

Chlorophyll-a variation in response to precipitation in a tropical urban lake

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Abstract

With increasing urbanization, urban lakes are becoming more common and serve as important flood control infrastructure, recreational uses, as well as habitat for a variety of biota. However, given their construction, function, and location, urban lakes are susceptible to disturbances including stormwater runoff from metropolitan catchment areas. For example, nutrient loading from stormwater runoff can cause eutrophication. Chlorophyll-a concentration is an important water quality parameter because it can be used to assess water quality and determine trophic state. Chlorophyll-a is known to be impacted by a number of environmental factors including precipitation and associated runoff. Previous studies indicate that the relationship between precipitation and chlorophyll-a is complex and often site-specific. In this study, we examined the relationship between chlorophyll-a and precipitation in an urban, tropical lake located in East Kalimantan Province, Indonesia. Chlorophyll-a, precipitation, and several basic water quality parameters were sampled at five stations during the 2022 rainy season. The data indicate that chlorophyll-a concentrations are negatively correlated with recent precipitation ($r^2=0.71$, $p<0.05$). This relationship is likely a result of dilution from increased lake volume. Although urban runoff is expected to increase nutrient loading, our monitoring indicates that dilution can mediate this process. Our findings suggest that timing matters when monitoring water quality in tropical, urban lakes. Sampling immediately following heavy precipitation and stormwater runoff can lead to an underestimation of normal chlorophyll-a concentrations. Further studies are necessary to better understand these urban aquatic ecosystems to continue to improve future management efforts.

Keywords: chlorophyll-a, precipitation, lake, lentic, Samarinda, Kalimantan, Indonesia

Introduction

The world is becoming increasingly urbanized resulting in a myriad of effects on ecosystems (Elmqvist et al., 2013). Concomitant with increases in urbanization are increases in the abundance of urban water bodies (Strokal et al., 2021). Urban water bodies, both lentic and lotic, are characterized by higher influence from anthropogenic activities and as a result have altered ecosystems that may require different monitoring standards than natural systems (Schueler dan Simpson, 2001; Naselli-Flores, 2008). Consistent patterns of alterations that occur in urbanized streams/rivers have been identified by Walsh et al. (2005) and defined as the “urban stream syndrome”, whose characteristics include a flashier hydrograph, altered channel morphology and stability, and elevated concentrations of nutrients and contaminations. These urban stream syndrome characteristics have frequently been documented in temperate regions but are also likely to occur in tropical regions and in different types of water bodies, including lakes (Yule et al., 2015; Lee et al., 2019).

Urban lakes differ from natural lakes in a number of ways. For example, they are usually smaller and shallower, and the majority are man-made, also known as constructed lakes (Schueler dan Simpson, 2001). As constructed lakes, their water bodies tend to have geometric shapes and often function as flood control infrastructure, water storage, and/or for recreational uses (Naselli-Flores, 2008). These constructed lakes often have area/drainage area of at least 10:1, meaning that the catchment area strongly influences the lake (Schueler dan Simpson, 2001). The rainfall-discharge variation in the catchment area drives water quality dynamics in corresponding water bodies (Jakeman and Hornberger, 1993), and this relationship is more pronounced in urban lentic systems. Because urban

stormwater runoff typically originates from impervious surfaces and often comes into contact with human organic waste, it can collect larger amount of nutrients than runoff in less developed areas (Miller et al., 2014). Because they function as retention rather than flow conveyance, urban lakes are typically more sensitive to nitrogen and phosphorus loading from stormwater runoff than rivers or streams (Kakade et al., 2021). Therefore, water quality changes resulting from this nutrient loading can be a concern for managers, especially when the urban lake is used for recreation or water storage for consumptive use. Increases in urban development can result in nutrient loading that promotes rapid algal growth, destabilizes ecological balance, and impairs lake water quality (Qin et al., 2013; Alprol et al., 2021), which could not only exceed thresholds for aquatic biota but might also exceed health standards for humans.

Phytoplankton, also known as microalgae, are similar to terrestrial plants in that they contain chlorophyll-a as an essential photosynthetic pigment and require sunlight and carbon dioxide in order to live and grow. The excessive growth of phytoplankton due to nutrient enrichment can lead to eutrophication, which is the condition of imbalanced primary and secondary productivity and a faster rate of succession from natural to higher seral stage (Khan and Ansari, 2005). Eutrophication can lead to harmful algal blooms, dead zones, and fish kills (Wurtsbaugh et al., 2019). The concentration of chlorophyll-a in water helps quantify phytoplankton levels, which can be used as an indicator to assess trophic status and water quality (Devercelli and Peruchet, 2008; Cunha et al., 2013).

In recent years, many studies observed the spatial and temporal distribution of chlorophyll-a and its relation with multiple environmental factors (Filazzola et al., 2020). Precipitation was predicted as an important environmental factor that affects chlorophyll-a

concentration in lake water, among other environmental factors such as nitrogen and phosphorus concentrations, geographic location, and water temperature (Filazzola et al., 2020; Huang et al., 2022) However, little is known how precipitation (within a short temporal period) affects phytoplankton dynamics. Previously published studies typically report the relationship between phytoplankton concentrations and precipitation at monthly or annual scales (Wu et al., 2021; Huang et al., 2022), thus the finer temporal resolution often important to managers is not well understood. Furthermore, these studies typically use data generated from earth system modeling rather than on-the-ground measurements, limiting applicability to smaller, more dynamic bodies of water such as urban lakes.

In this study, our objective was to identify the fine-scale temporal relationship between chlorophyll-a concentration and precipitation based on *in situ* measurements in a tropical, urban lake. Two competing predictions were tested: precipitation and subsequent stormwater runoff 1) increase chlorophyll-a concentration through nutrient addition, or 2) decrease chlorophyll-a concentration through dilution.

