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Investigating Factors Influencing Algal Bloom Development – a Preliminary Case Study of Putrajaya Lake Inlet, Malaysia

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Abstract. Algal bloom phenomena are increasingly occurring in many urban lakes worldwide. To enhance understanding of how environmental factors influence the development of harmful algal bloom (HAB), a preliminary study was carried out at one of the inlets in Putrajaya Lake. Physicochemical variables, nutrients, weather conditions, chlorophyll-*a*, and phycocyanin were measured over two weeks. Algal indicators, namely chlorophyll-*a* values, were strongly correlated to dissolved oxygen (DO), pH, conductivity, turbidity and nitrate. There is no correlation recorded between chlorophyll-*a* with phosphate and total phosphorus. This preliminary study showed the complex relationship influencing algal development and bloom formation. Blue-green algae (BGA) was the most dominant phytoplankton assemblages during the study. A positive correlation was also observed between chlorophyll-*a* and solar radiation, temperature, and wind speed. Despite no strong correlation between chlorophyll-*a* and rainfall amount, a strong relationship between chlorophyll-*a* and turbidity indicated other environmental factors contributing to algal bloom occurrence. BGA density was correlated to DO, pH, turbidity, air temperature and nitrate. Management measures recommended to reduce algal bloom development include external nutrient reduction through the constructed wetland. Artificial mixing is also recommended to improve vertical mixing and circulation pattern.

INTRODUCTION

Harmful algal blooms (HAB) are a primary concern in temperate and tropical freshwater environments [1] due to toxins releasing potentially fatal effects on humans, livestock, and wildlife. Such cyanobacterial toxin poisoning from water reservoirs has been reported in Northeast Brazil and Australia [1]. Cyanobacterial bloom phenomena are increasingly occurring in many urban recreational lakes worldwide, including in tropical countries such as Malaysia. Incidence of algal bloom can affect water quality, including a reduction in water clarity and oxygen levels, and causes fish kills and food web alterations that reduce lake ability to produce ecosystem services [2].

Algal bloom incidence has been reported in mesotrophic and eutrophic water bodies; the accumulated biomass associated with algal bloom varied with species and environmental conditions, including water temperature, water column stratification and mixing dynamics, light climate, and nutrient supply [3]. Certain cyanobacteria such as *Aphanizomenon* and *Nodularia* can fix nitrogen in nitrogen-limited waters, and elevated temperature could trigger their bloom in the water with an excess of total phosphorus [4]. Other cyanobacteria such as *Microcystis* have the buoyant ability to drift vertically to exploit light at the surface and nutrients in deeper parts of the water column to blossom [4].

Nutrient supply, mainly total phosphorus (TP) and total nitrogen (TN) were reported to promote bloom-forming cyanobacteria; increasing TN concentrations, for example, were related to more frequent *Microcystis* blooms [1],

while elevated TP levels were related to regular *Anabaena* blooms [4]. Data analysis involving lakes in the USA revealed that nutrients had an extensive control on cyanobacterial biovolume. Their significant influence was more apparent in nutrient-poor or oligotrophic lakes [4].

Other environmental factors that may affect cyanobacterial blooming include meteorological conditions or climatic factors such as air temperature, wind speeds, and solar irradiance. The eco-physiological characteristics among cyanobacterial taxa may lead to varying responses to climate change [1,4,5]. The effects of temperature on HAB are well studied in many kinds of literature. High temperatures exceeding 25°C promote stable water column stratification that is idyllic for buoyant cyanobacteria to migrate upward for light [1, 5]. Increasing water temperature or warming could also favour cyanobacteria taxa with higher maximal growth rates at elevated temperature levels [4,5].

Additionally, other studies showed that global warming could also change the onset of stratification in spring, and the onset of destratification in autumn subsequently extends optimal growth periods for cyanobacteria [6]. Synergistic effects of temperature and nutrients were more apparent in nutrient-rich or eutrophic and hyper-eutrophic water bodies [4]. Turbulent mixing dynamic shaped by wind effects and heat exchange could also alter the competition between algal communities; buoyant *Microcystis* could competitively displace other algal species during weak mixing while the diatoms and green algal competitively replace *Microcystis* in well-mixed waters [7].

