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INFLUENCE OF SEASONAL RAINFALL TO THE WATER QUALITY OF SLIM RIVER LAKE IN PERAK, MALAYSIA

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Abstract

Rapid pace of development surrounding many lake catchments substantially affects the waterbody quality, thus causing public health concerns, threats to endangered aquatic species, aesthetic issues and algal blooms. This study assessed physicochemical and biological profiles of water quality in Slim River Lake (Perak, Malaysia), and relate with rainfall. On-site and laboratory analyses performed include turbidity, dissolved oxygen (DO), total nitrogen, total phosphorus, water temperature, chlorophyll-*a* and cyanobacteria biovolume. The effects of rainfall on the lake's water quality were analysed based on the Pearson correlation analysis. Results showed a significant correlation between rainfall and water temperature ($r = 0.480$ $p < 0.01$), total phosphorus ($r = 0.478$, $p < 0.01$) and DO ($r = -0.406$, $p < 0.05$). In addition, the results also showed a positive correlation between the rainfall and biovolume of *Phormidium* spp. test ($r = 0.372$, $p < 0.05$). This study provides significant contribution on the impact of seasonal rainfall to the variability of physical, chemical and biological profiles of the lake ecosystem, and reflected its health status and pollution.

Key words: Eutrophication, Lakes, Water quality, Slim River Lake, Rainfall

Introduction

Lake has performed a variety of functions including water source, drainage, food supply, flood control, hydroelectricity generation, transportation, recreational and eco-tourism (Kertész *et al.,* 2019). Due to the detrimental impacts on environmental, economic and health aspects, lake degradation has been a major concern recently and was addressed as serious issues both locally and globally.

Lakes receive a various source of pollutants, primarily from changes in land use, domestic activities and farming (Kertész *et al.,* 2019). Even from visual assessment alone, it can be deduced that there is something wrong with the current water quality status of the lake. However, from the scientific standpoint, determination of lake water properties is needed to identify its trophic level and water quality classification (Zaki, 2010). Tremendous efforts have been made to investigate the factors that affecting lake's water quality. These efforts were taken to prevent lake degradation from happening and to ensure adequate management and remediation efforts are made to restore its stability (Zaki *et al.,* 2014; Vogt *et al.,* 2018). Nevertheless, complex and inter-connected impacts of natural factors such as local weather and rainfall, industrialisation and urbanisation have become the key challenges and obstacles in maintaining the lake's water quality and ecosystems (Muzzammil-Shahabudin & Musa, 2018).

Eutrophication is one of the major concerns of lake pollution. Eutrophication is a natural process by which organic productivity increases within a water body to the point where the ground surface has built up, DO is reduced and microorganism concentrations of the water are altered (Ansari *et al.,* 2011). This phenomenon can be classified into two categories; natural and cultural. The process of natural eutrophication happens gradually and very slowly in geological time, but it can be dramatically accelerated by anthropogenic actions

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generally known as man-made, cultural and industrial eutrophication (Bhagowati & Ahamad, 2019). The discharge of industrial and domestic waste to the rivers, ponds and lakes has resulted in a hypereutrophic state of water bodies, characterised by excessive nutrients availability, low light penetrability, and frequent algal blooms (Du *et al.,* 2019).

In eutrophic aquatic ecosystem especially lakes, their natural ecological balances are often disturbed by the changes in phytoplankton community structure. Lake is a confined water body completely encircled by land with no immediate connection to sea except by a stream or river that sustains or drains the lake. It is regarded as a lentic system or standing water with long water retention period and complex population dynamics (Huang *et al.,* 2015). Generally, lakes are categorised into natural lakes (i.e., wetlands, marshes, estuarine lakes) and man-made lakes (i.e., reservoirs, retention pond, ex-mining pond, recreational lakes) (Huang *et al.,* 2015).

In eutrophic lakes, phytoplankton is often dominated by cyanobacteria. Cyanobacterial bloom is a term used to describe condition in lake ecosystem where its phytoplankton community are mainly dominated by cyanobacteria (Shan *et al.,* 2019). Cyanobacteria (also referred to as blue-green algae) is a photosynthetic bacteria present in most water columns. With adequate nutrition, they can grow quickly form large populations on the surface of the water surface, thus forming blooms (Josué *et al.*, 2019). Cyanobacterial blooms in a freshwater lake ecosystem primarily consisted of *Microcystis* spp., *Anabaena* spp. or *Cylindrospermopsis* spp., whereas in the marine ecosystem, *Lyngbya* spp., *Synechococcus* spp. and *Trichodesmium* spp. were often dominated (Mohamad *et al.*, 2016). Cyanobacterial blooms are a major ecological and human health problem worldwide due to the ability of some cyanobacteria to produce toxins (Krztoñ *et al.,* 2019). Exposure of cyanotoxin such as microcystin to the livestock, wildlife, and human presents a serious health hazard including poisoning, liver failure, tumors and death (Preece *et al.,* 2017).