Methodology

Site Description

Samarinda is the capital city of East Kalimantan Province, which is the wealthiest province in Indonesia due to revenue from oil and gas production. With a 2020 population density of 1,147 people/km² (BPS Kota Samarinda, 2020), Samarinda is highly urbanized and is the most developed part of the province. This increasing urbanization combined with other factors such as topography, climate, soil type, and limited runoff/drainage infrastructure, this city routinely suffers from flooding in lowland areas (Suryadi, 2020). One flood control measure implemented by city managers and administrators was the

construction of urban lakes to catch and store stormwater runoff. Constructed in 2004, Air Hitam Lake has been used for both flood control as well as for recreation, is known to have occasional water quality issues (Hamdhani et al., 2023), and is the subject of our study. This urban lake has a total area of 60,500 m² and an estimated volume of 120,000 m³ with a perimeter of 1,203 m. The surrounding area of the lake consists of a mixture of residential and commercial buildings. Surrounding the lake are a concrete road, pedestrian walkway, and on most sides a 10-15m wide, vegetation buffer zone with grasses and trees. The maximum depth of the lake varies between 2-3 m in the middle, but is approximately 1 m deep near the perimeter. The city regularly dredges the lake to maintain storage capacity for flood control. This lake has no outlet, but there are two concrete inlets that convey runoff from the city, however, this inflow volume is unmeasured. Human organic waste from untreated sewage systems can also drain into the lake. Sewage inputs are unknown, but are assumed to vary in relation to precipitation and runoff.

Data collection

Chlorophyll-a concentration was measured *in situ* through the *in vivo* chlorophyll method using a fluorometer (FluoroSense™). This method has been tested effective for rapid chlorophyll-a monitoring (Hamdhani et al., 2021). This *in situ* application reduces potential chlorophyll-a concentration changes associated with the required time to transport and prepare the sample when using traditional extraction methods (Hamdhani et al., 2021).

Using the calibrated fluorometer, chlorophyll-a measurements were taken at five stations in the Air Hitam Lake (Fig. 1). At each station, surface water samples were collected from the top 20cm of the lake using a 1L container. Measurements were taken using the fluorometer in the sample container following protocols documented in

Hamdhani et al. (2021). Lake sampling occurred from October to December 2022 during the rainy season. Two measurements were taken per month. Due to potential diurnal variation in measured chlorophyll-a concentrations, sampling occurred consistently from 4:00 to 5:00pm in the afternoon. Precipitation was recorded using an electronic tipping bucket (Model WH0531) that was placed near the Air Hitam Lake, following standard rain-gauge installation protocols (Brooks et al., 1997). Concurrent with chlorophyll-a and precipitation measurements, several basic water quality parameters were also quantified: turbidity (SPER Scientific turbidity meter model 860040), dissolved oxygen (DO) (Apera Instruments AI480 DO850 probe), water temperature, pH, electric conductivity (EC), and total dissolved solids (TDS) (Apera Instruments SX823-B multiprobe). Phosphate was measured by collecting 750 ml water from each station, and transported immediately to the Water Quality Laboratory of the Faculty of Fisheries and Marine Science, Mulawarman University. Ascorbic acid method using a spectrophotometer (US-EPA., 1978) was applied to quantify phosphate (PO_4) concentration.

Data analysis

We measured the chlorophyll-a concentration and examine the relationship with total precipitation within the four days prior to sampling. The four-day precipitation accumulation was chosen based on two months of pre-monitoring using an installed meter scale for measuring lake depth. The result indicated that 5 or more days following precipitation, the water surface level of Air Hitam Lake returned to its normal surface level. Therefore, the 4-day period encompasses a stronger relationship with runoff. To test our hypotheses, we used linear regression analysis using statistical program R (version 3.5.1: R Core Team, 2019) to determine the trend and significance of precipitation (independent

variable) in affecting chlorophyll-a concentration (dependent variable). Because turbidity and nutrient (phosphate) concentrations also impact chlorophyll-a levels, we also ran regressions with those as well.

Results and discussion

Basic water quality

Our water quality data presented in Table 1 showed that pH was high, ranging from 8.80-9.76, showing slightly alkaline conditions throughout our study period. This pH level is most likely impacted by the discharge of domestic wastewater which generally contains surfactant found in detergents or cleaning products (Bajpai 2007; Siyal et al., 2020). In Samarinda City, the discharged domestic wastewater into the city drainage system was untreated, consequently ending up in the nearby water bodies including the Air Hitam Lake. A similar tendency of high pH has been reported in urban water bodies receiving significant concentrations of domestic wastewater (Ustaoğlu et al., 2017; Al-Ani et al., 2022). The pH level in the lake was slightly above the optimal range of 6.5 to 8.5 to support sensitive aquatic life as suggested by the US-EPA (2013). However, lower pH values indicating acidity are typically more detrimental to aquatic biota than high pH values like those found in Air Hitam Lake. Zang et al. (2011) reported that the relationship between pH and chlorophyll-a was complex and sometimes inconclusive, in certain conditions such as at high chlorophyll-a concentration ($>10\mu\text{g/L}$), the correlation between the two was significantly positive.

Measured dissolved oxygen levels fluctuated widely between 3.79 to 16.63 mg/L. Persistent cloudy weather that occurred in the beginning of the study (including when the first two samples were taken) could be responsible for relatively low dissolved oxygen

levels in the beginning compared to later samples. The weather on the other sampling days was relatively sunny, likely increasing photosynthesis rates and subsequent dissolved oxygen. Dissolved oxygen concentrations below 3 mg/L are of concern for most aquatic organisms (US-EPA, 2022). Photosynthetic activities by microalgae led to the production of large amounts of oxygen causing an increase in dissolved oxygen in the water. Under non-aquaculture waters with a chlorophyll-a concentration greater than 10 µg/L, Zang et al. (2011) reported a significant positive correlation between chlorophyll-a and dissolved oxygen. In our studied lake, we found that the average concentration of dissolved oxygen was mostly high; this might have resulted from corresponding photosynthetic activities, indicated by high chlorophyll-a concentrations. Although we did not sample at night, we expect that this algal driven dissolved oxygen levels would decrease dramatically when photosynthesis stopped and respiration began.

