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Role of Internal and External Nutrients Loading in Regulating In-Lake Nutrient Concentrations in a Eutrophic Shallow Lake

Amy Rose Aeriyanie[1], Som Cit Sinang[1*], Nasir Nayan[2] and Keong Bun Poh[1]

[1]*Biology Department, Faculty of Science and Mathematics, Sultan Idris Education University, Perak, Malaysia*
[2]*Geography Department, Faculty of Human Sciences, Sultan Idris Education University, Perak, Malaysia*

*Corresponding author: somcit@fsmt.upsi.edu.my

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Abstract

The information on changes in total phosphorus and total nitrogen concentrations of lake in response to variations of different nutrients loading is critical for the selection of an appropriate lake management strategy. This study aimed to evaluate the influence of internal and external nutrients loading in controlling in-lake nutrient concentrations in a shallow lake system. This study was conducted in Slim River Lake for 12 months to quantify internal, external total phosphorus and total nitrogen loading, and in-lake total phosphorus and total nitrogen concentrations. Total phosphorus and total nitrogen in storm water and grab water samples were quantified using ascorbic acid and hydrazine reduction method. Study results indicated that internal total phosphorus and total nitrogen loading fluctuated from 150.17 kg to 7,538.33 kg and 2.72 kg to 42.23 kg, respectively, thus suggesting the significant sediment phosphorus and nitrogen released into the water column. Mobilization of nutrients from the surrounding area was indicated by external total phosphorus and total nitrogen loading, which ranged from 19,800 kg to 401,500 kg and 67.81 kg to 4,611.67 kg, respectively. In-lake total phosphorus and total nitrogen concentrations ranged from 1.2 mg/L to 46.22 mg/L and from 0.14 mg/L to 0.65 mg/L, respectively. Pearson correlation analysis suggests that in-lake nutrient concentrations were only significantly correlated to the internal total phosphorus ($r = 0.82$, $p < 0.05$) and internal total nitrogen ($r = 0.60$, $p < 0.05$) loading. These results indicated that the internal total phosphorus and total nitrogen loading could have more impact on the lake eutrophication as compared to external sources. Hence, future restoration strategies that include internal and external nutrients management should be considered to restore Slim River Lake.

Keywords: Nutrients; Eutrophication; Internal loading; External loading; Total phosphorus; Total nitrogen; Slim River Lake

1. Introduction

Phosphorus and nitrogen are two primary limiting nutrients in regulating water quality in a lake (Liang *et al.,* 2015; Rabalais, 2002; Shah *et al.,* 2019). These nutrients often cause eutrophication problems in lakes, which poses health risks not only to humans but also to the animals receiving direct or indirect services from lakes (Du *et al.,* 2019; Hoagland *et al.,* 2009; Meneely and Elliott, 2013). In addition, eutrophication leads to potential economic losses due to reduced functional and aesthetic values of the lake for recreational and eco-tourism (Nayan *et al.,* 2014). In Malaysia, more than 60 percent of the 90 lakes surveyed have experienced eutrophication problems (Huang *et al.,* 2015). The quality of lake water in Malaysia is evaluated according to National Lake Water Quality Criteria and

Standard (NAHRIM, 2015), which set the permissible limit of total phosphorus and total nitrogen at 0.01 mg/L and 0.35 mg/L, respectively.

Phosphorus and nitrogen are introduced into a lake ecosystem through various point and non-point sources, accumulated into the sediment (Dubey and Dutta, 2020; Liang *et al.,* 2015; Wongaree, 2019; Yang *et al.,* 2019). The release of phosphorus and nitrogen from sediment into water-column is known as internal loading. This process is controlled by various mechanisms involving chemical (redox potential, pH), biological (mobilization, mineralization), or physical (diffusion, sediment mixing) processes (Kowalczewska-Madura *et al.,* 2019; Yang *et al.,* 2013). In other words, internal loading also derived from the old external loading that sinks in the sediments (Nürnberg *et al.,* 2013) or decomposition of organic matter in the sediment (Small *et al.,* 2018). A study conducted by Lee et al. (2019), had demonstrated that sediment acts as a sink of nutrients and creates nutrients flux, which triggers the algal bloom. Regulation on the internal cycling of phosphorus and nitrogen leads to long term eutrophication that hinder the lake restoration (Immers *et al.,* 2015).

In addition to the internal loading, external loading, particularly from stormwater runoff, also bring extensive eutrophication into a lake (Brudler *et al.,* 2019; Haque *et al.,* 2016). The stormwater runoff from different sources carries together phosphorus and nitrogen into lakes. This process is influenced mainly by rainfall intensity, especially in a tropical climate region (Brudler *et al.,* 2019; Maharjan *et al.,* 2016). Moreover, anthropogenic activities or land development also contribute to transporting phosphorus and nitrogen into a lake (Yang and Toor, 2018).