In Malaysia, the eutrophication has dramatic impacts on aquatic ecosystems. The adverse effects of eutrophication include public health concerns, threats to endangered aquatic species and aesthetic issues. These concerns have been growing in recent years as well as the need for formulation and implementation of laws and programmes for its prevention (Tang, 2019). Although eutrophication is the most widespread water quality issue, no well-defined standard or regulation exists for its control (Sharip *et al.,* 2014). The complexities of eutrophication and the associated mechanisms and responses have resulted in a changing and often an imprecise threshold between healthy and unhealthy aquatic ecosystems and water quality.

Local weather, climate change and hydrologic conditions are examples of factors that influence the water quality, nutrient loads and eutrophication of a waterbody (Vinçon-Leite & Casenave, 2019). Among other factors, rainfall could play a major role to trigger the dominance of cyanobacteria, aggravate eutrophication, and influence the stability of lake properties including turbidity, water temperature, DO and nutrient availability. To date, the research on the impact of local seasonal rainfall to the lake water quality, eutrophication and cyanobacterial dynamics is still scarce and need furtherance. The existing knowledge on eutrophication suggests that its progression may also be influenced by many locally unique and site-specific environmental factors such as seasonal weather patterns.

Therefore, in this study, the influence of rainfall on the dynamics of various lake water quality parameters was evaluated. The physical, chemical and biological assessments of lake water quality such as temperature, DO, turbidity, total phosphorus, total nitrogen, chlorophyll-*a* and biovolume of cyanobacteria were performed in Slim River Lake, Perak, Malaysia.

Materials and Methods

Study Area

Slim River Lake, a man-made shallow lake located in Muallim District (Perak State), was selected in this study. The hydrology system of this lake is mainly affected by the rainfall pattern and a strong seasonal hydrological cycle. Slim River Lake is used for recreation, fishing and entertainment among local communities and is classified as a shallow lake. Slim River Lake was chosen for this study because of its high algae and floating macrophyte growth. Fig. 1 shows the maps and satellite image of the Slim River Lake within Perak State.

Sampling Procedures

In this study, three locations around the lake were selected as sampling stations. The first station was located in the upstream of the lake, the second was at the western side of the lake exactly beside the highway and the third station was at the right side of the lake's opposite station 2. Water sampling were conducted on monthly basis from August 2017 to July 2018. For each sampling station, triplicate samples were collected during each sampling.

During the sampling period, on-site measurements, water samples and phytoplankton samples were taken