Water temperature ranged between 29.2 and 32.7°C, indicating that the lake water should be capable support tropical, aquatic organisms, including microalgae. Singh and Singh (2015) observed that 20 to 30°C is the optimum temperature for general microalgae species growth. In a temperate lake, Elliott et al. (2006) reported that elevated temperature contributed to the increase of phytoplankton biomass, however, nutrient loading was identified as the most prominent factor. Lake surface water temperature can be influenced by precipitation rate. Yang et al. (2021) reported that rate of precipitation was positively correlated with surface water temperature in an urban lake that drained majority impervious surfaces.

Total dissolved solids and electrical conductivity tolerance limits are usually not given for fish and other aquatic organisms, although they can be used as a water pollution

indicator (Das et al., 2006; Pal et al., 2015). The values of our total dissolved solids and electrical conductivity measurements were typically lower than values reported in other urban tropical lakes (Sri Lanka: Weerasinghe and Handapangoda, 2019) but were very similar to those reported in Malaysia (Hossain and Mahmud, 2019).

Turbidity ranged between 29.1 and 79.3 NTU. The relationship between turbidity and chlorophyll-a concentration is complex. Decreased water clarity can limit sunlight penetration, which can result in photosynthesis limitations. Consequently, when microalgae are unable to carry out photosynthesis, chlorophyll-a concentrations can decrease (Irigoien and Castel, 1997). However, the concentration of chlorophyll-a in a lake can also impact turbidity. When the eutrophication level is high, this algal growth can contribute to increased turbidity, which can result in reduced water clarity (measured by secchi disk) (Gulati and Van Donk, 2002). It is important to understand that other factors can also influence the concentration of chlorophyll-a in water, such as nutrient availability and water temperature (Carrick et al., 1994). Therefore, while there may be a correlation between turbidity and chlorophyll-a, it is not always direct or consistent. The specific threshold for acceptable turbidity levels can vary depending on the intended use of the water body, such as drinking water, recreational activities, or aquatic biota habitat. In general, lower levels of turbidity are typically preferred as they indicate clearer and cleaner water. In Indonesia, there are no national turbidity limits for water quality, but turbidity is regulated in other countries, for example, Australia, Canada, and USA (Collins et al., 2011). Several published studies suggest that considering allowable increases of turbidity in clearwater systems for fish and wildlife, no more than 25 NTU above natural in streams and no more than 5 NTU

above natural in lakes (Lloyd, 1987; Collins et al., 2011). Turbidity levels in Air Hitam Lake were consistently higher than these levels.

Anthropogenic driven nutrient enrichment of lakes has profound impacts on phytoplankton blooms. In a hypereutrophic lake in Turkey (Çelik, 2006) reported that chlorophyll-a showed significant positive correlations with phosphate concentrations during rainy seasons. Similarly, in a Swedish lake warming period, there was a concurrent increase in both phosphate and chlorophyll-a levels (Pettersson et al., 2003). Phosphate concentration in Air Hitam Lake ranged between 0.052 and 0.246 mg/L. According to Indonesia water quality monitoring regulation (PP RI No. 2/2021), concentration of 0.1 mg/L phosphate is the upper threshold to conduct aquaculture in lentic system.

Chlorophyll-a is one of the essential component in determining lake trophic status. The trophic state of aquatic ecosystems provides crucial information, as it indicates the relative health of the water body including the impact of human activity on water quality and the ecological processes of water bodies, including lakes, and reservoirs. Trophic state indices are useful in understanding phytoplankton development, which are indicated by chlorophyll-a concentration and are typically governed by the availability of nutrients and light (Carlson, 1977). Moreover, Mehner et al. (2005) reported that level of chlorophyll-a concentration is an important factor to determine fish community composition, in addition to maximum and mean depth and volume of German lakes. In tropical regions, a concentration of 10.1 µg/L and above indicates that lake or reservoir is in eutrophic state (Cunha et al., 2013). In our sampling of Air Hitam Lake, the chlorophyll-a concentration ranged between 18.6 and 116.67 µg/L indicating that it was consistently eutrophic.

Chlorophyll-a response

According to the result, chlorophyll-a in the water showed a significant negative correlation with the total precipitation ($r^2=0.71$, $p=0.035$) (Fig. 3A), meaning that the increase in the total precipitation resulted in a chlorophyll-a concentration decrease. We posit that mechanism at play here is dilution. This result is in line with the relationship between chlorophyll-a and precipitation reported by Jeong et al. (2011), who observed that summer rainfall had suppressed the high concentration of chlorophyll-a in a regulated river. However, Huang et al. (2022) reported the opposite in Chinese lakes: chlorophyll-a concentration in water was positively correlated with monthly precipitation. Positive relationships between precipitation and chlorophyll-a are assumed to be driven by the scouring effect of runoff, which transports nutrients from soils (mainly phosphorus) to lakes (Carpenter et al., 1998; Ekholm et al., 2012). In fact, mineral iron in the soil may also play an indirect effect on chlorophyll-a concentration by regulating nutrient contents such as phosphorus in the lake water (Tang et al., 2019). Interestingly, we observed that increases in total precipitation resulted in lower phosphate concentration (Fig. 2). This relationship between total precipitation and phosphate concentration helps explain why chlorophyll-a concentration responded negatively toward total precipitation (Fig. 3A) as phosphate concentration is typically positively correlated with chlorophyll-a production as seen in this study (Fig. 3C), although the regression was not significant ($r^2=0.59$, $p=0.072$). Tang et al. (2019) reported that intense rainfall can decrease the time water stays in a particular water body and increase water movement, which can lead to a decrease in the concentration of phosphorus in the water.

