RESPONSE OF CYANOBACTERIA AND MACROPHYTES COMMUNITIES ON SELECTED NUTRIENTS IN SLIM RIVER LAKE ECOSYSTEM

AMY ROSE AERIYANIE BINTI A RAHMAN

UNIVERSITI PENDIDIKAN SULTAN IDRIS

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May all of us blessed with guidance, gratitude, and creativity.

ABSTRACT

This study aimed to determine the response of cyanobacteria and macrophytes communities on selected nutrients in Slim River Lake ecosystem. The sampling was carried out twice a month at six sampling sites for 13 months for lake water and 12 months for stormwater runoff. Lake water level was measured monthly to develop a bathymetric map. Total phosphorus and total nitrogen concentration in lake water and stormwater runoff were analyzed using ascorbic acid and hydrazine reduction methods, respectively. Internal nutrients loading was calculated during five identified dry periods, while external nutrients loading was calculated at every storm event. Total chlorophyll-*a* of all phytoplankton taxa, cyanobacteria biomass, cyanobacteria biovolume, and total macrophyte abundance were also measured throughout the sampling period. The result indicated that Slim River Lake has a mean depth of 3.84 m. In-lake total phosphorus and total nitrogen concentrations were found to be significantly correlated with internal total phosphorus (r=0.82, p<0.05) and total nitrogen (r=0.60, p<0.05) loading. Meanwhile, total chlorophyll-*a*, cyanobacteria biomass, and total cyanobacteria biovolume significantly correlated with internal total phosphorus loading. In contrast, total macrophyte abundance significantly correlated with external total phosphorus (r=0.50, p<0.05) and external total nitrogen (r=0.44, p<0.05) loading. Based on PCA model, internal nutrients loading is a primary contributor to the lake's eutrophication progression. In conclusion, sediment's nutrient is a significant source of nutrient which mainly enhance the primary productivity in Slim River Lake. This research implicates that internal nutrients loading should be reduced to manage eutrophication problem in this lake.

RESPON SIANOBAKTERIA DAN KOMUNITI MAKROFIT KE ATAS NUTRIEN TERPILIH DALAM EKOSISTEM TASIK SLIM RIVER

ABSTRAK

Kajian ini bertujuan untuk menentukan respon sianobakteria dan komuniti makrofit ke atas nutrien terpilih dalam ekosistem Tasik Slim River. Persampelan dilakukan dua kali sebulan pada enam lokasi persampelan selama 13 bulan untuk air tasik dan 12 bulan untuk air larian hujan. Paras air tasik diukur setiap bulan untuk membangunkan peta batimetri. Kepekatan total fosforus dan total nitrogen dalam air tasik dan air larian hujan masing-masing dianalisis menggunakan kaedah asid askorbik dan penurunan hidrazin. Pemuatan nutrien dalaman dikira semasa lima tempoh kering yang telah dikenalpasti, manakala pemuatan nutrient luaran dikira pada setiap hari hujan. Total klorofil-*a* bagi kesemua taxa fitoplankton, biojisim sianobakteria, isipadu sianobakteria dan total kelimpahan makrofit juga diukur sepanjang tempoh persampelan. Hasil kajian menunjukkan Tasik Slim River mempunyai purata kedalaman 3.84 m. Kepekatan total fosforus dan total nitrogen dalam tasik didapati mempunyai kolerasi yang signifikan dengan pemuatan dalaman total fosforus (r=0.82, p<0.05) dan total nitrogen (r=0.60, p<0.05). Manakala, total klorofil-*a*, biojisim sianobakteria, dan isipadu total sianobakteria didapati mempunyai kolerasi yang signifikan dengan pemuatan total fosforus dalaman. Sebaliknya, total kelimpahan makrofit didapati mempunyai kolerasi yang signifikan dengan pemuatan total fosforus (r=0.50, p<0.05) dan total nitrogen (r=0.44, p<0.05) luaran. Berdasarkan model PCA, pemuatan nutrien dalaman adalah penyumbang utama kepada perkembangan eutrofikasi di tasik. Kesimpulannya, nutrien sedimen adalah sumber nutrien yang penting dalam meningkatkan produktivti utama dalam Tasik Slim River. Implikasi kajian ini menunjukkan pemuatan nutrien dalaman seharusnya dikurangkan bagi menguruskan masalah eutrofikasi di tasik ini.