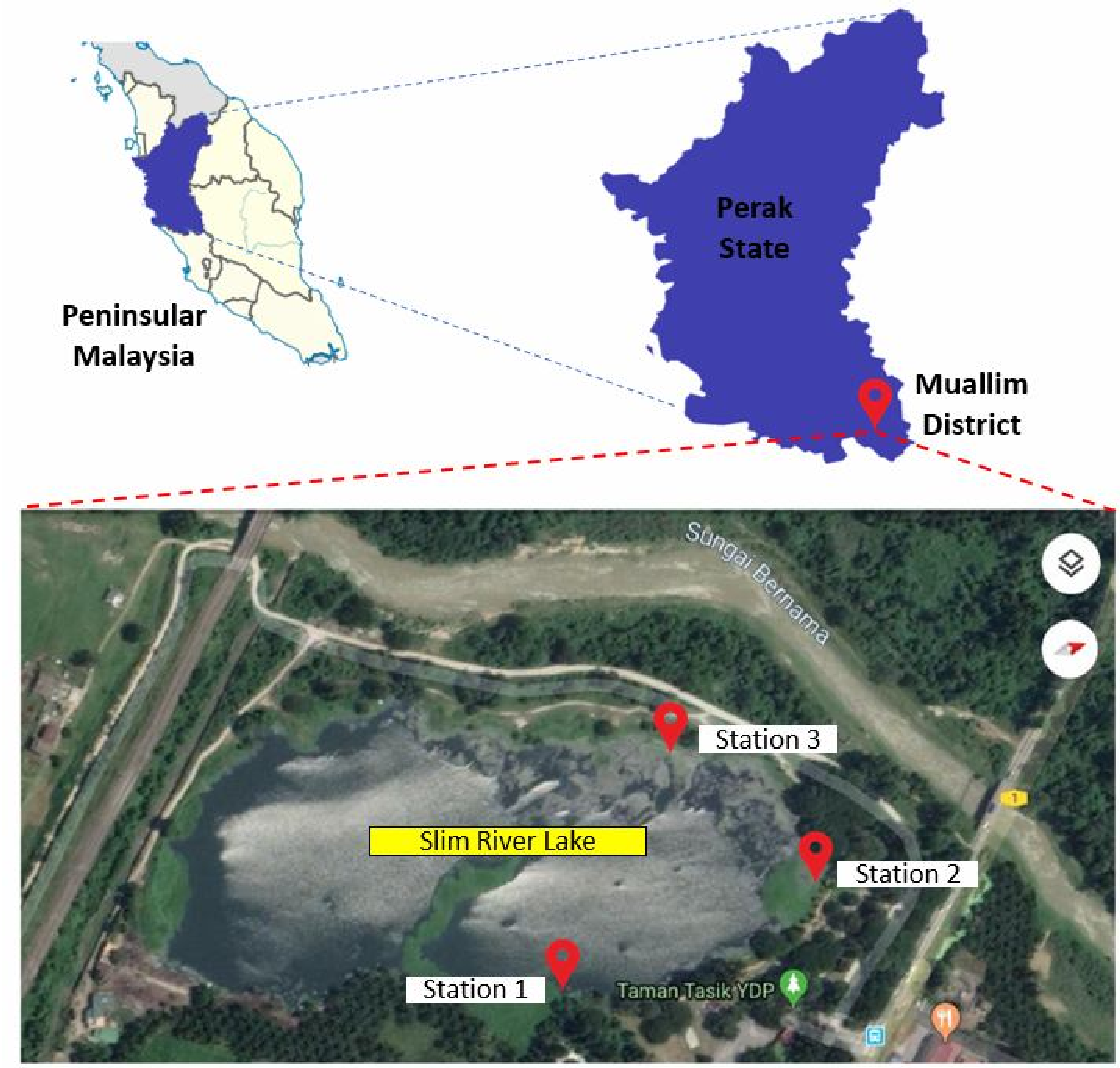

Fig. 1: Maps and satellite image of Slim River Lake within Perak State (3° 49' 26.688" N; 101° 24' 30.6216" E).

from the depth of 15 – 30 cm. Water samples were collected using polyethylene bottles which had been acid washed overnight to avoid any contamination. Phytoplankton samples were collected using plankton net. Sampling was conducted from 8:30 am to 10:00 am to reduce the influence of air temperature variations. Three replicate samples were taken randomly at each sampling station, stored in an ice box and transferred to the laboratory for further analysis. The samples were analysed separately and the data was reported as mean and standard deviation of the three sampling points.

On-site measurements and laboratory analyses

On-site measurements were conducted for water temperature, DO and turbidity. Water temperature and DO of the lake were measured on-site using a portable DO meter (YSI Incorporated 550A, USA). The turbidity of lake water sample was examined through a physical checking using turbidity meter (Hanna Instrument LP 2000-11, Italy).

In laboratory, total phosphorus was analysed using Test 'N Tube Total High Range Phosphorus Reagent Set (HACH, USA) following the molybdovanadate with acid persulfate digestion method 10127. About 5 mL of sample was mixed with potassium persulfate in a vial, and the mixture was heated for 30 min in a digital reactor block (HACH DRB200, USA). After cooled to room temperature, 2 mL of 1.54 N NaOH and molybdovanadate reagent was added to the vial and mixed by inverting the vial. After 7 min of reaction period, the phosphorus concentration was determined using spectrophotometer (HACH DR2500 Odyssey, USA).

Total nitrogen was quantified using Test 'N Tube High Range Total Nitrogen Reagent Set (HACH, USA) following the persulfate digestion method 10072. The vial containing 0.5 mL sample and digestion reagents (nitrogen persulfate and nitrogen hydroxide) was placed into a digital reactor block (HACH DRB200, USA) and heated for 30 min to digest. The digested samples were left to cool to room temperature before other nitrogen reagents were added. The nitrogen concentration was subsequently quantified using spectrophotometer (HACH DR2500 Odyssey, USA) against blank.

Cyanobacterial diversity was identified to the genera level in accordance with phytoplankton taxonomic guidelines (Bellinger & Sigee, 2010) using an inverted microscope (Nikon Eclipse TE 2000-U, UK). Phytoplankton samples were mixed thoroughly prior to microscopic analysis, and cyanobacteria were identified down to genera level based on their morphological characteristics. The cyanobacteria biovolume was measured using the imaging software NIS Elements Basic Research version 3.

Total chlorophyll-*a* concentration was determined according to the standard method (Rice *et al.,* 1905) and as previously described by Carlson, 1997. Known volume of water sample was filtered through glass fiber filter paper (Whatman Glass Microfiber GF/C 47 mm, UK). Algae-containing filter paper was freeze-thawed three times before it was submerged in a test tube containing 10 mL of 10% acetone, and sonicated in a cold water bath for 10 min to break up algae cell wall. Then, the extract was subjected to 5 min centrifugation at 5000 rpm to separate the particulate matter and remaining debris. The absorbance at 750 nm and 665 nm was measured using spectrophotometer (PRIM-SECOMAM, France) against 90% acetone blank, before and after acidification with 0.2 mL of 1% HCl. The concentration of chlorophyll-*a* was then calculated based on modified Lorenzen's equation (Smith *et al.,* 2007).

Rainfall Data

The meteorological data of daily total rainfall in the study area from August 2017 to July 2018 was obtained from Department of Meteorology, Malaysia. The data was obtained from Felda Sungai Behrang Meteorology Station as it is located nearest to the study lake.Statistical Analysis

Pearson correlation analysis was carried out using IBM SPSS Statistic software version 25 to determine the association of seasonal rainfall with the physical, chemical and biological profiles of the lake.

Results and discussion

The rainfall variability in the study area is strongly associated with the Southwest and the Northeast Monsoons, which occurred between April to September and October to March, respectively (Tang, 2019). The Southwest Monsoon has drier weather with lower precipitation relative to the Northeast Monsoon. The amount of rainfall (mm) received in the study area throughout the study period is presented in Fig. 2. According to previous study, seasonal rainfall changes in Peninsular Malaysia can be categorised based on the regional pattern; i) east coast, ii) west coast and iii) inland region (Wong *et al.,* 2009). The rainfall pattern in the study area indicated there were two maximum rainfall periods, separated by minimum rainfall periods; which is the common rainfall distribution for the inland region. The primary and secondary maximum rainfall were recorded in March (528.5 mm) and November (439.2 mm), respectively.