In the area surrounding Air Hitam Lake, there are no specific activities, other than wastewater discharge, that potentially contribute to the addition of high nutrient contents in

runoff (i.e. no industrial activities, urban agriculture, city slaughterhouse, etc.). Direct stormwater runoff to the lake potentially discharge larger amounts of nutrients from soils and eventually could elevate algae growth (Huang et al., 2022). Our result suggests that inflows from the inlets and direct stormwater runoff post four-day precipitation carried too little nutrients to increase the chlorophyll-a concentration in that time period. Municipal infrastructure in Samarinda City is not fully developed, and many stretches of drainage systems, for runoff and sewage, are not lined. As a result, infiltration rates are expected to be higher compared to concrete lined or piped conveyance systems. Consequently, under normal conditions, very little if any sewage discharges into Air Hitam Lake. However, during rainy periods, we observed that sewage inflows into the lake typically increased with heavy runoff. Despite increases in sewage input, we did not observe predictable, corresponding changes in measured nutrient concentrations (Fig. 2). Similar to chlorophyll-a concentrations, we suspect this was also due to dilution.

Turbidity can create a shadowing effect that can reduce photosynthesis and retard algal growth as well as chlorophyll-a concentration (Wang, 1974; Park and Kang, 2006), so we also tested the relationship between turbidity and chlorophyll-a concentration (Table 1 and Fig. 3B). Interestingly, it resulted a positive correlation between the two variables ($r=0.79$, $p=0.063$), however, the correlation was not significant. Using an identical probe, Hamdhani et al. (2021) observe similar positive trend between turbidity and chlorophyll-a concentration. Moreover, Fig. 2 shows that the accumulated rainfall had a negative trend toward turbidity, indicating that stormwater runoff carried relatively little soil (silt) particles. In this case, the precipitation runoff increased the water dilution and likely suppressing turbidity levels, similar to phosphate and chlorophyll-a concentration.

Overall, precipitation was the only significant predictor for chlorophyll-a (Table 2). The dilution from precipitation runoff likely plays an important role in Air Hitam Lake and other tropical, urban lakes, demonstrating that variations in chlorophyll-a concentration were likely affected more by dilution than by other factors. For example, the highest average of chlorophyll-a, turbidity, and phosphate levels were observed when there was zero accumulated precipitation (Figure 2). The roles of precipitation to improve water quality by diluting substance concentration in lentic systems have also been reported in other studies (Moses et al., 2011; Wu et al., 2017; Han and Bu, 2023). Finally, our findings indicate that in tropical, urban lakes, intense precipitation and resulting stormwater runoff can moderate eutrophication. This knowledge also can help managers appropriately time water quality measurements to better reflect the conditions of tropical, urban lakes.

Conclusion

In this study, the short-term relation between chlorophyll-a and the total precipitation was investigated. In the tropical urban constructed lake, we found that recent, total precipitation resulted in a significant negative correlation with the concentration of the chlorophyll-a. Our investigation indicated that although runoff increases connectivity between sewage discharge and Air Hitam Lake, the resulting nutrient loading and silt loading was relatively small. Furthermore, our findings suggest that total precipitation elevated lake water dilution, thus decreasing chlorophyll-a concentration.

Our data indicates that monitoring of chlorophyll-a in urban lakes following recent precipitation and runoff likely underestimates the normal chlorophyll-a concentration present in the system. This underestimation has implications for managers who monitor lakes for eutrophication in accordance with ecological and recreational goals and

guidelines. Although the trends observed in Air Hitam Lake appear to mirror those from other tropical urban lakes, additional research can help fine tune our understanding of these relationships. Additional research should examine other environmental factors under a variety of conditions such as longer-term scenarios that might encompass any delayed effects from runoff as well as different lake sizes and types of lake construction.

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References

- Al-Ani, R. R., Hassan, F. M., & Al-Obaidy, A. H. M. J. (2022). Environmental evaluation of surfactant: case study in sediment of Tigris River, Iraq. *River Deltas Research: Recent Advances*, 85.
- Alprol, A. E., Heneash, A. M., Soliman, A. M., Ashour, M., Alsanie, W. F., Gaber, A., & Mansour, A. T. (2021). Assessment of water quality, eutrophication, and zooplankton community in Lake Burullus, Egypt. *Diversity*, 13(6), 268.
- Bajpai, D. (2007). Laundry detergents: an overview. *Journal of oleo science*, 56(7), 327-340.
- BPS Kota Samarinda (2020). 2020 Population Census Results. Retrieved February 26, 2023, from <https://samarindakota.bps.go.id/pressrelease/2021/01/26/101/hasil-sensus-penduduk-2020.html>
- Brooks, K. N., Ffolliott, P. F., Gregersen, H. M., & DeBano, L. F. (1997). *Hydrology and the management of watersheds*. Iowa State University Press.

- 339 Carlson, R. E. (1977). A trophic state index for lakes 1. *Limnology and*
 340 *oceanography*, 22(2), 361-369.
- 341 Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith,
 342 V. H. (1998). Nonpoint pollution of surface waters with phosphorus and
 343 nitrogen. *Ecological applications*, 8(3), 559-568.
- 344 Carrick, H. J., Worth, D., & Marshall, M. L. (1994). The influence of water circulation on
 345 chlorophyll-turbidity relationships in Lake Okeechobee as determined by remote
 346 sensing. *Journal of Plankton Research*, 16(9), 1117-1135.
- 347 Çelik, K. (2006). Spatial and seasonal variations in chlorophyll-nutrient relationships in the
 348 shallow hypertrophic Lake Manyas, Turkey. *Environmental monitoring and*
 349 *assessment*, 117, 261-269.
- 350 Collins, A. L., Naden, P. S., Sear, D. A., Jones, J. I., Foster, I. D., & Morrow, K. J. H. P.
 351 (2011). Sediment targets for informing river catchment management: international
 352 experience and prospects. *Hydrological Processes*, 25(13), 2112-2129.
- 353 Cunha, D. G. F., do Carmo Calijuri, M., & Lamparelli, M. C. (2013). A trophic state index
 354 for tropical/subtropical reservoirs (TSItsrs). *Ecological Engineering*, 60, 126-134
- 355 Das, R., Samal, N. R., Roy, P. K., & Mitra, D. (2006). Role of electrical conductivity as an
 356 indicator of pollution in shallow lakes. *Asian Journal of Water, Environment and*
 357 *Pollution*, 3(1), 143-146.
- 358 Devercelli, M., & Peruchet, E. (2008). Trends in chlorophyll-a concentration in urban water
 359 bodies within different man-used basins. In *Annales de Limnologie-International*
 360 *Journal of Limnology* (Vol. 44, No. 1, pp. 75-84). EDP Sciences.

