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RESEARCH ARTICLE

RELATIONSHIP BETWEEN CHLOROPHYLL-A, PH, AND DISSOLVED OXYGEN IN A TROPICAL URBAN LAKE WATERS: A CASE STUDY FROM AIR HITAM LAKE, SAMARINDA CITY, INDONESIA

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ABSTRACT

The relation between chlorophyll-a concentration, pH, and dissolved oxygen in a tropical urban lake is important but relatively unknown. Globally, due to population growth and urban area expansion, it is predicted that the number of constructed urban lakes will also increase. The main objectives of this paper were to observe the general patterns and connections between these parameters in the Air Hitam Lake in Samarinda City, East Kalimantan, Indonesia. The variation of chlorophyll-a, pH, and DO were obtained at five different stations. Eight weekly measurements were conducted between mid-October and mid-December 2022 (n = 40). The linear model relationship between pH and chlorophyll-a in our study resulted in a significant positive correlation (R^2 = 0.16; *p-value* = 0.01). A significant correlation between DO and chlorophyll-a was also identified, with an R^2 = 0.10 and a *p-value* = 0.042. Lastly, a significant positive correlation was also identified between pH and DO (R^2 = 0.48; *p-value* = 6.02E-07). Algal photosynthesis is a key factor responsible for the changes in both pH levels and the presence of dissolved oxygen. In Air Hitam Lake, the substantial amount of algae, as indicated by the concentration of chlorophyll-a, significantly influences the pH of the water and the fluctuations in dissolved oxygen.

KEYWORDS

water pollution management, Borneo, microalgae, eutrophication, lentic

1. INTRODUCTION

Over the past decade, rapid industrial and agricultural growth has resulted in the ample release of nutrients mainly from fertilizers into various water bodies such as oceans, rivers, lakes, reservoirs, and more. This discharge has subsequently led to eutrophication (Bennett et al., 2001; He et al., 2022). Eutrophication, in its accelerated form, has emerged as a critical global environmental concern (Glibert, 2017; Wurtsbaugh et al., 2019). It has manifested in various symptoms, including the proliferation of benthic and planktonic algae.

Chlorophyll-a serves as a significant marker for the presence of algae and is commonly regarded as the primary factor when evaluating eutrophication. The growth of algae is complexly linked to several key environmental water quality aspects, including total phosphorus, total nitrogen, light intensity, water temperature, pH, and DO (Smith, 2016). Variations in the abundance and composition of algae are often associated with these parameters.

The pH is a measure of the acidity or alkalinity of a solution and serves as a crucial chemical water quality indicator (Glass and Silverstein, 1998; Alabaster and Lloyd, 2013). Within natural freshwater environments, the pH level can fluctuate based on geological and environmental influences. In eutrophic waters, the pH can reach relatively high values, potentially reaching 9 or even 10 (Scholz, 2015). Elevated pH levels can potentially impede the photosynthetic activity of algae (Middelboe and Hansen, 2007).

Dissolved oxygen (DO) plays a crucial role as one of the limiting factors affecting the metabolic processes of aquatic organisms. Additionally, it serves as an indicator of the growth conditions and pollution levels in aquatic environments (Coffin et al., 2018; Yang et al., 2020). In the context of eutrophic waters, the concentration of DO exhibits daily fluctuations due to the interplay between algal photosynthesis and aquatic respiration (Rixen et al., 2010; Coffin et al., 2018).

Lakes in tropical areas differ from those in subtropical and temperate regions in several ways. They are notable for experiencing high and frequent precipitation, which leads to increased runoff entering the lakes (Alemu et al., 2020). In tropical regions, elevated solar radiation is also a significant factor in the dynamics of these lakes (Santoso et al., 2018). The air temperature in tropical areas remains relatively high throughout the year, influencing the temperature of the lake's surface water and its evaporation rate (Talling, 2001; Alemu et al., 2020; de Farias Mesquita et al., 2020). Water temperature in these tropical lakes is a critical factor that affects various metabolic processes within the aquatic ecosystem, including photosynthesis in aquatic plants and algae (Lewis, 2010).