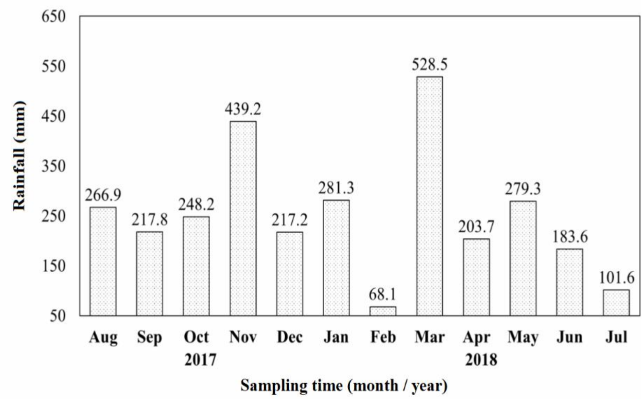

Fig. 2: Rainfall (mm) of Slim River Lake from August 2017 to July 2018.

However, based on the data, it was revealed that the rainfall pattern in the study area was also influenced by the Sumatra's phenomenon, which resulted in a minimum rainfall of 68.1 mm to occur in February (Malaysian Meteorological Department, 2019). Sumatra's phenomenon occurred due to the fact that most of the winds during southwest monsoon directed to Peninsular Malaysia from Sumatra were obstructed by high mountain peaks, which caused a rain sheltering effect to the affected area, especially west coast of Peninsular Malaysia. Therefore, it was concluded that the rainfall received by the Slim River Lake was a combination of seasonal rainfall patterns on the inland and west coast region.

In terms of lake's water quality, Fig. 3 shows the turbidity (NTU) of the lake throughout the sampling period. The turbidity values of the Slim River Lake ranged from 2.18 NTU to 7.67 NTU. The Pearson correlation analysis revealed that there is no correlation exist between the turbidity and rainfall ($r = -0.15$, $p = 0.40$).

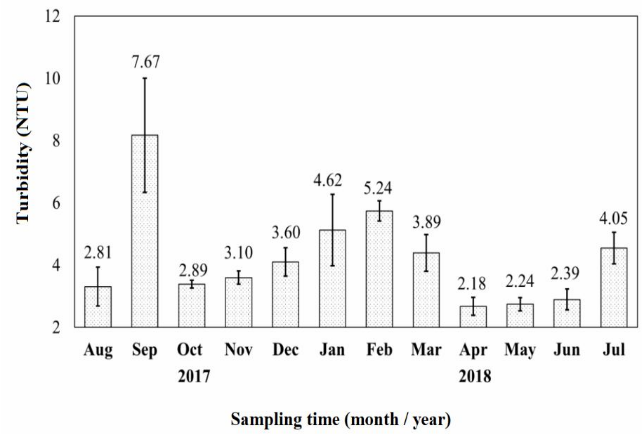

Fig. 3: Turbidity (NTU) of Slim River Lake from August 2017 to July 2018.

Fig. 3: Turbidity (NTU) of Slim River Lake from August 2017 to July 2018. According to the previous study, high turbidity observed in a lake was induced by the collapse and erosion of sediment on the lake's slope caused by high volume overflow and rainfall (Roberts *et al.*, 2019). This result indicated that no significant amount of sediment was transported by the rainfall into the lake (Ling *et al.*, 2017).

The monthly variation of DO (mg/L) during the sampling period is shown in Fig. 4. The DO was recorded in a range of 6 mg/L to 9.66 mg/L, with an annual average of 7.48 mg/L. The lack of aquatic life has led to the low use of DO and the large surface area of Slim River has also contributed to the high concentration of oxygen dissolved in the lake (Sulaiman *et al.*, 2018). Furthermore, a correlation was found between the rainfall and DO throughout the sampling duration ($r = -0.406$, $p < 0.05$). Rainfall provides an aeration to the lake which causes the DO value to increase. Furthermore, the frequent occurrence of rainfall allowed the DO to recover more quickly (Ling *et al.*, 2017).

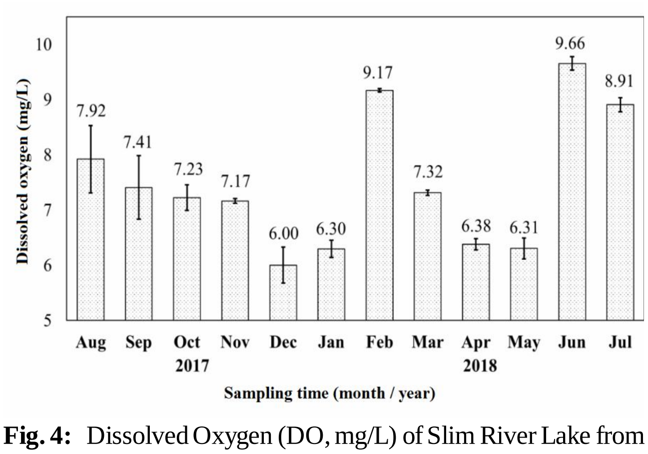

Fig. 4: Dissolved Oxygen (DO, mg/L) of Slim River Lake from August 2017 to July 2018.