- Ekholm, P., & Lehtoranta, J. (2012). Does control of soil erosion inhibit aquatic eutrophication?. *Journal of environmental management*, 93(1), 140-146.
- Elliott, J. A., Jones, I. D., & Thackeray, S. J. (2006). Testing the sensitivity of phytoplankton communities to changes in water temperature and nutrient load, in a temperate lake. *Hydrobiologia*, 559, 401-411.
- Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., ... & Wilkinson, C. (2013). *Urbanization, biodiversity and ecosystem services: challenges and opportunities: a global assessment* (p. 755). Springer Nature.
- Filazzola, A., Mahdian, O., Shuvo, A., Ewins, C., Moslenko, L., Sadid, T., ... & Sharma, S. (2020). A database of chlorophyll and water chemistry in freshwater lakes. *Scientific data*, 7(1), 1-10.
- Gulati, R. D., & Van Donk, E. (2002). Lakes in the Netherlands, their origin, eutrophication and restoration: state-of-the-art review. *Ecological restoration of aquatic and semi-aquatic ecosystems in the Netherlands (NW Europe)*, 73-106.
- Hamdhani, H., Eppehimer, D. E., Walker, D., & Bogan, M. T. (2021). Performance of a handheld chlorophyll-a fluorometer: Potential use for rapid algae monitoring. *Water*, 13(10), 1409.
- Hamdhani, H., Sharaha, M., Fadhilla, F. N., & Harijono, G. V. (2023). Aplikasi perhitungan tingkat kesuburan perairan dengan Metode Carlson pada perairan urban Danau Polder Air Hitam di Kota Samarinda: Application of Carlson trophic state index on trophic state determination of urban Polder Air Hitam Lake in Samarinda City. *Jurnal Ilmu Perikanan Tropis Nusantara (Nusantara Tropical Fisheries Science Journal)*, 2(1), 73-78. <https://doi.org/10.30872/jipt.v2i1.494>

- 384 Han, Y., & Bu, H. (2023). The impact of climate change on the water quality of
 385 Baiyangdian Lake (China) in the past 30 years (1991–2020). *Science of The Total*
 386 *Environment*, 870, 161957.
- 387 Hossain, N., & Mahmud, L. (2019). Experimental investigation of water quality and
 388 inorganic solids in Malaysian urban Lake, Taman Tasik Medan Idaman. *Lakes &*
 389 *Reservoirs: Research & Management*, 24(2), 107-114.
- 390 Huang, H., Wang, W., Lv, J., Liu, Q., Liu, X., Xie, S., ... & Feng, J. (2022). Relationship
 391 between chlorophyll a and environmental factors in lakes based on the random forest
 392 algorithm. *Water*, 14(19), 3128.
- 393 Irigoien, X., & Castel, J. (1997). Light limitation and distribution of chlorophyll pigments
 394 in a highly turbid estuary: the Gironde (SW France). *Estuarine, Coastal and Shelf*
 395 *Science*, 44(4), 507-517.
- 396 Jakeman, A. J., & Hornberger, G. M. (1993). How much complexity is warranted in a
 397 rainfall-runoff model?. *Water resources research*, 29(8), 2637-2649.
- 398 Jeong, K. S., Kim, D. K., Shin, H. S., Yoon, J. D., Kim, H. W., & Joo, G. J. (2011). Impact
 399 of summer rainfall on the seasonal water quality variation (chlorophyll a) in the
 400 regulated Nakdong River. *KSCE Journal of Civil Engineering*, 15, 983-994.
- 401 Kakade, A., Salama, E. S., Han, H., Zheng, Y., Kulshrestha, S., Jalalah, M., ... & Li, X.
 402 (2021). World eutrophic pollution of lake and river: Biotreatment potential and future
 403 perspectives. *Environmental Technology & Innovation*, 23, 101604.
- 404 Khan, F. A., & Ansari, A. A. (2005). Eutrophication: an ecological vision. *The botanical*
 405 *review*, 71(4), 449-482.

- 406 Lee, J. M., Gan, J. Y., & Yule, C. M. (2019). The ecology of littoral zone Chironomidae in
 407 four artificial, urban, tropical Malaysian lakes. *Urban Ecosystems*, 22(1), 149-159.
- 408 Lloyd, D. S. (1987). Turbidity as a water quality standard for salmonid habitats in
 409 Alaska. *North American journal of fisheries management*, 7(1), 34-45.
- 410 Mehner, T., Diekmann, M., Brämick, U., & Lemcke, R. (2005). Composition of fish
 411 communities in German lakes as related to lake morphology, trophic state, shore
 412 structure and human-use intensity. *Freshwater Biology*, 50(1), 70-85.
- 413 Miller, J. D., Kim, H., Kjeldsen, T. R., Packman, J., Grebby, S., & Dearden, R. (2014).
 414 Assessing the impact of urbanization on storm runoff in a peri-urban catchment using
 415 historical change in impervious cover. *Journal of Hydrology*, 515, 59-70.
- 416 Moses, S. A., Janaki, L., Joseph, S., Justus, J., & Vimala, S. R. (2011). Influence of lake
 417 morphology on water quality. *Environmental monitoring and assessment*, 182, 443-
 418 454.
- 419 Naselli-Flores, L. (2008). Urban lakes: ecosystems at risk, worthy of the best care.
 420 In *Proceedings of Taal2007: the 12th world lake conference* (Vol. 1333, p. 1337).
- 421 Pal, M., Samal, N. R., Roy, P. K., & Roy, M. B. (2015). Electrical conductivity of lake
 422 water as environmental monitoring—A case study of Rudrasagar Lake. *Journal of*
 423 *Environmental Science, Toxicology and Food Technology*, 9(3), 66-71.
- 424 Park, C. G., & Kang, M. A. (2006). Impact assessment of turbidity water caused clays on
 425 algae growth. *The Journal of Engineering Geology*, 16(4), 403-409.
- 426 Pettersson, K., Grust, K., Weyhenmeyer, G., & Blenckner, T. (2003). Seasonality of
 427 chlorophyll and nutrients in Lake Erken—effects of weather
 428 conditions. *Hydrobiologia*, 506, 75-81.