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APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
DOE	Department of Environment
GIS	Geographic Information System
IDW	Inverse Distance Weighted
NAHRIM	National Hydraulic Research Institute of Malaysia
NLWQS	National Lake Water Quality Criteria & Standard
NTU	Nephlometric Turbidity Unit
Ppt	Parts per thousand
PCA	Principal Component Analysis
SD	Secchi Disk
SPSS	Statistical Packages for Social Science
TCU	True Colour Unit
TIN	Triangulated Irregular Network
TSI	Trophic State Index
WQI	Water Quality Index

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CHAPTER 1

INTRODUCTION

This chapter provides an overview of this research. This chapter discusses water quality issues, research background, problem statement, research objectives, research significance, and also research limitation.

1.1 Water resources and quality in Malaysia

Water is essential for humans; while also serve as a habitat for aquatic life species (Hossain & Mahmud, 2019). Among other vital functions, water acts as a universal solvent and involves in most physical or chemical reactions. Water bodies consist of rivers, lakes, ponds, reservoirs, groundwater, and coastal streams (Zakaria & Sharip, 2007). In Malaysia, lakes and reservoirs contributed to almost 90% of the nation's water source (Hossain & Mahmud, 2019). In recent years, water demand has increased remarkably as population growth increases. This demand has resulted in the increment of water pollution (Bashar Bhuiyan et al., 2013). Water pollution is caused by either natural processes or man-made activities. The natural process of eutrophication is caused by lake aging across time, climate change, atmospheric deposition, or weathering rocks (Khatri & Tyagi, 2015). Along with that, urbanization, man-made activities such as deforestation for construction have worsened the situation as water bodies have been used as dumping sites or sewers that complicated their uses (Hossain & Mahmud, 2019; Rajendran, Rajan, Raja, Prathipa, & Dheenadayalan, 2015).

Water pollutants can be classified into various categories, including physical, inorganic, organic compounds, biological, and radiological. Physical pollutants refer to turbidity, suspended solids, or temperature. Meanwhile, an organic and inorganic compound such as oil and grease, detergent, coal, heavy metal, cyanide, and others is also one of the pollutants found in lakes. Additionally, biological pollutants such as viruses or bacteria and radiological pollutants like uranium might affect the water quality in lakes (Teow, Mohamad, Ramli, Sajab, & Mohamad Mazuki, 2018).

The increasing pollutants load into water bodies causes continuous degradation to its quality (Sharip, Zaki, Shapai, Suratman, & Shaaban, 2014). Focusing on the lake ecosystem, excessive pollutants could develop a toxic algae bloom, fishes death, excessive growth of macrophytes, and interfered with the water supply as well as economic losses (Du et al., 2019; Tibebe, Kassa, Melaku, & Lakew, 2019).

Therefore, water quality needs to be monitored from time to time to ensure the safety of the domestic water supply (Chan, Lee, & Zakaria, 2016). Besides, good water quality in various aquatic ecosystems will ensure optimum species survival (Naubi, Zardari, Shirazi, Ibrahim, & Baloo, 2016). In Malaysia, water quality monitoring is carried out by the Department of Environment (DOE) and the Engineering Services Division of the Ministry of Health. Water Quality Index (WQI) has been used as a reference to measure water quality. Water samples are collected at monitoring stations and analyzed to determine their physicochemical and biological features. The water quality is assessed based on parameters including dissolved oxygen, pH, temperature, suspended solids, nutrients, heavy metal, alkalinity, or electrical conductivity. These parameters gave a different range, which determines water quality status. Specifically, to the lake ecosystem, its water quality can be classified as oligotrophic, mesotrophic, or eutrophic based on physicochemical and biological features (Bhateria & Jain, 2016; Gorde & Jadhav, 2013).

Hence, to protect the water bodies, the primary cause of water pollution should be well understood. The mechanisms leading to water pollution and its associated ecosystem responses should be assessed on a local basis due to its site-specific nature (Sinang, Reichwaldt, & Ghadouani, 2015). Upon understanding the mechanisms, any suitable treatment or solution can be discussed and implemented to lessen the water pollution issues.

1.2 Research background

Lakes are one of the most crucial water resources provide a support system for the ecosystem and human beings. Lakes are also common in use for various recreational activities such as kayaking and swimming (Zakaria & Sharip, 2007). In Malaysia, there are three natural lakes known as Chini lake, Kenyir lake, and Bera lake, and around 73 man-made lakes. These lakes engage with their own functional for maintaining a dynamic ecosystem (Sharip & Zakaria, 2008). Lakes or reservoirs function as water supply, hydroelectricity sites, flood mitigation, aquaculture, and eco-tourism (Sharip, Zaki, Shapai, Suratman, & Shaaban, 2014). Anthropogenic and natural influences, climate, geological factors, and hydrological factors have been reported as recognized factors in affecting lake water quality (Low et al., 2016).