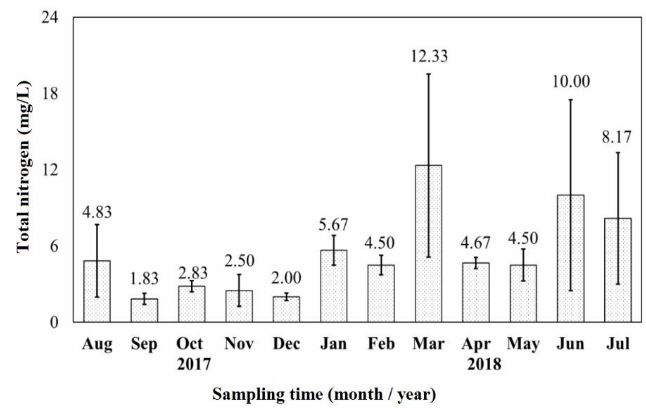

Fig. 5: Total Nitrogen (mg/l) of Slim River Lake from August 2017 to July 2018.

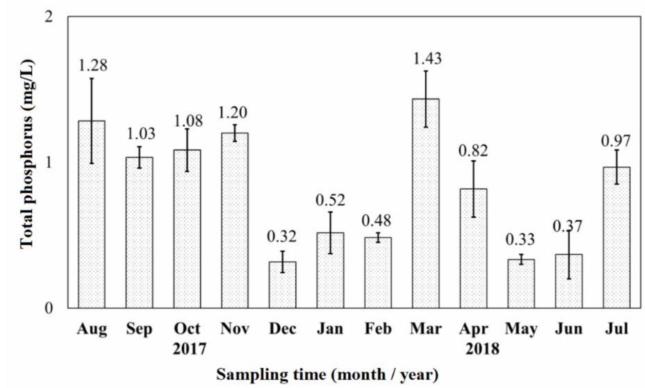

Fig. 6: Total Phosphorus (mg/l) of Slim River Lake from August 2017 to July 2018.

The total nitrogen (mg/L) and total phosphorus (mg/L) throughout the sampling period are presented in Fig. 5 and 6, respectively. Changes in the pattern of rainfall are known to alter the nutrients availability in the lakes and often contributes to their trophic status (Weirich *et al.*, 2019). On the positive side, rainfall may dilute the contaminants present in the water bodies. But on the negative side, it may also increases the export of nutrients to the lakes, resulting in increased sedimentation and eutrophication (Wan-Mohd-Khalik & Abdullah, 2012). Previous researchers had reported significant relationship between rainfall and nutrients availability (Shuhaimi-Othman *et al.*, 2007).

However, based on our Pearson correlation analysis, there is no significant correlation existed between rainfall and total nitrogen ($r = 0.12$, $p = 0.47$) in the Slim River Lake. In contrast, the total phosphorus was positively correlated with the rainfall ($r = 0.478$, $p < 0.01$). The highest concentration of nitrogen (12.33 mg/L) and phosphorus (1.43 mg/L) were recorded in March which was also the month of the highest rainfall received. However, the lowest concentration of both nitrogen and phosphorus were not measured in the month of the most minimum rainfall. This suggested that there are other internal factors that may contribute to the presence of the both nutrients in this lake.

The phosphorus level in the Slim River Lake was more stable compared to nitrogen. The phosphorus concentration was recorded in a range of 0.32 mg/L to 1.28 mg/L. Since the rainfall is the major cause of soil drift, the main source of phosphorus in the lake may originate from the fertilisers of nearby soil. Meanwhile, the nitrogen concentration remained below than 5.67 mg/L throughout the year, but fluctuated in March, June and July. Due to the lack of a significant relationship of total nitrogen concentration with rainfall, these fluctuations could be caused by discharges from nearby farm or other anthropogenic factors.

The water temperature (°C) recorded throughout study period is shown in Fig. 7. The maximum water temperature value of 31.75 °C was recorded in December, while the minimum value of 28.22 °C was recorded in February. Moreover, the seasonal rainfall was proved to have significant effect on the lake's water temperature based on the correlation observed between these two parameters ($r = 0.480$, $p < 0.01$). Global scenarios of climate change have seen a rise in lake water temperature up to 4 °C, and this elevation has resulted in a restructuring of the diversity and abundance of plankton population towards species that can withstand warmer and unpredictable temperature settings (Rasconi *et al.,* 2017). Previous study found that water temperature is a key environmental factor that stimulated the cyanobacteria colonisation and was statistically verified to be a better predictor of cyanobacterial bloom compared to pH (Sinden & Sinang, 2016).