Urban lakes exhibit several distinctions when compared to natural lakes. They are typically smaller and shallower, with a majority of them being man-made or constructed lakes (Schueler dan Simpson, 2001). These constructed lakes often feature geometric shapes and serve multiple purposes, including flood control, water storage, and recreational activities (Naselli-Flores, 2008). One notable difference arises from the fact that urban stormwater runoff, which originates from impermeable surfaces and can come into contact with human organic waste, tends to accumulate higher nutrient levels compared to runoff in less developed

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areas (Miller et al., 2014). The extent of this issue varies across different cities worldwide and largely depends on the presence and effectiveness of stormwater and wastewater infrastructure. Many urban areas globally face challenges due to inadequate or absent wastewater infrastructure (Hamdhani et al., 2020). Urban lakes, functioning more as retention reservoirs rather than flow conveyance channels, are particularly sensitive to phosphorus and nitrogen loading from stormwater runoff, more so than rivers or streams (Kakade et al., 2021). Consequently, changes in water quality resulting from this nutrient loading become a concern for lake managers, especially when the urban lake is utilized for recreation or as a source of consumptive water.

Over the past thirty years, numerous studies have been conducted to examine the connections between chlorophyll-a, pH, and DO. These investigations have primarily focused on natural bodies of water, including oceans, natural lakes, and controlled laboratory micro-ecosystems (Zang et al., 2011). However, there has been a notable lack of attention given to the study of constructed urban lakes. Globally, with population growth and urban area expansion, it is predicted that in the future, the number of constructed urban lakes will also increase.

Recognizing the significance of understanding the relationships among chlorophyll-a, pH, and DO as well as the limitations of previous research, the main objectives of this study were to find out the general patterns and connections between these parameters. This research aims to provide valuable insights for water monitoring and early warning systems for managing and mitigating eutrophication. The selection of Air Hitam Lake in the Samarinda City, East Kalimantan, Indonesia as a case study is attributed to its man-made origin. Furthermore, the lake's relatively small and shallow nature makes it a suitable representative for many urban lakes commonly found in tropical regions.

2. METHODOLOGY

2.1 Site Description

Samarinda serves as the capital city of East Kalimantan Province, the most prosperous province in Indonesia, mainly due to its significant revenue generated from oil and gas production. In 2020, the city had a population density of 1,147 people/km^2 (BPS Kota Samarinda, 2020), making it highly urbanized and the most developed part of the province. However, the city faces recurrent flooding issues in lowland areas, influenced by factors such as its topography, climate, soil composition, and the limited capacity of its drainage systems (Suryadi, 2020). To deal with these flooding challenges, local authorities have implemented various flood control measures. One notable solution was the creation of urban lakes designed to capture and store stormwater runoff. Among these urban lakes is Air Hitam Lake, constructed in 2004, which has been employed for flood control and recreational purposes. However, it has been known to experience occasional water quality problems (Hamdhani et al., 2023).

Air Hitam Lake covers a total area of 60,500 m^2 and has an estimated volume of 120,000 m^3, with a perimeter measuring 1,203 m. Its surroundings comprise a mixture of residential and commercial buildings. The lake is bordered by a concrete road, pedestrian walkways, and, on most sides, a 10 to 15-meter-wide buffer zone filled with vegetation, including grasses and trees. The lake's maximum depth varies between 2 to 3 m at its center and is approximately 1 meter-deep near its perimeter. Periodically, the city undertakes dredging operations to maintain the lake's storage capacity for flood control. Notably, the lake lacks an outlet, but it has two concrete inlets that receive runoff from the city, although the exact volume of this inflow remains unmeasured. Additionally, human organic waste from untreated sewage systems may enter the lake, though the specific sewage inputs are unknown but are assumed to fluctuate in response to precipitation and runoff conditions.