To date, eutrophication is a global problem that continuously deteriorates lakes' water quality (Du et al., 2019; Withers, Neal, Jarvie, & Doody, 2014). Eutrophication can be interpreted as the excessive growth of algae biomass and aquatic plants due to the enrichment of nutrients (Ansari & Gill, 2014; Frumin & Gildeeva, 2014; Lewis, 2011; Smith, Wood, McBride, Atalah, & Hamilton, 2016). Sharip and Zakaria (2008) had reported that around 60% of 90 lakes in Malaysia are experiencing eutrophication.

Eutrophication devalues the water quality in terms of pH, dissolved oxygen, turbidity, odor, or taste (Frumin & Gildeeva, 2014). Chlorophyll-*a*, total phosphorus, and total nitrogen are critical indicator in evaluating eutrophication levels in lake ecosystems (Du et al., 2019). As eutrophication has become a global interest, further clarification of mechanisms involved in eutrophication progression is needed. The sources or determinants for eutrophication might differ between lakes, and this has become the crucial element in determining the trophic state of the lake (Najib, Ismail, & Omar, 2017; Sharip & Zakaria, 2008).

Water quality in lakes is influenced by external input into the lake, nutrient cycling, and internal loading (Yuk, Shin, Khia, & Teang, 2015). Nutrients are known as an accelerator for eutrophication (Ansari & Gill, 2014). Nitrogen (N) and phosphorus (P) are the main elements that contribute to eutrophication (Ansari & Gill, 2014; Dodds & Smith, 2016). In fact, some studies have suggested that phosphorus by itself is the leading cause of eutrophication (Kane, Conroy, Richards, Baker, & Culver, 2014; Schindler, Carpenter, Chapra, Hecky, & Orihel, 2016). Phosphorus is the limiting factor for eutrophication and significantly increases phytoplankton growth (Carpenter et al., 1998; Xu et al., 2015). Phosphorus is a fundamental nutrient that needs to be controlled to reduce eutrophication as it can be found naturally or artificially (especially in agriculture) (Lee, 1973). Phosphorus enters the lake either in organic or inorganic forms. In a lake, phosphorus can be categorized into dissolved inorganic phosphorus (DIP), dissolved organic phosphorus (DOP), particulate inorganic phosphorus (PIP), and particulate organic phosphorus (POP) (Ready, Kadlec, Flaig, & Gale, 1999).

Previous research has established that other than phosphorus, nitrogen also plays a crucial role in eutrophication (Jiang et al., 2016; Monchamp, Pick, Beisner, & Maranger, 2014; Rabalais, 2002). The high solubility of mineral nitrogen entered the lake more than molecules or organic forms of nitrogen (Zieliński, Dunalska, Grochowska, Bigaj, & Szymański, 2013). High nitrogen concentration in lakes caused by nitrogen retention, which is determined by three factors known as denitrification, sedimentation, and uptake by aquatic plants (Saunders & Kalff, 2001). Lakes that are sensitive to excessive nitrogen due to the nitrogen cycle gave an insight that there is a need for combined phosphorus and nitrogen removal management (Paerl et al., 2016).

Nutrient input into lakes arises from two distinct external pollution sources, point and non-point sources. For example, point sources may include industrial waste, while non-point sources include surface runoff from agriculture or residential areas (Ashraf, Maah, & Yusoff, 2010). Point sources are manageable. In contrast, non-point sources elicit more significant areas and difficult to control (Carpenter et al., 1998).

In addition to the inputs from external sources, phosphorus, and nitrogen input into the lake ecosystems can also be described in terms of internal loading. Internal loading of phosphorus originates from lake sediments (Pettersson, 1998; Zhang, Liu, & Lu, 2015). Internal phosphorus loading is different in a deep lake and shallow lake. In a deep lake, lake stratification influences the release of phosphorus compared to the shallow lake, where sediment and water are fused regularly (Johnson, 2010).