The abundance of phytoplankton, especially cyanobacteria in the Slim River Lake was depicted by the variability of total chlorophyll-*a* throughout the sampling period as illustrated in Fig. 8. However, unlike

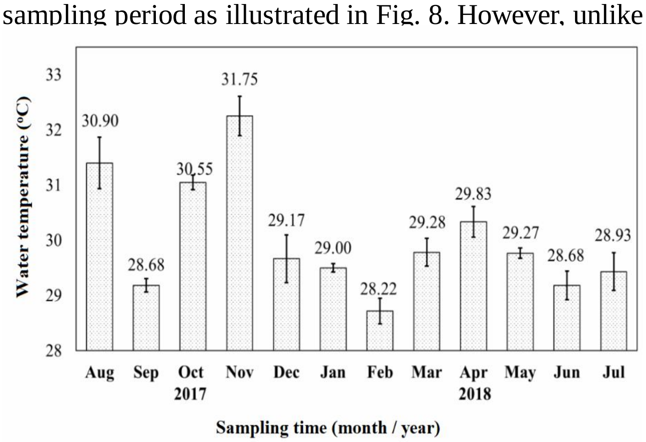

Fig. 7: Water temperature (°C) of Slim River Lake from August 2017 to July 2018.

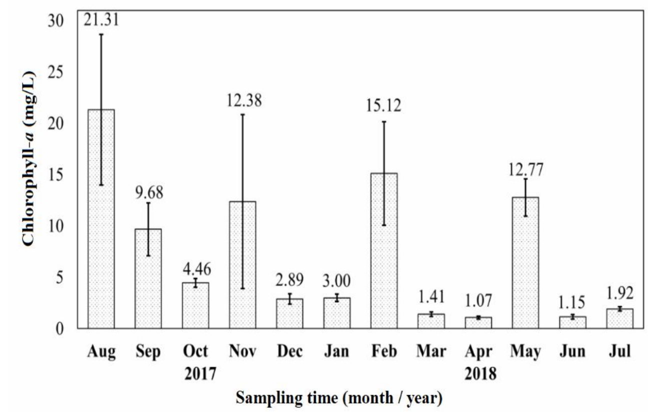

Fig. 8: Chlorophyll-*a* (mg/L) Slim River Lake from August 2017 to July 2018

water temperatures, there is no correlation observed between the rainfall and total chlorophyll-*a* ($r = -0.12$, $p = 0.47$). The maximum and minimum values of chlorophyll-*a* was observed in August (21.31 mg/L) and April (1.07 mg/L), respectively.

Therefore, it was suggested that the phytoplankton growth was limited by other inter-connected environmental factors such as light and nutrients availability. Extreme rainfall can lead to high flushing rates and reduce the availability of solar energy due to cloud coverage (Sobahan *et al.,* 2013). In addition, extreme rainfall also lead to a flooding cycle which contributed to unfavourable conditions for the growth of phytoplankton and submerged macrophytes (Sobahan *et al.,* 2013).

Based on the microscopic observation, the phytoplankton population in Slim River Lake was dominated by various cyanobacteria species. Other than that, dinoflagellates (i.e., *Peridinium* spp., *Ceratium* spp.), green algae (i.e., *Staurastrum* spp., *Selenastrum* spp., *Oocystis* spp., *Coelastrum* spp.) and diatoms (i.e., *Synedra* spp.) were also found in this lake. The cyanobacterial bloom of Slim River Lake was primarily dominated by *Microcystis* spp., followed by *Oscillatoria* spp. and *Phormidium* spp. The biovolumes (μm^3/mL) of *Microcystis* spp., *Oscillatoria* spp. and are shown in Fig. 9.

The highest biovolumes of *Microcystis* spp. and *Phormidium* spp. were recorded in November, while the highest biovolume of *Oscillatoria* spp. was recorded in December. According to Pearson correlation analysis, there is a positive relationship between rainfall and the biovolume of *Phormidium* spp. ($r = 0.372$, $p < 0.05$), but there was no connection between rainfall and the remaining two species of cyanobacteria.

Rainfall not only affect the water level and volume of the lake, but it also resulted to the increased of water discharges and disruption of stagnant conditions that sustained the bloom (Havens *et al.,* 2019). Moreover, previous study reported that high rainfall frequency enhanced sedimentation and eutrophication (Sharip *et al.*, 2019).

