the algal growth. Rainfall is one of the climatic factors that distinguish between the tropical and sub-tropical conditions. Rain causes the reservoir to receive a number of nutrients from the river or through a process of precipitation which falls directly into the reservoir. This will cause the dynamics of nutrients in the reservoir to be different during the rainy and

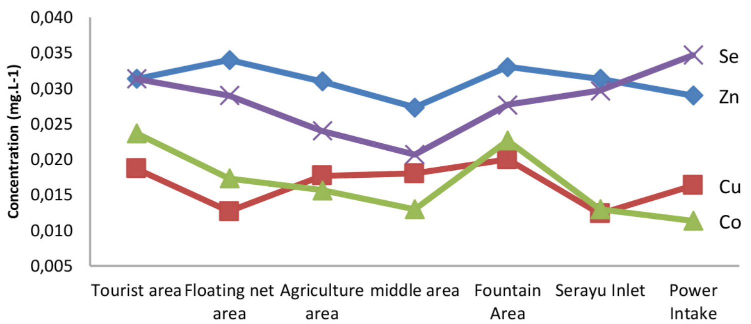

Figure 10. Micronutrient concentrations (Se, ZN, Cu and Co) during the study

dry seasons so that it is possible that the response of organisms in the reservoir to the presence of nutrients in the reservoir is also different.

If the development of algal biomass is only determined by each type of nutrient singly, the relationship between macronutrients (Si, NO_2, NH_3, Ca, Mg, NO_3, Na, SO_4, Fe, and PO_4) and micronutrients (Se, Zn, Cu, Co, Mn, and Mo) with chlorophyll showed that different properties and degrees of correlation (Tables 1 and 2).

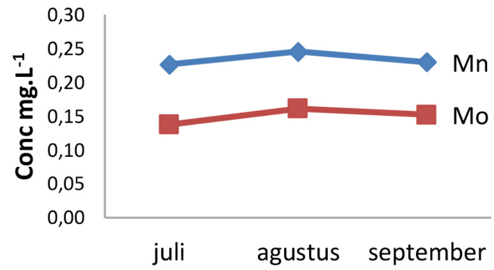

Figure 11. Concentrations of Mn and Mo

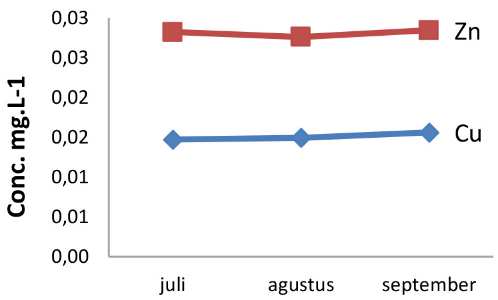

Figure 12. Concentrations of Zn and Cu

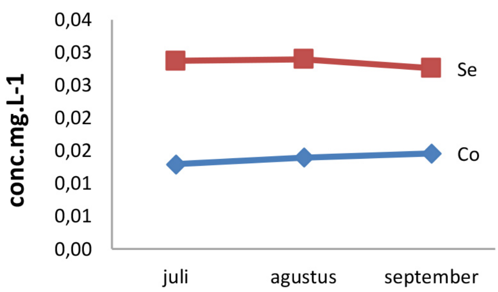

Figure 13. Concentrations of Se and Co

The relationship between macro nutrients and chlorophyll (Table 1) shows that the relationship between Mg and chlorophyll is very weak, whereas PO_4, NO_3, SO_4 and Fe with chlorophyll have a low effect on increasing the algal biomass, while NO_2, Si, Ca, and Na have a relatively stronger effect on algal growth. The nutrients that have a negative relationship direction (nutrient concentration is inversely proportional to the abundance of algae), for macronutrients are Ca, Na, SO_4 and Fe, while micronutrients are Zn, Se and Co. This means that if each type of nutrient is the sole factor in determining the algal development, the increase in the concentration of each of these nutrients causes a decrease in the amount of algae in the waters.

The results of the correlation analysis between micronutrients and chlorophyll showed that there was a very weak – moderate relationship (Table 2). In most studies on the effect of nutrients on the growth of microalgae or plants, research has been carried out on the effects of individual nutrients as a single factor, but the conclusion of this single factor experiment cannot fully explain the phenomenon of the algal growth that occurs realistically. This is due to the fact that the algal growth rarely occurs barely due to a single factor. It is known that a natural lake or river is a complex system with many reactions between very large masses of matter. In addition, although much research has been carried out for the effects of trace element fertilization on harmful algae blooms; however, little attention has been paid to the interactions between multi-metallic elements in influencing the algal biomass. Nevertheless, a few experimental studies have been carried out on measuring the upper or lower threshold concentrations for positive effect of typical trace elements. In order to help bridge