Algal blooms were occasionally reported in Putrajaya Lake in Malaysia, especially near the inlets and required investigation to enable better management of the lake under changing climate. This study aimed to investigate the environmental factors that influence algal bloom occurrences in one of the inlets of Putrajaya Lake, Malaysia.

MATERIALS AND METHODS

Study Area

Putrajaya Lake is one of the most popular recreational lakes in Malaysia. The lake, which was in operation in 2002, has a total surface area of 400 hectares and a catchment area of 51 km² [8, 9]. With a total depth ranging between 3 to 14 m, the total water storage volume is about 20 million m³ [8]. Incidents of algae bloom have been reported to occur especially near inlets, possibly due to fluxes of nutrient concentration. The area for this study was focused on one of the algae bloom hotspots areas identified in 2013 [10], where algal removal exercise was carried out using micro-bubble generating devices in 2016 [9]. There are seven areas identified as hotspots for algae bloom incidents in Putrajaya Lake, as shown in Figure 1.

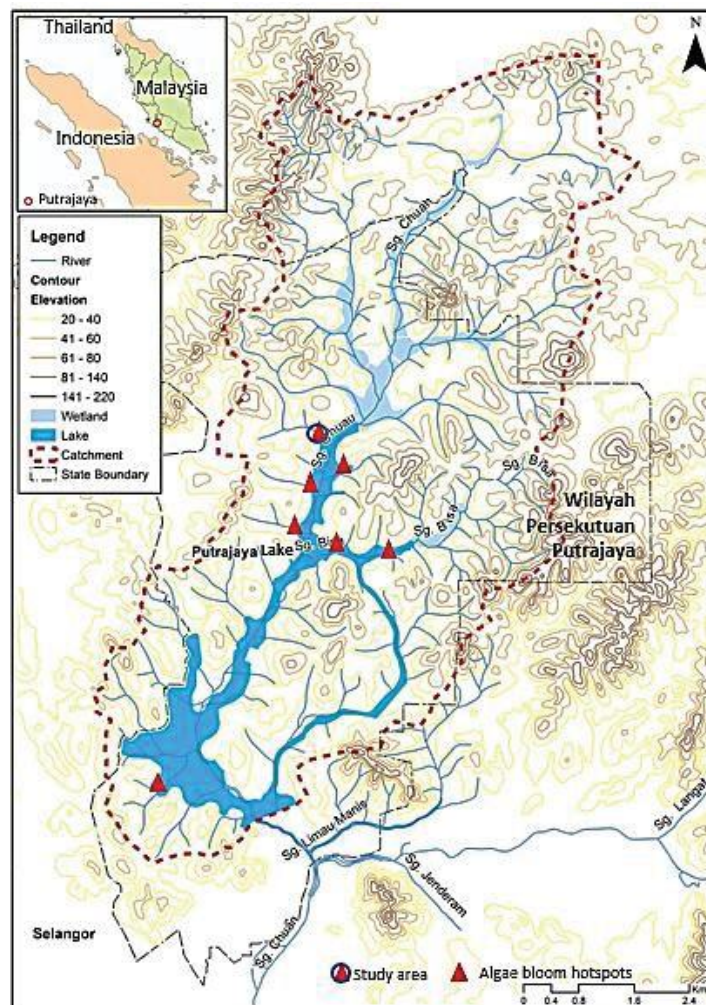


FIGURE 1. Study Area at Putrajaya Lake.

Method

Physicochemical variables, nutrients, weather conditions, chlorophyll-*a*, and phycocyanin were measured three times daily over two weeks. *In situ* measurements of physicochemical parameters, namely temperature, dissolved oxygen, pH, and turbidity, were carried out near the lake surface using a multi-parameter probe, proteus (RS Hydro, UK). Water samples were collected using a Van Dorn sampler. They were preserved in more excellent boxes at 4 °C and transported to the laboratory to analyse chlorophyll-*a*, total phosphorus, phosphate and nitrate by standard methods [11].

One litre of water samples was collected below the surface of the water column (~0.5 m) for phytoplankton analysis and fixed with Lugol's iodine to achieve a 1% final solution. The samples were identified to the taxa, and densities were calculated based on the number of cells/ml in the sample.

Past water quality data were obtained from a nearby telemetry station that measured water quality every 15 minutes and monthly manual sampling. Data were initially tested for normality and homogeneity; any skewed data were transformed before further analysis of variance (ANOVA) and correlation.