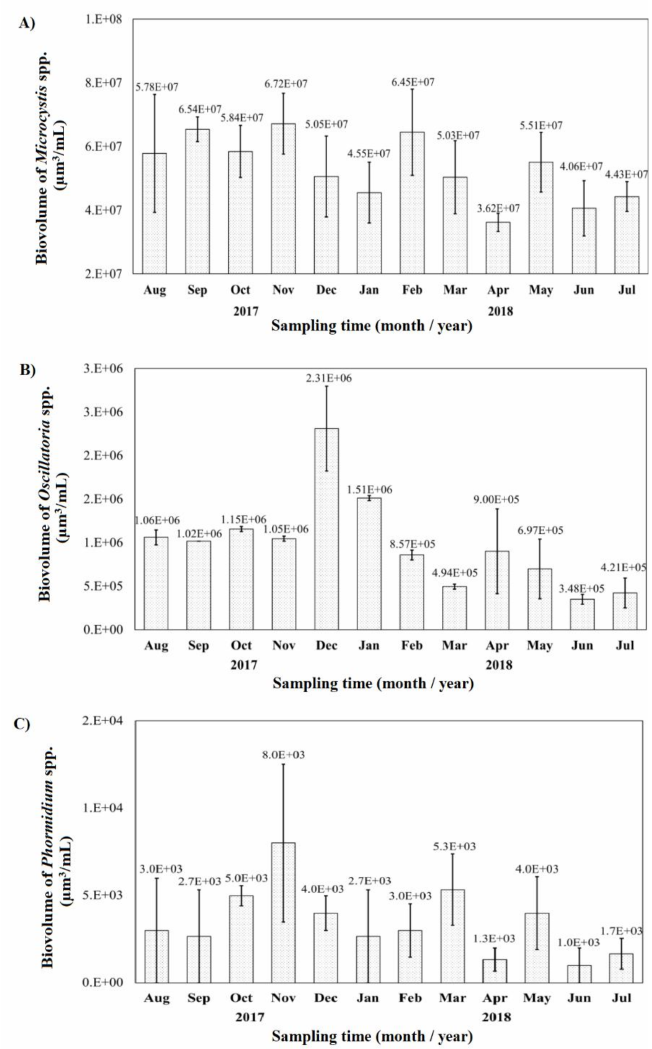

Fig. 9: Biovolumes (µm³/mL) of A) *Microcystis* spp., B) *Oscillatoria* spp. and C) *Phormidium* spp.

While cyanobacterial bloom is affected by many variables, the previous study indicated that meteorological factors (rainfall) played a significant role in species selection in cyanobacterial bloom, while other water quality parameters such as availability of nutrients, DO, water temperature dictated the growth and abundance of the species (Descy *et al.,* 2016).

Conclusion

This study focused on Slim River Lake Perak, Malaysia. The water quality of this lake was studied through physical, chemical and biological assessments. The correlation study was based on the statistical analysis between the rainfall and lake's parameters. From the results, there is strong positive correlation between the rainfall and water temperature ($r = 0.480$, $p < 0.01$), total phosphorus ($r = 0.478$, $p < 0.01$), DO ($r = -0.406$, $p < 0.05$), and biovolume of *Phormidium* spp. ($r = 0.372$, $p < 0.05$). However, no correlation was observed between the rainfall and other parameters including turbidity, total nitrogen and chlorophyll-*a*. Rainfall has a beneficial effect on the value of the lake DO as it can promote self-purification. However, the lake was contaminated by the high concentration of nitrogen and phosphorus which led to its hypereutrophic; which requires further action to determine the source of the contamination, its prevention and suitable remediation.

References

Ansari, A.A., G.S. Singh, G.R. Lanza and W. Rast (2011). *Eutrophication: causes, consequences and control*. New York: Springer.

Bellinger, E.G. and D.C. Sigee (2010). *Freshwater algae*. John Chichester UK: Wiley & Sons Ltd.

Bhagowati, B. and K.U. Ahamad (2019). A review on lake eutrophication dynamics and recent developments in lake modeling. *Ecohydrology and Hydrobiology*, **19(1):** 155–166.

Carlson, R.E. (1977). A trophic state index for lakes. *Limnology and Oceanography*, **22(2):** 361–369.

Descy, J.P., F. Leprieur, S. Pirlot, B. Leporcq, J. Van Wichelen, A. Peretyatko, S. Teissier, G.A. Codd, L. Triest, W. Vyverman and A. Wilmotte (2016). Identifying the factors determining blooms of cyanobacteria in a set of shallow lakes. *Ecological Informatics*, **34:** 129–138.

Du, H., Z. Chen, G. Mao, L. Chen, J. Crittenden, R.Y.M. Li, and L. Chai (2019). Evaluation of eutrophication in freshwater lakes: a new non-equilibrium statistical approach. *Ecological Indicators*, **102(12):** 686–692.

Havens, K.E., G. Ji, J.R. Beaver, R.S. Fulton and C.E. Teacher (2019). Dynamics of cyanobacteria blooms are linked to the hydrology of shallow Florida lakes and provide insight into possible impacts of climate change. *Hydrobiologia*, **829(1):** 43–59.

Huang, Y.F., S.Y. Ang, K.M. Lee and T.S. Lee (2015). Quality of water resources in Malaysia. *Research and Practices in Water Quality*. https://doi.org/10.5772/58969

Josué, I.I.P., S.J. Cardoso, M. Miranda, M. Mucci, K.A. Ger, F. Roland and M.M. Marinho (2019). Cyanobacteria dominance drives zooplankton functional dispersion. *Hydrobiologia*, **831(1):** 149–161.

Kertész, Á., L.A. Nagy and B. Balázs (2019). Effect of land use change on ecosystem services in Lake Balaton catchment. *Land Use Policy*, **80:** 430–438.

Krztoñ, W., J. Kosiba, A. Pociecha and E. Wilk-WoŸniak (2019).

The effect of cyanobacterial blooms on bio- and functional diversity of zooplankton communities. *Biodiversity and Conservation*, **28(7):** 1815–1835.

Ling, T.Y., C.L. Soo, J.J. Liew, L. Nyanti, S.F. Sim and J. Grinang (2017). Influence of rainfall on the physicochemical characteristics of a tropical river in Sarawak, Malaysia. *Polish Journal of Environmental Studies*, **26(5):** 2053–2065.

Malaysian Meteorological Department. (2019). Iklim Malaysia. http://www.met.gov.my/pendidikan/iklim/iklimmalaysia

Mohamad, R., M. Rafatullah, T. Yusof, Y. Sim, N. Ismail and J. Lalung (2016). Detection of microcystin (Mcye) gene in recreational lakes in Miri, Sarawak, Malaysia. *Current World Environment*, **11(3):** 690–699.