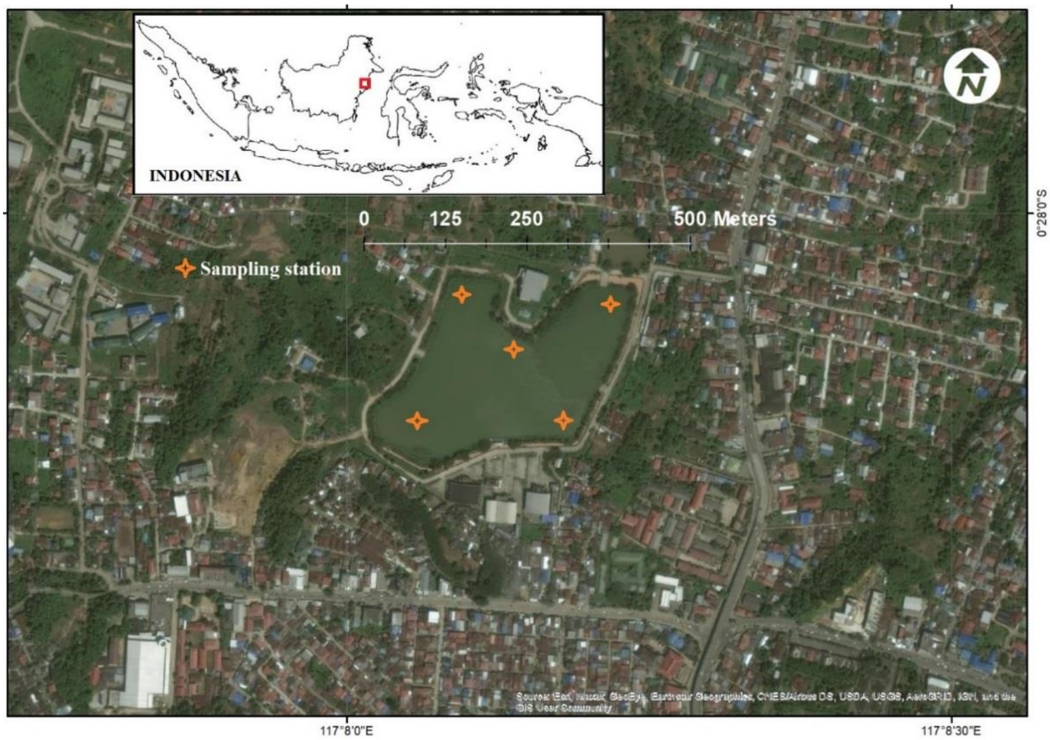

Figure 1: Map showing Air Hitam Lake in Samarinda City, Indonesia with five sampling stations denotes by orange stars.

2.2 Data collection

Chlorophyll-a concentration was measured directly on the study site using the *in vivo* chlorophyll method with a fluorometer, specifically the FluoroSense™. This method has been tested effective for rapid chlorophyll-a monitoring (Hamdhani et al., 2021). This *in situ* approach minimizes the risk of alterations in chlorophyll-a concentration that can occur when samples need to be transported and processed using traditional extraction methods (Hamdhani et al., 2021).

Chlorophyll-a measurements in Air Hitam Lake were obtained at five different stations (as shown on the map in Figure 1) using a calibrated fluorometer. At each of these stations, surface water samples were collected from the upper 20 centimeters of the lake using a 1-liter container. The measurements were conducted directly within the sample container using the fluorometer, following the established protocols outlined in the documentation by Hamdhani et al. (2021). Eight weekly measurements were conducted between mid-October and mid-December 2022 resulting in 40 data points. The sampling period is classified as the "wet season", however a tropical climate with wet and dry season characteristic is less pronounced in Kalimantan/Borneo Island as compared to other islands in Indonesia's archipelago (Cleary, 2011). Consequently, this less distinct seasonal pattern allowed our limited sampling period of three months to represent the year-round tropical climate conditions. To account for potential diurnal variations in the measured chlorophyll-a concentrations, all sampling activities were consistently carried out in the afternoon, specifically between 4:00 and 5:00 p.m. Dissolved oxygen levels were measured using an Apera

Instruments AI480 DO850 probe, while pH levels were determined using an Apera Instruments SX823-B multiprobe.

2.3 Data analysis

We employed linear regression analysis with the statistical program R (version 3.5.1: R Core Team, 2019). This analysis aimed to assess the significance of chlorophyll-a concentration as the independent variable on its impact on pH and DO, each treated as a dependent variable in separate analyses. Additionally, we conducted a correlation analysis to examine the relationship between pH, as the independent variable, and DO, which was treated as the dependent variable.