- 429 Qin, B., Gao, G., Zhu, G., Zhang, Y., Song, Y., Tang, X., ... & Deng, J. (2013). Lake
430 eutrophication and its ecosystem response. *Chinese Science Bulletin*, 58, 961-970.
- 431 R Core Team. (2019). R: A language and environment for statistical computing. R
432 Foundation for Statistical Computing, Vienna, Austria. [http://www. R-project. org/](http://www.R-project.org/).
- 433 Schueler, T., & Simpson, J. (2001). Introduction: Why urban lakes are different. *Watershed*
434 *Protection Techniques*, 3(4), 747.
- 435 Singh, S. P., & Singh, P. (2015). Effect of temperature and light on the growth of algae
436 species: A review. *Renewable and sustainable energy reviews*, 50, 431-444.
- 437 Siyal, A. A., Shamsuddin, M. R., Low, A., & Rabat, N. E. (2020). A review on recent
438 developments in the adsorption of surfactants from wastewater. *Journal of*
439 *environmental management*, 254, 109797.
- 440 Stokal, M., Bai, Z., Franssen, W., Hofstra, N., Koelmans, A. A., Ludwig, F., ... & Kroeze,
441 C. (2021). Urbanization: an increasing source of multiple pollutants to rivers in the
442 21st century. *npj Urban sustainability*, 1(1), 24.
- 443 Suryadi, N. (2020). Peran Pemerintah Dalam Menanggulangi Banjir Di Kota
444 Samarinda. *EJournal Ilmu Pemerintahan*, 2, 425-436.
- 445 Tang, Q., Peng, L., Yang, Y., Lin, Q., Qian, S. S., & Han, B. P. (2019). Total phosphorus-
446 precipitation and Chlorophyll a-phosphorus relationships of lakes and reservoirs
447 mediated by soil iron at regional scale. *Water research*, 154, 136-143.
- 448 US-EPA. (1978). Method 365.3: Phosphorus, all forms (colorimetric, ascorbic acid, two
449 reagent). *US-EPA*.

- 450 US-EPA. (2013, November 21). Indicators: Acidification. US EPA. Retrieved April 1,
 451 2023, from [https://www.epa.gov/national-aquatic-resource-surveys/indicators-](https://www.epa.gov/national-aquatic-resource-surveys/indicators-acidification)
 452 acidification
- 453 US-EPA. (2022, June 16). Indicators: Dissolved Oxygen. US EPA. Retrieved April 7,
 454 2023, from [https://www.epa.gov/national-aquatic-resource-surveys/indicators-](https://www.epa.gov/national-aquatic-resource-surveys/indicators-dissolved-oxygen)
 455 dissolved-oxygen
- 456 Ustaoglu, F., Tepe, Y., Aydın, H., & Akbaş, A. (2017). Investigation of water quality and
 457 pollution level of lower Melet River, Ordu, Turkey. *Alinteri Journal of Agriculture*
 458 *Science*, 32(1), 69-79.
- 459 Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., & Morgan,
 460 R. P. (2005). The urban stream syndrome: current knowledge and the search for a
 461 cure. *Journal of the North American Benthological Society*, 24(3), 706-723.
- 462 Wang, W. (1974). Effect of turbidity on algal growth. *Circular no. 121*.
- 463 Weerasinghe, V. P. A., & Handapangoda, K. (2019). Surface water quality analysis of an
 464 urban lake; East Beira, Colombo, Sri Lanka. *Environmental Nanotechnology,*
 465 *Monitoring & Management*, 12, 100249.
- 466 Wu, Z., Zhang, D., Cai, Y., Wang, X., Zhang, L., & Chen, Y. (2017). Water quality
 467 assessment based on the water quality index method in Lake Poyang: The largest
 468 freshwater lake in China. *Scientific reports*, 7(1), 17999.
- 469 Wu, D. H., Jia, G. H., & Wu, H. Y. (2021). Chlorophyll-a concentration variation
 470 characteristics of the algae-dominant and macrophyte-dominant areas in lake taihu
 471 and its driving factors, 2007–2019. *J. Lake Sci*, 33(5), 1364-1375.

- 472 Wurtsbaugh, W. A., Paerl, H. W., & Dodds, W. K. (2019). Nutrients, eutrophication and
473 harmful algal blooms along the freshwater to marine continuum. *Wiley*
474 *Interdisciplinary Reviews: Water*, 6(5), e1373.
- 475 Yang, K., Zhang, Y., Luo, Y., & Shang, C. (2021). Precipitation events impact on urban
476 lake surface water temperature under the perspective of macroscopic
477 scale. *Environmental Science and Pollution Research*, 28, 16767-16780.
- 478 Yule, C. M., Gan, J. Y., Jinggut, T., & Lee, K. V. (2015). Urbanization affects food webs
479 and leaf-litter decomposition in a tropical stream in Malaysia. *Freshwater*
480 *Science*, 34(2), 702-715.
- 481 Zang, C., Huang, S., Wu, M., Du, S., Scholz, M., Gao, F., ... & Dong, Y. (2011).
482 Comparison of relationships between pH, dissolved oxygen and chlorophyll a for
483 aquaculture and non-aquaculture waters. *Water, Air, & Soil Pollution*, 219, 157-174.
484

Table 1 Water quality data from Air Hitam Lake from sampling on October 24, 2022 to December 12, 2022. Mean, maximum, and minimum values are reported.