Figure 1.1 presents an overview of the internal and external nutrients loading into a lake ecosystem. Phosphorus and nitrogen enter the lake and remain in sediment. Then, the dissolved phosphorus returns to the water column via various mechanisms (Søndergaard, Jensen, & Jeppesen, 2003). Ekholm, Malve, and Kirkkala (1997) outlined that the internal loading of phosphorus dispensation due to anoxia and flowing of the organic and inorganic bottom sediments. Distinctive mechanism of phosphorus released into the water column includes resuspension, temperature, redox, pH, iron-phosphorus ratio, chemical diffusion and bioturbation, mineralization and microbial processes, and submerged macrophytes (Søndergaard et al., 2003). Meanwhile, nitrogen enters lakes in the form of ammonia or nitrate, which can be released back into the water column from sediment (Zhang, Wang, & Wu, 2014).

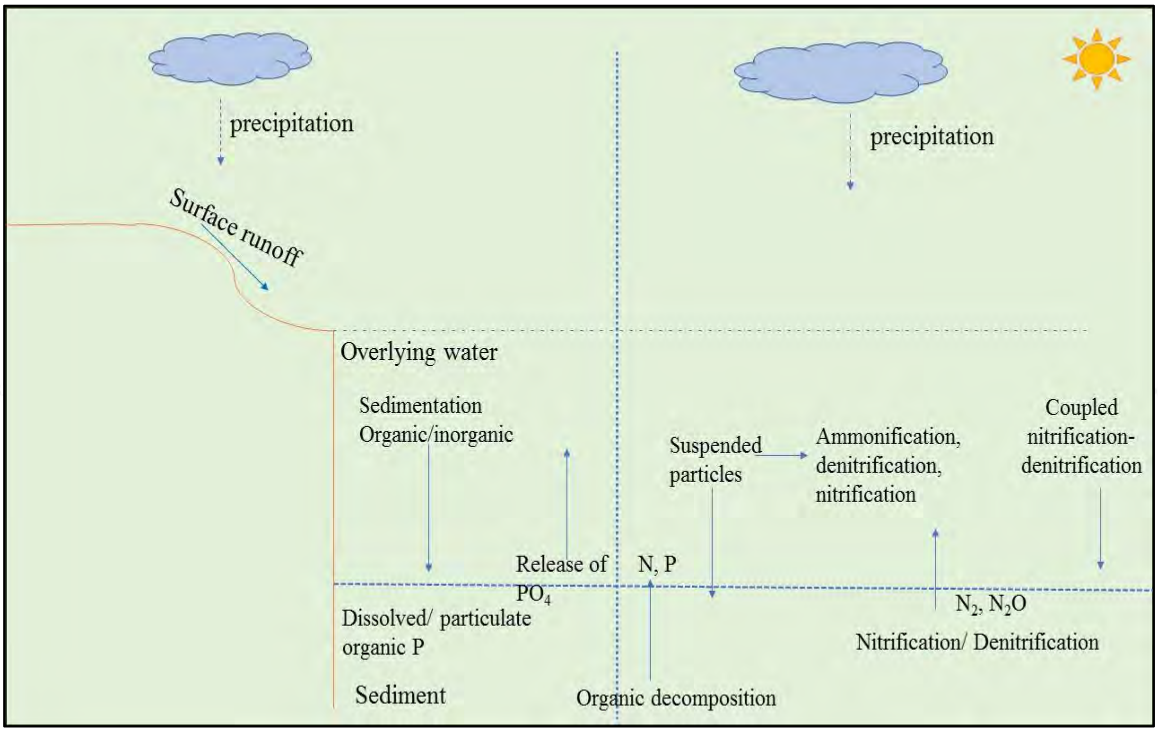

Figure 1.1. Sources of internal and external nutrients loading in lake's ecosystem. Adapted from Xia et al. (2018) and Ready et al. (1999)

External phosphorus and nitrogen loading due to human activities are known as the primary cause of increasing eutrophication worldwide (Fastner et al., 2016; Shi et al., 2019). Smith, Wood, McBride, Atalah, and Hamilton (2016) agreed that human activities enhance the input of phosphorus, causing eutrophication and inflate the algal growth. Likewise, various nitrogen sources include domestic and industrial sewage discharge, atmospheric deposition, livestock manure, fertilization, and soil nitrogen mineralization, are known to affect water quality (Zhang et al., 2018). Particularly, internal and external phosphorus and nitrogen loading in the lake bring an impact on the lake's ecosystem.