3. Results

The mean concentration of chlorophyll-a was calculated to be 40.23 µg/L ranged between 18.6 and 116.7 µg/L, this mean concentration is higher than the threshold of 10 µg/L according to the Indonesian Water Quality Standard for drinking water use, but still under the threshold 50 µg/L for aquatic recreation purposes. The mean pH was 9.39, ranged between 8.8 and 10. The mean pH was higher than the range suggested by the Indonesian Water Quality Standard (pH 6-9). The mean of DO was calculated to be 10.11 mg/L. The DO concentration is higher than the minimum threshold of 3 mg/L for freshwater aquaculture purposes according to the Indonesian Water Quality Standard.

Figure 2A and Table 1 show a significant positive linear model relationship between pH and chlorophyll-a. The correlation coefficient of determination was R^2 = 0.16 at *p-value* = 0.01. Every increase of chlorophyll-a concentration as much as 1 µg/L resulted in an average pH increase of 0.0056. Figure 2B and Table 1 show a significant positive linear model relationship between DO and chlorophyll-a as well. The correlation coefficient of determination was R^2 = 0.10 at *p-value* = 0.042. The rate indicated that an increase of chlorophyll-a concentration as much as 1 µg/L resulted in an average DO increase of 0.0506 mg/L.

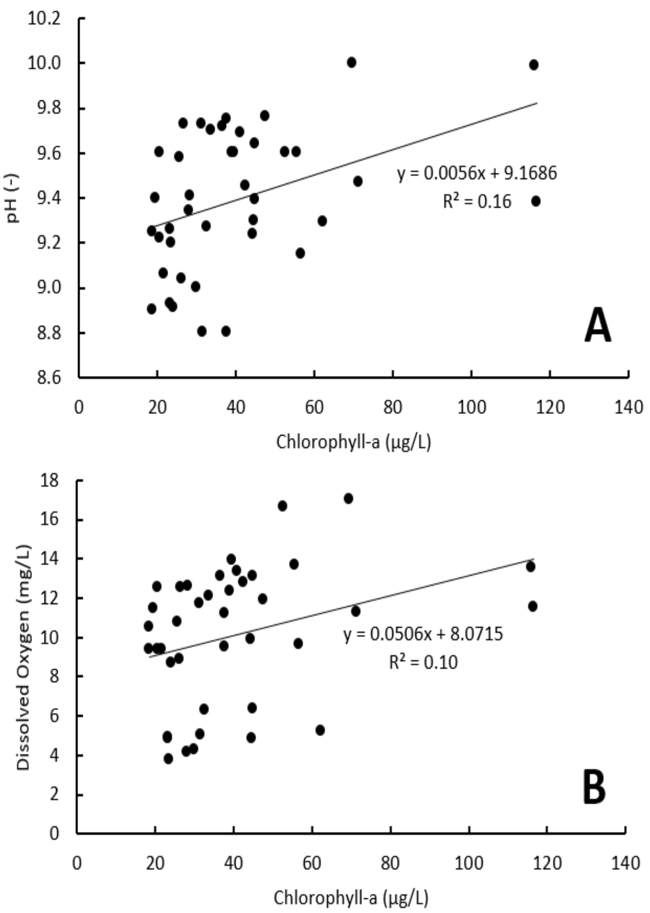

Figure 2: Regression curve for chlorophyll-a and pH (A) and chlorophyll-a and dissolved oxygen (B) in Air Hitam Lake

Figure 3 and Table 1 indicate that there was a significant positive correlation (*p-value* = 6.02E-07) between pH and DO with a correlation coefficient of determination was R^2 = 0.48, meaning that a pH increase of one resulted in an average DO increase of 7.8039 mg/L.