At present, various methods, including constructed wetlands and rain gardens, are employed for lake restoration measures to reduce the external nutrients loading. However, many difficulties in managing stormwater runoff have been identified (Lim and Lu, 2016). These difficulties include leaching of nutrients and low nutrients removal efficiency as compared to total suspended solids. Moreover, the poor performance of wetlands to remove phosphorus compared to nitrogen could also cause wetlands to become another source of phosphorus loads (Chua *et al.,* 2012; Lim and Lu, 2016). Lim and Lu (2016) also point out that land use and climate change might interfere with the performance of wetlands in managing stormwater runoff quality. Inclusively, most practices to limit the entrance of external nutrients loading may not be entirely successful due to the significance of internal nutrients loading (Steinman *et al.,* 2009).

Søndergaard *et al.* (2013) had highlighted that understanding of internal nutrients loading is essential in managing lake water quality. Roy *et al.* (2012) and Tammeorg et al. (2016) also emphasized that a continuous release of phosphorus sediment could happen even though there was a reduction of external nutrients loading. In addition, it was also reported that lack of efficiency in the bioretention basin to remove nutrients in tropical climates could happen due to high rainfall intensity (Wang *et al.,* 2017). Therefore, nutrients reduction either through internal or external loading is somewhat complicated, and the primary site-specific regulator of in-lake nutrients concentration is not commonly identified (Huang *et al.,* 2019; Kane *et al.,* 2014). Inadequate studies have been conducted to investigate how the internal and external nutrients loading in the tropical urban lake could affect in-lake total phosphorus and total nitrogen concentrations. Hence, it is essential to understand the influence of internal and external nutrients loading in controlling in-lake nutrient concentrations. This study aimed to investigate the relationship between internal and external loading of total phosphorus and total nitrogen with in-lake total phosphorus and total nitrogen concentrations in a local shallow lake. This lake has been classified as eutrophic based on data reported by Sinang *et al.* (2019). This information will assist the authority in deciding whether to implement an internal or external loading control strategy to combat eutrophication in maintaining the lake status as a recreational lake.

2.Materials and Methods

2.1 Study area and sampling

Slim River Lake (3° 49’ 26.688” N; 101° 24’ 30.6216” E) is situated at Muallim district, Perak state, Malaysia. This lake is a human-made lake with a mean depth of about 3.84 m and a width of about 20 m. Slim River Lake has the surface area and the volume of 82862.20 m^2 and 3.50×10^5 m^3, respectively. This lake is mainly utilized for recreational activities for residents. Land use around this lake is primarily residential, agriculture, such as oil palm plantation and livestock breeding.

Sampling was carried out on storm water runoff and lake water for 12 months started in May 2018 and ended in April 2019. Lake water was sampled twice a month, while the storm water runoff was sampled on every storm event. Grab lake water and storm water samples were taken from six sampling locations around the lake (Figure 2). Three grab lake water samples were collected 15 cm below the surface from each sampling site on every sampling event. Storm water runoff samples were collected in a 500 mL tank fixed and leveled on the ground (Department of Ecology, 2007). The water samples were placed into a chilled container (4 ºC) during transport to the laboratory and analyzed within 24 hours. The collected samples were analyzed for its total phosphorus and total nitrogen using the ascorbic acid method and hydrazine reduction method (APHA, 2005), respectively. Additionally, in-situ parameters such as water temperature (Aquaprobe AP-Lite), dissolved oxygen (YSI 550A), pH (Sartorius), and turbidity (Turbidimeter-TN-100, Eutech) were measured in each sampling event.

2.2 Total phosphorus and total nitrogen analysis

For each collected sample, 50 mL water was used for total phosphorus analysis. Samples were predigested using persulphate digestion method to allow the formation of orthophosphate. Then, the samples were analyzed using the ascorbic acid method. Meanwhile, 20 mL of water samples were used for total nitrogen analysis. The samples were predigested using alkaline persulphate method to oxidize nitrogenous compounds to nitrate completely. The samples were then analyzed using the hydrazine reduction method. The samples for total phosphorus and total nitrogen were measured at 880 nm and 535 nm absorbance using a UV-vis spectrophotometer (Biomate 3s, Thermo Scientific) (APHA, 2005), respectively.