Parameters		Date					
		24-Oct	31-Oct	7-Nov	21-Nov	5-Dec	12-Dec
pH	Mean	9.05	9.30	9.31	9.17	9.57	9.62
	Min	8.80	9.26	9.04	8.90	9.15	9.45
	Max	9.34	9.39	9.47	9.40	9.76	9.75
Dissolved Oxygen (mg/L)	Mean	4.41	5.53	10.85	10.03	11.80	13.48
	Min	3.79	4.85	8.90	9.36	9.61	11.20
	Max	5.00	6.35	12.63	11.44	13.10	16.63
Temperature (°C)	Mean	30.3	30.8	29.5	31.1	30.6	30.1
	Min	29.3	30.3	29.2	29.6	30.0	30.0
	Max	31.5	31.3	29.8	32.7	31.1	30.3
Total Dissolved Solids (ppm)	Mean	146.00	159.40	172.20	151.00	173.80	180.60
	Min	145	158	171	146	172	179
	Max	147	161	173	158	176	182
Conductivity (µS/cm)	Mean	292.20	318.80	345.00	301.80	347.80	362.00
	Min	290	317	341	291	343	359
	Max	295	322	347	315	351	365
Turbidity (NTU)	Mean	40.00	53.08	65.19	33.24	42.61	38.39
	Min	34.70	43.78	53.00	29.10	33.90	36.70
	Max	44.58	70.66	79.30	37.40	54.60	40.23
Phosphate (mg/L)	Mean	0.069	0.073	0.166	0.075	0.125	0.205
	Min	0.052	0.059	0.137	0.052	0.106	0.070
	Max	0.085	0.091	0.246	0.096	0.155	0.670
Chlorophyll-a (µg/L)	Mean	27.31	41.60	57.39	19.80	44.36	45.00
	Min	23.33	23.33	26.30	18.60	33.60	36.60
	Max	31.60	62.33	116.67	21.60	56.60	55.60
Total 4-day Precipitation (mm)		16.80	5.70	0.30	11.70	0.90	7.40

Table 2 Summary of linear regression for total 4-day precipitation (mm), turbidity (NTU), and phosphate (mg/L) predictors with chlorophyll-a concentration in Air Hitam Lake. Results include beta estimates (Estimates), confidence interval (CI), R^2 , adjusted R^2 , and p-value. Bold indicates significant p-values with $\alpha < 0.05$

Predictors	Estimates	CI	R^2	R^2 adjusted	p-value
(Intercept)	52.02	37.37 – 66.68	0.709	0.636	0.001
Precipitation	-1.79	-3.39 – -0.20			0.035
(Intercept)	-2.12	-48.24 – 44.00	0.621	0.526	0.905
Turbidity	0.91	-0.08 – 1.90			0.063
(Intercept)	12.57	-19.89 – 45.04	0.595	0.493	0.343
Phosphate	269.88	-39.51 – 579.27			0.073