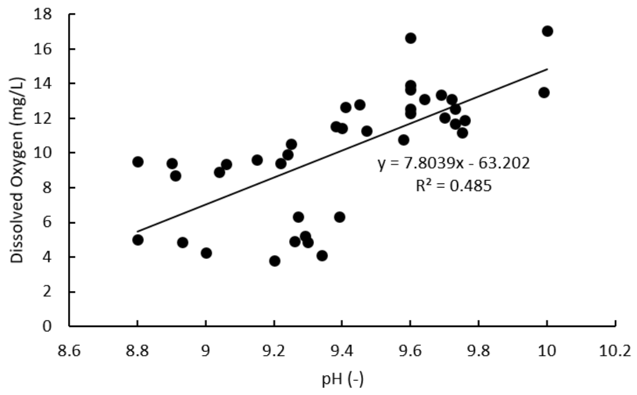

Figure 3: Regression curve for pH and Dissolved Oxygen in Air Hitam Lake

Table 1: Summary of linear model results explaining the coefficient, standard error, and *p-value* of observed pH, dissolved oxygen, and chlorophyll-a

Correlation between Chlorophyll-a and pH			
	Coefficients	*Standard Error*	*P-value*
Intercept	9.1686	0.0955	5.88E-47
Chlorophyll-a	0.0056	0.0021	**0.01**
Regression Statistics			
Multiple R	0.40		
R Square	0.16		
Adjusted R Square	0.14		
Standard Error	0.29		
Observations	40		
Correlation between Chlorophyll-a and Dissolved Oxygen			
	Coefficients	*Standard Error*	*P-value*
Intercept	8.0715	1.1056	9.67E-09
Chlorophyll-a	0.0506	0.0241	**0.04**
Regression Statistics			
Multiple R	0.32		
R Square	0.10		
Adjusted R Square	0.08		
Standard Error	3.37		
Observations	40		
Correlation between pH and Dissolved Oxygen			
	Coefficients	*Standard Error*	*P-value*
Intercept	-63.2022	12.2610	8.18E-06
pH	7.8039	1.3045	**6.02E-07**
Regression Statistics			
Multiple R	0.70		
R Square	0.48		
Adjusted R Square	0.47		
Standard Error	2.55		
Observations	40		

4. Discussion

4.1 pH and Chlorophyll-a

The linear model relationship between pH and chlorophyll-a in our study resulted significant positive correlation between the two factors (R^2 = 0.16; *p-value* = 0.01). A strong association between pH levels and chlorophyll-a content has been observed in various lentic water systems, as reported by Lopez-Archilla et al. (2004) and Zang et al. (2011). This phenomenon can largely be attributed to the rapid proliferation of algae, triggered by the introduction of nutrients through sources like surface runoff and sewage loading. A key nutrient in this process is phosphorus, as emphasized by Schindler (2012) and Dodds and Smith (2016). Phosphorus is derived from both inorganic phosphates released by soil particles in lakes, due to stormwater runoff, and organic phosphates originating from untreated sewage. In Samarinda City, the incomplete development of municipal infrastructure has led to the discharge of untreated sewage into Air Hitam Lake, resulting in elevated nutrient levels.

The pH level is primarily controlled by the presence of carbon dioxide (CO_2), which can react with water, carbonate, and bicarbonate to form intricate yet reversible carbonate systems (Boyd, 2015). In general, the concentration of carbon dioxide in water is influenced by factors such as algal photosynthesis, aquatic respiration, water temperature, and the oxidative decomposition of organic matter (Carroll and Mather, 1992). During algal photosynthesis, carbon dioxide is transformed into organic matter ($C_6H_{12}O_6$) and oxygen. Conversely, aquatic respiration uses organic matter and produces carbon dioxide. As a result of photosynthetic activities, carbon dioxide is rapidly absorbed by algae, shifting the equilibrium towards bicarbonate decomposition and causing an increase in pH value (Boyd, 2015). On the other hand, the increase in carbon dioxide produced by aquatic respiration processes can hinder bicarbonate decomposition, leading to a subsequent decrease in pH value. In other words, high concentrations of chlorophyll-a in aquatic environments can absorb substantial quantities of carbon dioxide through photosynthesis. As a consequence, a positive correlation between the pH value and the concentration of chlorophyll-a should be observed.