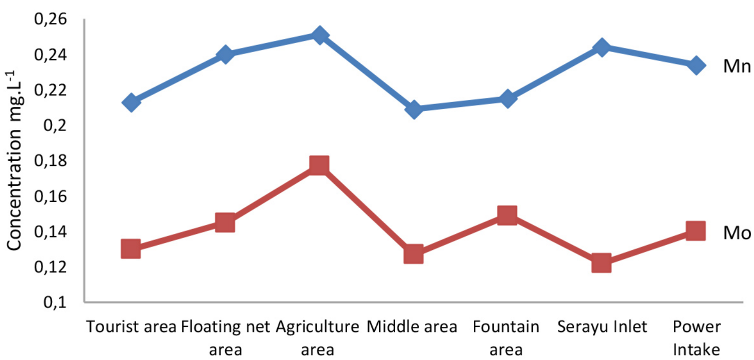

Figure 14: Micronutrient concentrations (Se, ZN, Cu and Co) during the study

Table 1. Macronutrient and chlorophyll relationships

No	Hubungan	Koef. Korelasi (r)	Kekuatan
1	NO_2 – Chlorophyll	+ 0,421	Moderate
2	PO_4 – Chlorophyll	+ 0,209	Low but definite
3	NO_3 – Chlorophyll	+ 0,372	Low but definite
4	Si – Chlorophyll	+ 0,527	Moderate
5	Ca – Chlorophyll	- 0, 675	Moderate
6	Mg – Chlorophyll	+ 0,110	Very weak
7	Na – Chlorophyll	- 0,555	Moderate
8	SO_4 – Chlorophyll	- 0,282	Low but definite
9	Fe – Chlorophyll	- 0,385	Low but definite

Table 2. Relationship of micronutrients and chlorophyll

No	Relationship	(r)	Strength
1	Mn – Chlorophyll	+ 0,101	Very weak
2	Zn – Chlorophyll	- 0,474	Moderate
3	Cu – Chlorophyll	+ 0,465	Moderate
4	Mo – Chlorophyll	+ 0,584	Moderate
5	Se – Chlorophyll	- 0,322	Low but definite
6	Co – Chlorophyll	- 0,143	Very weak

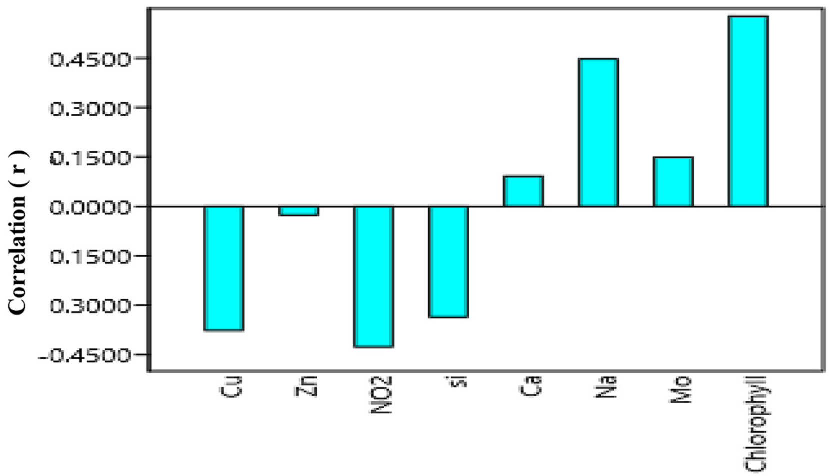

Figure 15. Determinants of algal blooming in the Menjer Lake

the knowledge gap above, an experimental investigation was carried out to obtain explicit results for the growth response (specific growth rate and final biomass) from fresh algal colonies (cyanobacteria and chlorophyta) to various metal concentration gradients, as well as interactions between multi-elements such as iron, manganese and zinc in phycophytes.

The results of the analysis of the relationship between macronutrients and micronutrients as a single factor that has a significant effect were further analyzed using PCA (Principle Component Analysis). The analysis showed that Cu, NO_2, Si, and Na were significant determinants that influenced the development of algae in the Menjer Lake Wonosobo (Figure 15). The effect of Cu, NO_2 and Si in the lake is to trap the algal biomass. The concentration is inversely proportional to the abundance of algae, while the concentrations are in line with the abundance of algae are Ca, Na and Mo (Figure 15).

CONCLUSIONS

Understanding the factors that trigger algal blooms is very important to predict its prevention. The concentrations of macronutrients and micronutrients in the Menjer Lake were spatially even in all locations and the temporally slightly increased concentrations were relatively the same during the measurement period. The Cu, NO_2, Si, and Na macronutrients are the determining factors for algal blooming in the Menjer Lake Wonosobo. The effect of Cu, NO_2 and Si concentrations was inversely related to algal abundance, while the Ca, Na and Mo concentrations were in line with the abundance of algae.

Acknowledgement

Thanks to Dean of Biology Faculty of UNSOED on behalf of the Directorate General of Higher Education Research and Technology of Indonesia for funding this project through the Institutional Reseach (RIU) Scheme with contract Number of Kept. 119/UN23.18/PT.01.05/2020

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