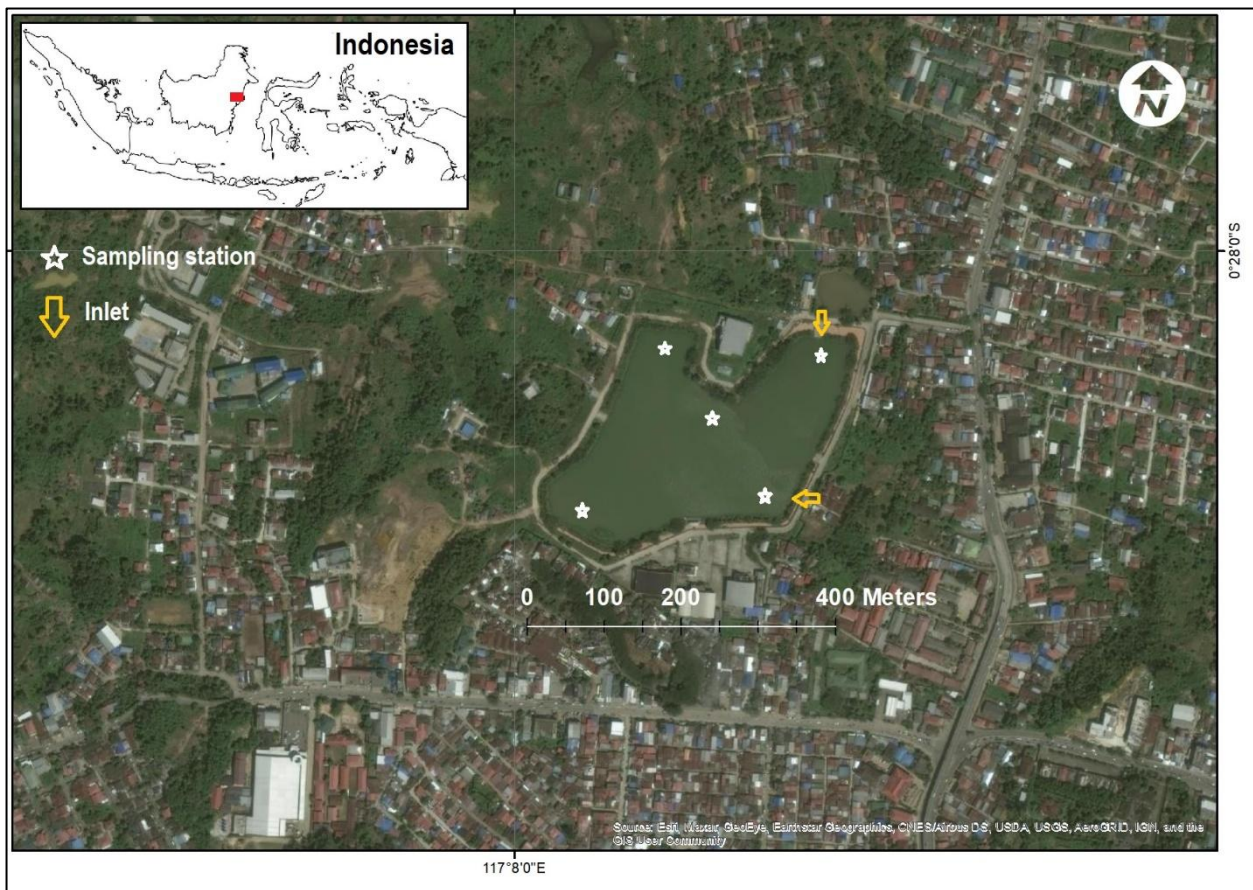


Figure 1 Map showing Air Hitam Lake study site in Samarinda City, Indonesia with five sampling stations denotes by white stars and two inlets denoted by yellow arrows.

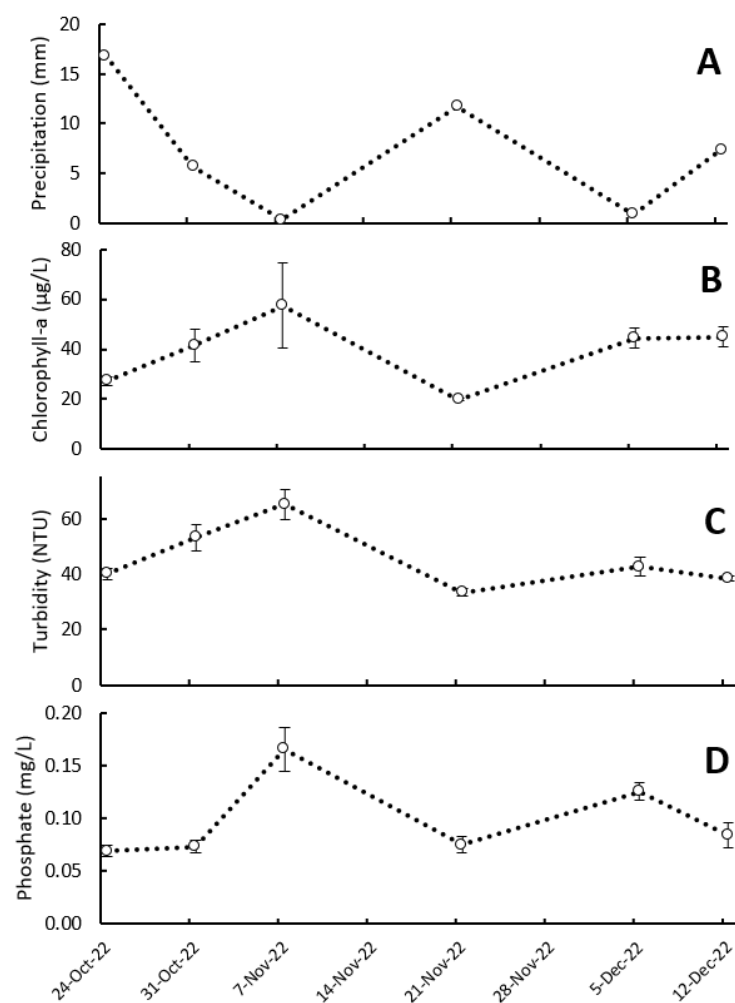


Figure 2 Plots illustrating A) 4-day total precipitation (mm) and B) average chlorophyll-a concentration ($\mu\text{g/L}$), C) turbidity (NTU), and D) phosphate concentration (mg/L) from five stations at Air Hitam Lake. Error bars indicate the Standard Error.

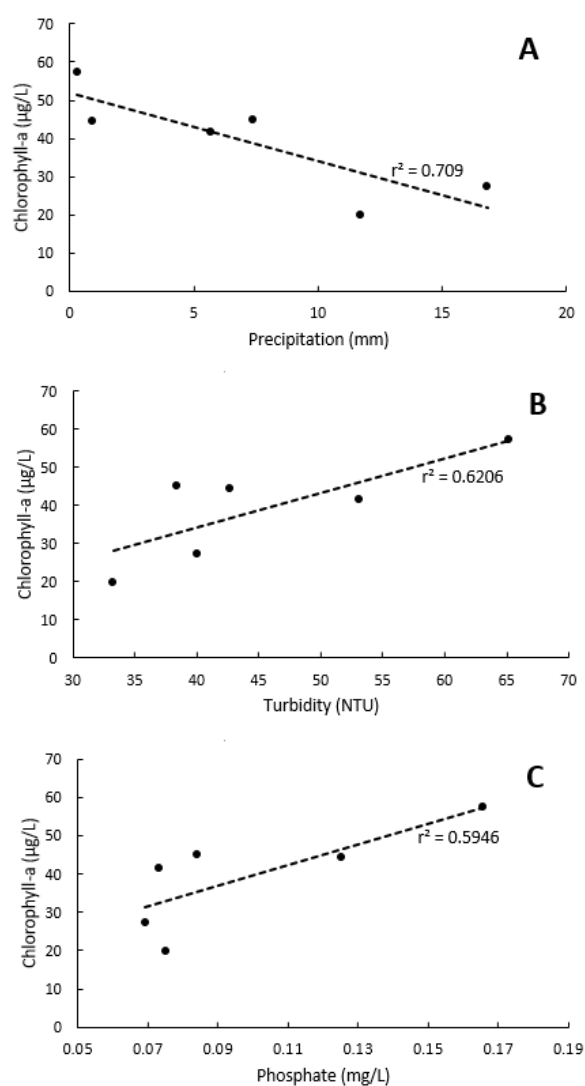


Figure 3 Scatter plots showing the relationship between Air Hitam Lake mean chlorophyll-a concentration (µg/L) with A) 4-day total precipitation (mm), B) mean turbidity (NTU), and C) mean phosphate concentration (µg/L). Dashed black line denotes the line of best fit.