RESULT AND DISCUSSION

The overall water quality index of the areas based on long-term manual and telemetry station reported a value around 90, which is in the category of Class II. The environmental conditions during the study were characterised by high dissolved oxygen, conductivity, and nutrient levels. Mean chlorophyll-*a* was low (5.5 µg/L) while nitrate and TP level were high (**Table 1**). The chlorophyll-*a* values found in this study are consistent with published records [12]. The nutrient levels differed with records; TP levels were higher than past data [12], while nitrate was higher than the recorded level in 2015 but lower than values recorded in 2016 [9]. Mean Carlson's trophic state index remains in meso-eutrophic conditions [12], which range between 39 to 77. TP values exceeded the National Lake Water Quality Criteria and Standards [13]. Other parameters such as chlorophyll-*a*, nitrate, turbidity and pH were within the standard limit.

TABLE 1. Daily Mean Values of Environmental Variables.

Parameter	Unit	Mean ± SD	National Lake Water Quality Criteria and Standard – (secondary body contact recreation)
Dissolved oxygen	mg/L	9.2 ± 0.8	5.5 – 8.7
pH		7.2 ± 0.3	6.5 – 8.5
Temperature	°C	31.2 ± 1.6	28 ± 3
Turbidity	NTU	74.4 ± 78.3	40 - 170
Conductivity	µS/cm	113 ± 8	1000
Nitrate	mg/L	0.54 ± 0.45	7.0
Phosphate	mg/L	0.03 ± 0.06	-
Total phosphorus	mg/L	0.09 ± 0.02	0.035
Chlorophyll- <i>a</i>	µg/L	5.5 ± 2.9	3 - 12
Wind speed	m/s	0.6 ± 0.1	-
Air temperature	°C	27.3 ± 1.3	-

In general, the weather during the experimental measurement was dry during the morning and mid-afternoon and occasionally wet in the evening. The highest daily rainfall amount measured was 61.6 mm, while the warmest air temperature was 30.6 °C. Wind speeds at the study area were generally low < 1 m/s throughout the experiment. Analysis of variance indicated significant differences in the daily pattern of dissolved oxygen, pH, conductivity, turbidity, chlorophyll-*a*, and nitrate. Discharge of turbid water containing suspended particulate matter flows from the catchment areas to the study area through the nearby gross pollutant traps was observed after rainfall events.

Algal indicators, namely chlorophyll-*a* values, were strongly correlated to dissolved oxygen, pH, conductivity, nitrate, and turbidity. There is no correlation between chlorophyll-*a* with phosphate and total phosphorus in contrast to findings in [14], where a positive correlation was observed between TP and chlorophyll-*a*. This finding collaborated with [14], where chlorophyll-*a* was negatively correlated to nitrate. A positive correlation was observed between chlorophyll-*a* and solar radiation, temperature, and wind speed consistent with other studies. Increased air temperature and wind speed are associated with elevated levels of chlorophyll-*a*. A similar positive correlation between air temperature and chlorophyll-*a* was recorded in [14]. However, chlorophyll-*a* was negatively correlated with maximum and average wind speed average [14]. Cyanobacterial species can grow in abundance at higher temperatures due to their high optimum growth temperature exceeding 25 °C [1, 2, 15]. An increase in air temperature induced by global warming can increase algal bloom occurrence [1, 2]. Higher wind speed improves nutrient transport and water column mixing, which leads to an increase in chlorophyll-*a* concentrations. The wind was the primary factor influencing algal bloom in Lake Taihu with bloom formation along shallow bays [16].

TABLE 2. Correlation Between Environmental Variables and Algal Indicators.

Parameter	Chlorophyll- <i>a</i>	BGA density
Dissolved oxygen	0.626**	0.506**
pH	0.481**	0.489**
Temperature	0.444*	0.465*
Turbidity	0.482**	0.449**
Conductivity	0.359*	0.066
Nitrate	-0.577**	-0.405*
Phosphate	0.312	0.128
Total phosphorus	-0.064	-0.219
Phycocyanin	0.116	-0.068
Wind speed	0.406*	0.125
Rainfall	-0.231	-0.360*
Air temperature	0.353*	0.440**
Solar radiation	0.171	0.277

Note: ** Significant correlation ($p < 0.01$), * Significant correlation ($p < 0.05$)

Despite no strong correlation between chlorophyll-*a* and rainfall observed in this study, a strong relationship between chlorophyll-*a* and turbidity indicated other environmental factors contributing to algal bloom growth during this study.