In the micro-ecosystem of non-aquaculture lentic waters, Zang et al. (2011) reported that as the hydrological and meteorological conditions were constant and nutrients were sufficiently abundant, the water pH was mainly affected by algal photosynthesis when the mean concentration of chlorophyll-a was higher than 10 μg/L. With an increase in the algal biomass as indicated by chlorophyll-a concentration, the consumption of carbon dioxide caused by photosynthesis has increased and subsequently resulted in an increased value of pH. The mean chlorophyll-a concentration in Air Hitam Lake was 40.23 μg/L, ranged between 18.60 and 116.67 μg/L. According to the trophic state classification for tropical regions proposed by Cunha et al. (2013), this range should be classified as falling within the eutrophic, supereutrophic, and hypereutrophic conditions. In this context, a significant increase in the concentration of chlorophyll-a in Air Hitam Lake is expected to be the primary factor in the regulation of pH by consuming carbon dioxide.

4.2 Dissolved Oxygen and Chlorophyll-a

Our data reveals a significant correlation between DO and chlorophyll-a, with R^2 value of 0.10 and *p-value* of 0.042. This relationship is also a result of the rapid proliferation of algae. The corresponding photosynthetic activities contribute to the substantial production of DO, leading to an increase in DO levels. In general, it can be observed that high phytoplankton activity in water, indicated by a higher concentration of chlorophyll-a, leads to greater oxygen production. Consequently, fluctuations in DO are closely driven by the variations in chlorophyll-a concentration, demonstrating a positive association between the two. Zang et al. (2011) documented that when the mean concentration of chlorophyll-a surpasses 10 mg/L, DO levels are predominantly influenced by algal photosynthesis. When algal biomass increases as indicated by chlorophyll-a concentration, the oxygen production likewise rises, subsequently boosting DO levels.

4.3 pH and Dissolved Oxygen

Our result indicates that there was a significant positive correlation (R^2 = 0.48; *p-value* = 6.02E-07) between pH and DO. This may be the result of complex interactions between algal photosynthetic processes, respiration, and oxidative decomposition of organic matter. Increased phytoplankton activity in water, as indicated by higher levels of chlorophyll-a, leads to an increase in oxygen production. This process is dependent on the presence of carbon dioxide. During algal photosynthesis, carbon dioxide is converted into organic matter and oxygen. As a result of these photosynthetic activities, algae efficiently absorb carbon dioxide, shifting the equilibrium towards bicarbonate decomposition and causing a rise in the pH level.

Given that the sampling was carried out in the afternoon, it is expected that the rate of the photosynthesis process will be at its peak during daylight hours. However, at night when sunlight is absent, a different scenario unfolds as respiration takes place. Consequently, the level of dissolved carbon dioxide increases. The pH of water can be affected by the presence of carbon dioxide in the water since carbon dioxide can react with water to create carbonic acid (H_2CO_3), which is a weak acid. Carbonic acid can ionize in water, releasing hydrogen ions (H^+) and bicarbonate ions (HCO_3^-) in a reversible reaction (Boyd, 2015). The release of hydrogen ions (H^+) from the carbonic acid into the water results in an increase in the concentration of H^+ ions, making the water more acidic and lowering the pH of the water. Therefore, we suggest conducting observations throughout the day and night in this tropical urban lake is essential for a comprehensive understanding of this system.

5. Conclusion

The study highlighted the significant correlation between the concentration of chlorophyll-a and the pH as well as DO levels in the urban lake water. Algal photosynthesis plays a crucial role in driving the fluctuations in both pH and DO. The abundance of algae, represented by the concentration of chlorophyll-a, was notably higher in Air Hitam Lake, exerting strong control over the water's pH and variations in DO. Monitoring levels of chlorophyll-a, pH, and DO in these systems is essential for understanding their overall health and ecological conditions. Our findings also imply that pH and DO levels can serve as indicators of algae abundance, potentially becoming essential parameters for water monitoring and early warning systems aimed at managing and mitigating eutrophication.

Future research should focus on more complex urban lentic systems, especially concerning diurnal changes in tropical urban lakes. This focus is essential since many urban lakes receive significant inflows of stormwater runoff, rendering them vulnerable to organic pollutants and the potential eutrophication they may induce.

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