Since 1960, aquatic organisms, biomass, and community structure changes due to the elevation of phosphorus and nitrogen in lakes (Köhler et al., 2005). Even in low nutrient levels, a high abundance of cyanobacteria biomass can be detected. This is due to the fact that some cyanobacterial physiology is capable of altering nutrient cycling in the lake (Cottingham, Ewing, Greer, Carey, & Weathers, 2015). Anoxia and high water turbidity are also common symptoms of lake eutrophication (Schindler et al., 2008).

In conclusion, phosphorus and nitrogen inputs either from external anthropogenic sources or internal sediment release can lead to eutrophication progression in lakes (Schindler et al., 2016). In-line with the growing concern of lake eutrophication, further studies on the influence of internal and external phosphorus and nitrogen loading on eutrophication progression are needed for more sustainable lake protection.

1.3 Problem statement

Eutrophication has been the subject of recent investigations as it is considered a significant threat to the vital sources of water (Mir, Sahid, Gasim, & Rahim, 2015; Sharip & Zakaria, 2008). Waste from municipal and industries, sewage treatment plants, animal farms, and agriculture are the rising factors recognized as significant water pollution sources in Malaysia (Daud, Abdulrahman, & Idrus, 2016; Mir et al., 2015). These anthropogenic activities are known to cause eutrophication (Schindler et al. 2016) due to their abundant phosphorus and nitrogen content (Brase, Sanders, & Dähnke, 2018; Wu, Wu, Liang, Liu, & Wang, 2018).

Phosphorus retains either in organic or inorganic forms through physical, chemical, and biological processes in lakes (Reddy, Newman, Osborne, White, & Fitz, 2011). Phosphorus enrichment enhances the primary productivity in lakes (Smith et al., 2016). Soluble reactive phosphorus from sediments has also been identified to stimulate primary productivity (Roy, Nguyen, Bargu, & White, 2012). For example, phytoplankton biomass is influenced by nutrient accumulation in lakes (Dubourg et al., 2015). However, environmental factors, such as turbidity and light influence primary productivity (Tse et al., 2015). Apart from phosphorus, nitrogen is also involved in contributing to eutrophication in water bodies. Nitrogen from agriculture, land clearing activities, anoxic conditions of the lakes, and organisms' decay raise the nitrogen concentration in lakes (Suratman, Bedurus, & Seng, 2017).

To date, many studies had been carried out to investigate the role of phosphorus, nitrogen, and its abatement in controlling the lake's eutrophication. It is generally accepted that reducing phosphorus concentration in the lake would reverse the eutrophication process (Schindler,2012). Moreover, Wu et al. (2018) and Woodland et al. (2015) highlighted that reducing external phosphorus and nitrogen inputs is the prevalent practice in controlling eutrophication. Even so, the dynamics of different phosphorus and nitrogen inputs as either internal or external in regulating the eutrophication symptoms remain widely unexplored. Kane et al. (2014) had described that there is a lack of information on the patterns of external and internal phosphorus loading and how the lakes respond to the loads from different sources. In addition, reducing eutrophication becomes complicated as the continuous release of phosphorus from sediments throughout the year (North et al., 2015). Likewise, nitrogen content from fertilizer brings high risk in lake water quality, and reducing internal and external nitrogen input from different sources might mitigate the lake from becoming more eutrophic (Gao et al., 2019). Therefore, it shows that there is less understanding of the phosphorus and nitrogen cycle that regulates eutrophication in lakes.

Moreover, climate changes play as one influential factor that will likely increase the internal and external phosphorus and nitrogen loading by rising sediment oxygen demand and phosphorus or nitrogen release (Nürnberg, LaZerte, Loh, & Molot, 2013; Qiu, Huang, Zeng, & Zhou, 2019; Xia et al., 2016). However, the effect depends on the lake and seasons (Wagner & Erickson, 2017). Sinha, Michalak, and Balaji (2017) highlighted that precipitation would play an essential factor in determining eutrophication status in lakes as high precipitation increases runoff that transports nutrients into lakes (Wagner & Erickson, 2017). Therefore, eutrophication also depends on climate change, which varies between regions that can positively or negatively impact the lake's ecosystem (Ventelä et al., 2011).

On the other hand, nutrient loading might react with another site-specific response, thus produces different in-lake responses (Sinang et al., 2015). Lake morphometry can also significantly influence lake water quality (Noges, 2009). It was suggested that low water levels might worsen the eutrophication condition in a lake

(Sharip, Yusoff, & Jamin, 2018). The variability in climatic conditions or lake water depths influences the phosphorus and nitrogen retention in lakes, which is proportionally related to high nutrient inputs (Barbosa, Bellotto, Silva, & Lima, 2019). Yet, fewer studies that have focused on the impact of water level on eutrophication (Robertson, Juckem, Dantoin, & Winslow, 2018). Therefore, it is crucial to investigate a relationship of nutrient loading with eutrophication symptoms and progression on site-specific basis, as the lake's water quality varies based on their climate, local geology, and land use (Ashraf, Maah, & Yusoff, 2012).