Analysis of past water quality data indicated no clear trend between long-term chlorophyll-*a* values and environmental variables. However, chlorophyll-*a* concentrations were positively correlated to conductivity and pH in 2019. Over eight years, the monthly chlorophyll-*a* pattern showed that the highest chlorophyll-*a* concentrations were recorded in August and September. However, water quality monitoring data in 2019 recorded different patterns. A severe increase in algal growth was recorded in March, where chlorophyll-*a* levels exceeding 32 $\mu\text{g/L}$ were observed at the study area whilst the highest chlorophyll-*a* concentration of 56 $\mu\text{g/L}$ was recorded at another arm of the lake, about 3 to 4 km downstream from the site (Figure 2). Numerical simulation studies showed that the hydrodynamic patterns linked to the wind effects and complex lake morphology could promote the transport of nutrient and algal biomass from other areas throughout the lake [17].

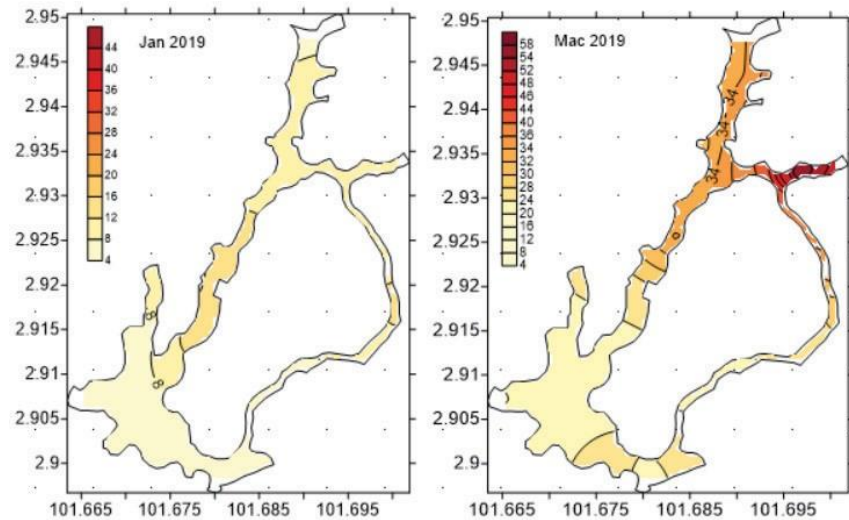


FIGURE 2. Temporal Pattern of Chlorophyll-*a* Concentration ($\mu\text{g/L}$) within Putrajaya Lake in 2019.

During the study, blue-green algae (BGA) was the most dominant phytoplankton group, contributing about 72% of the total phytoplankton density (Figure 3). According to [18], cyanobacterial dominance in Putrajaya Lake was reported to start in 2012. However, the seasonal pattern varied between years, with BGA dominance peaking intermittently with nutrient fluctuations. The main genus and/or species found in this study were *Planktothrix* sp. and *Aphanothece smithii*, different from previous recorded cyanobacterial species. Other studies reported that the occurrence of *Planktothrix* blooms was associated with high TP levels in Lake Kasumigaura [19]. In this study, high TP values exceed the standard limits, which coincide with the dominance of *Planktothrix* sp. A strong positive correlation was observed between BGA density and dissolved oxygen, pH, and turbidity. Certain species from *Planktothrix* taxa were observed to be more tolerant to turbid environments, prefers nutrient-rich waters and can strongly compete for light [4]. In terms of nutrients, BGA was negatively correlated to nitrate. Other studies in Taihu Lake reported that the warmer temperature and elevated nutrient level were related to cyanobacterial dominance, such as *Microcystis* and *Ulothrix* [20].