Muzzammil-Shahabudin, M. and S. Musa (2018). An overview on water quality trending for lake water classification in Malaysia. *International Journal of Engineering & Technology*, **7:** 5–10.

Preece, E.P., F.J Hardy, B.C. Moore and M. Bryan (2017). A review of microcystin detections in estuarine and marine waters: environmental implications and human health risk. *Harmful Algae*, **61:** 31–45.

Rasconi, S., K. Winter and M.J. Kainz (2017). Temperature increase and fluctuation induce phytoplankton biodiversity loss - evidence from a multi-seasonal mesocosm experiment. *Ecology and Evolution*, **7(9):** 2936–2946.

Rice, E., R. Baird, A. Eaton and L. Clesceri (1905). Standard methods for the examination of water and wastewater.

Roberts, N., S.L Allcock, H. Barnett, A. Mather, W.J. Eastwood, M. Jones, N. Primmer, H. Yiðitba?ýoðlu and B. Vannière (2019). Cause and effect in Mediterranean erosion: the role of humans and climate upon Holocene sediment flux into a central Anatolian lake catchment. *Geomorphology*, **331:** 36–48.

Shan, K., L. Song, W. Chen, L. Li, L. Liu, Y. Wu, Y. Jia, Q. Zhou, and L. Peng (2019). Analysis of environmental drivers influencing interspecific variations and associations among bloom-forming cyanobacteria in large, shallow eutrophic lakes. *Harmful Algae*, **84:** 84–94.

Sharip, Z., A.T.A. Zaki, M.A.H.M. Shapai, S. Suratman and A.J. Shaaban (2014). Lakes of Malaysia: water quality, eutrophication and management. *Lakes and Reservoirs: Research and Management*, **19(2):** 130–141.

Sharip, Z., F.M. Yusoff and A. Jamin (2019). Seasonal water quality and trophic status of shallow lentic waters and their association with water levels. *International Journal of Environmental Science and Technology*, **16(8):** 4851–4862.

Shuhaimi-Othman, M., E.C. Lim and I. Mushrifah (2007). Water quality changes in Chini Lake, Pahang, West Malaysia. *Environmental Monitoring and Assessment*, **131(1–3):** 279–292.

Sinden, A. and S.C. Sinang (2016). Cyanobacteria in aquaculture systems: linking the occurrence, abundance and toxicity with rising temperatures. *International Journal of Environmental Science and Technology*, **13(12):** 2855–2862.

Smith, K., L. Webster, E. Bresnan, S. Fraser, S. Hay and C. Moffat (2007). A review of analytical methodology used to determine phytoplankton pigments in the marine environment and the development of an analytical method to determine uncorrected chlorophyll a, corrected chlorophyll a and phaeophytin a in marine phytoplankton. *Fisheries Research Services Internal Report*, **3:** 1–56.

Sobahan, M.A., S.I. Mir, I. Zakaria and M.A.H Hossain (2013). Surface water contamination due to industrial activities in Gebeng area, Kuantan, Malaysia. International Conference on Civil and Architecture Engineering (ICCAE'2013) May 6-7, 2013 Kuala Lumpur (Malaysia), 53–61.

Sulaiman, N.H., S.I. Khalit, Z. Sharip, M.S. Samsudin and A. Azid (2018). Seasonal variations of water quality and heavy metals in two ex-mining lake using chemometric assessment approach. *Malaysian Journal of Fundamental and Applied Sciences*, **14(1):** 67–72.

Tang, K.H.D. (2019). Climate change in Malaysia: trends, contributors, impacts, mitigation and adaptations. *Science of the Total Environment*, **650:** 1858–1871.

Vinçon-Leite, B. and C. Casenave (2019). Modelling eutrophication in lake ecosystems: a review. *Science of the Total Environment*, **651:** 2985–3001. https://doi.org/10.1016/j.scitotenv.2018.09.320

Vogt, R.J., S. Sharma and P.R. Leavitt (2018). Direct and interactive effects of climate, meteorology, river hydrology, and lake characteristics on water quality in productive lakes of the Canadian Prairies. *Canadian Journal of Fisheries and Aquatic Sciences*, **75(1):** 47–59.

Wan-Mohd-Khalik, W.M.A. and M.P. Abdullah (2012). Seasonal influence on water quality status of Temenggor Lake, Perak. *Malaysian Journal of Analytical Sciences*, **16(2):** 163–171.

Weirich, C.A., D.M. Robertson and T.R. Miller (2019). Physical, biogeochemical, and meteorological factors responsible for interannual changes in cyanobacterial community composition and biovolume over two decades in a eutrophic lake. *Hydrobiologia*, **828(1):** 165–182.

Wong, C.L., R. Venneker, S. Uhlenbrook, A.B.M. Jamil and Y. Zhou (2009). Variability of rainfall in Peninsular Malaysia. *Hydrology and Earth System Sciences Discussions*, **6(4):** 5471–5503.

Zaki, Z. (2010). Benchmarking river water quality in Malaysia. *Jurutera*, **2:** 12–15.