To date, the eutrophication model focused only on the nutrients and phytoplankton, which likely limits the understanding of eutrophication. More complex predictive models, especially between internal and external nutrients loading on eutrophication progression, are needed to understand and manage the eutrophication process (Hellweger, 2017; Sharip et al., 2016; Vinçon-Leite & Casenave, 2019). Also, about 60% of lakes in Malaysia were eutrophic (Sharip et al., 2014). Since eutrophication is generally critical in Malaysia, a deep understanding of nutrient loading, especially phosphorus and nitrogen, need to be further investigated. Lake morphology will also be highlighted as only a few studies discussed this, although it is vital to understand lake water quality status (Fazli et al., 2016). In this study, Slim River Lake was chosen as a sampling site to explore and understand the role of different phosphorus and nitrogen input in regulating eutrophication symptoms and progression. Moreover, this study also investigate the connection between cyanobacteria and macrophyte growth to variations in phosphorus and nitrogen loading patterns into the lakes. Model development in this study potentially brings additional knowledge to understand eutrophication progression in a shallow freshwater lake.

1.4 Research objectives

Five objectives were identified to investigate the role of phosphorus and nitrogen as the pollutants that contribute to cyanobacteria and macrophyte growth in Slim River lake. In more specific, this study aims to:

1. Establish the hydro morphology profiles for Slim River Lake.
2. Determine temporal variations of water physicochemical properties for Slim River Lake.
3. Analyze the correlation between different nutrient loads and in-lake total phosphorus and in-lake total nitrogen levels.
4. Measure the effect of different nutrient loading on cyanobacteria biomass, cyanobacteria community structure, and total macrophyte abundance.
5. Develop a PCA model for eutrophication progression forecast based on nutrient loading patterns and water column physicochemical properties.

The question of concern in this study is:

1. What are the hydro morphology profiles of Slim River Lake?
2. What are temporal variations of water physicochemical properties in the Slim River Lake?

3. How does internal or external nutrients loading correlate with in-lake total phosphorus and in-lake total nitrogen levels?
4. How does internal and external nutrients loading affects cyanobacteria biomass, cyanobacteria community structure, and total macrophyte abundance?
5. How the progression of eutrophication can be forecasted based on nutrients loading patterns and water column physicochemical properties?

The hypotheses of this study include:

1. The variability of in-lake total phosphorus and in-lake total nitrogen loading is influenced by either internal or external total phosphorus and total nitrogen loading.

2. Fluxes of internal and external nutrients loading promote the rapid cyanobacteria growth and cyanobacteria dominance and increase total macrophyte abundance.

1.5 Significance of the study

This study is essential to understand the role of phosphorus and nitrogen in the eutrophication process. In this present study, the internal and external loading of phosphorus and nitrogen are the critical factor in investigating eutrophication in the lake. This study added to the body of knowledge in understanding eutrophication progression in an urban shallow lake ecosystem, especially phosphorus and nitrogen from the lake's sediment and stormwater runoff. In addition, this study developed a model to explained the role of internal and external nutrients loading in regulating eutrophication indicators in the Slim River Lake. In conclusion, the lack of knowledge on the lake's responses to different phosphorus and nitrogen loading sparks an interest in exploring how this phosphorus and nitrogen input leads to eutrophication. With this knowledge, accessible treatment to restore lakes from eutrophication can be taken. Any suitable treatment will help improve water quality so that there is no effect on humans' health and the ecosystem.

1.6 Limitation of the study

This study highlighted several limitations. Firstly, the sampling area is only limited to Slim River lake with 13 months sampling duration. Slim River Lake is chosen as this lake is surrounded by different land uses. This lake is also a popular spot for various recreational activities among the local communities. Furthermore, this lake had been reported to have high algal bloom in the previous studies. Secondly, this study solely focused on the internal and external loading of phosphorus and nitrogen in Slim River lake. Phosphorus and nitrogen are only quantified as total phosphorus and total nitrogen. Thirdly, this study only highlighted the primary producers such as cyanobacteria and macrophyte as eutrophication symptoms.