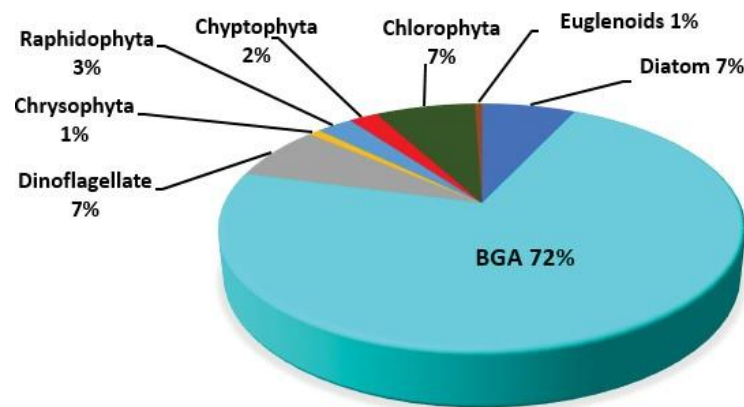


FIGURE 3. Characteristics of the Algal Community during the Study.

In this study, BGA was positively correlated to air and water temperature and negatively correlated to rainfall. A positive correlation between cyanobacterial bloom outbreaks with air temperature and rainfall was reported in Lake George, Florida [21]. A negative correlation between BGA and rainfall is probably due to the increase in rainfall and the associated discharge rates causing a reduction in cyanobacterial biomass [15]. This is consistent with the daily pattern of BGA, where the lowest percentage of BGA was recorded on day 12, consistent with the heaviest rainfall recorded (Figure 4).

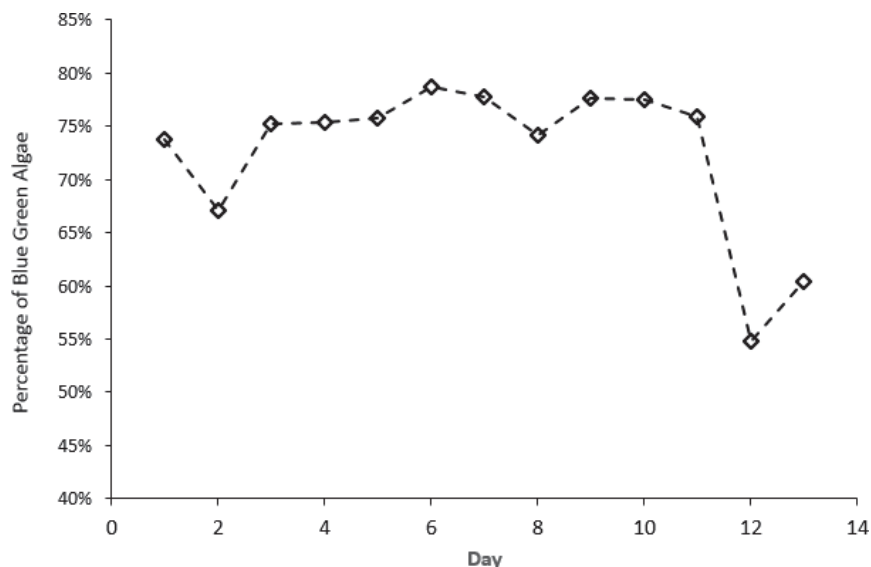


FIGURE 4. Pattern of Blue-Green Algae Dominance Throughout the Study.

The most recommended management measure worldwide to reduce algal bloom incidents is external nutrient reduction [5, 22, 23]. This measure is suitable to be carried at the pond upstream of the gross pollutant traps to remove excess nutrient input in the water that drains from the catchment to the Putrajaya Lake inlet. Wetland plants should be planted in the ponds to uptake excess nutrients. Another measure to reduce nutrient input is to establish constructed wetlands near the lake inlet or along the riparian of the forebay.

Hydrodynamic measures such as artificial mixing by diffuse air bubbling operator can also be introduced to increase oxygen levels in the water column and enhance vertical mixing during the night where wind speed is lowest [5, 22, 23]. Surface aeration can prevent the accumulation of cyanobacterial scum and reduce foul odours, while air-bubble screening can be targeted to control nuisance related to inflow cyanobacteria [22, 23]. Superficial skimming of the algal scum can be used for small areas [22].

CONCLUSIONS

This preliminary study showed the complex relationship influencing algal development and bloom formation. For example, weather conditions such as higher wind speed that usually occurs during rainfall events possibly can induce turbulence and mixing of the water column and affect bloom formation. Although the research was conducted near an inlet, water circulation patterns and mixing dynamics associated with lake morphology may also influence the vertical and horizontal transport of environmental variables and plankton communities and limit the study findings. This study concludes that air temperature and nitrate were essential factors associated with both algal indicators.

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