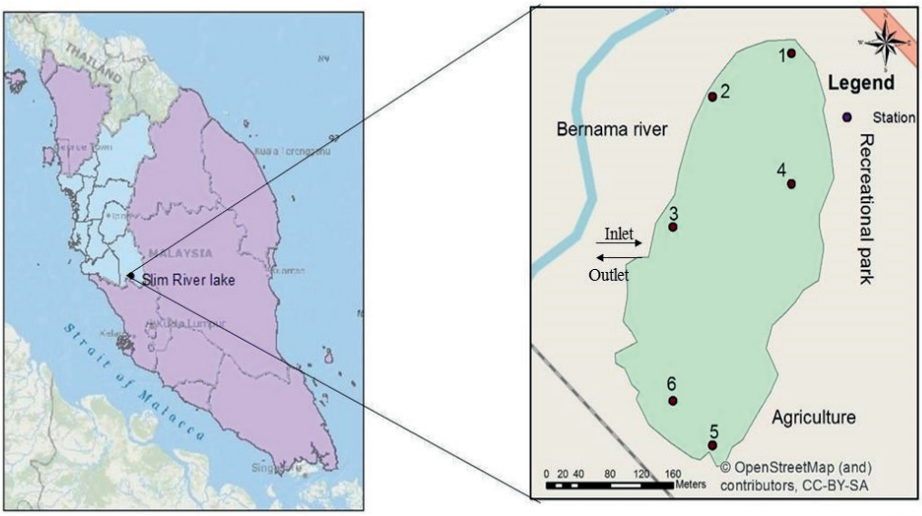

Figure 1. Location and the surrounding area of Slim River Lake

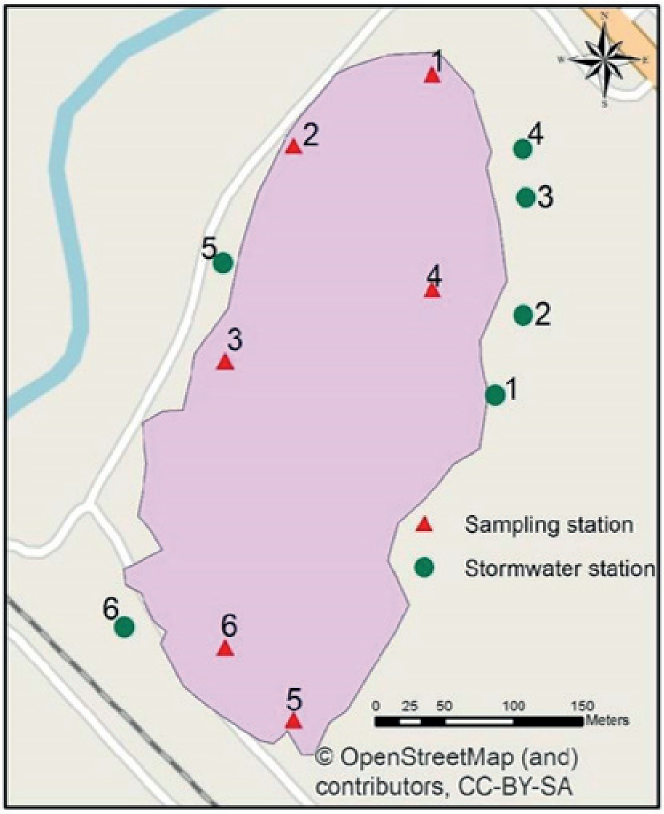

Figure 2. Locations of lake water and storm water sampling points around the Slim River Lake

2.3 Rainfall data and analysis

The daily rainfall data from Behrang and Ulu Slim stations were obtained from the Malaysian Meteorology Department and Department of Irrigation and Drainage. The minimum monthly rainfall in Malaysia has been reported at 115 mm (Wong *et al.*, 2009; Wong *et al*., 2018). Therefore, on average, 3.8 mm of minimum rainfall per day (115 mm divide by 30 days) was used as a threshold limit in identifying the dry period in this study. Any period with rainfall lower or equal to 3.8 mm was defined as a dry period. Based on this minimum daily rainfall, five dry periods have been identified throughout the study period.

2.4 Internal loading calculation

In this study, internal loading was calculated by referring to the dry period identified throughout the study period. For each dry period, start date, end date, initial lake elevation, final lake elevation, initial total phosphorus, and total nitrogen, and final total phosphorus and total nitrogen were determined. The identified dry periods were noted as Period 1 (P1), Period 2 (P2), Period 3 (P3), Period 4 (P4), and Period 5 (P5), which indicated the period having less or equal to 3.8 mm of minimum rainfall. Lake volume was calculated from the lake water level data using Geographic Information System (GIS) software. The lake water level was measured once a month for 12 months. The water level was interpolated using the Inverse Distance Weighted (IDW), followed by a Triangulated Irregular Network (TIN) method. Lake volume of Slim River Lake was calculated for TIN data using a 3D analyst toolbox in GIS (Cross and Moore, 2014). The internal total phosphorus and total nitrogen loading were calculated using the following equation (Johnson, 2010):

$$L = (C_2 \times V_2) - (C_1 \times V_1)$$

L = Total period internal total phosphorus/total nitrogen load
C1 = Observed in-lake total phosphorus/ total nitrogen at the beginning of period
C2 = Observed in-lake total phosphorus/ total nitrogen at the end of period
V1 = Lake volume at the beginning of period
V2 = Lake volume at the end of period

2.5 External loading calculation

The external total phosphorus and total nitrogen loading were calculated from monthly runoff, total phosphorus, and total nitrogen concentration, and catchment area data using the following equation (McCarthy, 2008):

$$L = 0.226 \times R \times C \times A$$

where,
L = Load (monthly basis)
R = Monthly runoff (inches). This will be calculated from monthly runoff volume and runoff coefficient=0.3
C= Total phosphorus/ total nitrogen concentration
A = Catchment area (Acres)

The catchment area for Slim River Lake is manually calculated based on the location of the water inlet for this lake from the topography map. The catchment area for Slim River Lake was estimated at 4386 acres.

2.6 Statistical analysis

Data normality test was performed prior to detailed statistical analysis. The normality of data was assessed based on the Shapiro-Wilk test. Data were then log-transformed to meet the assumption of normality. Pearson correlation analysis was used to examine the relationship between the internal loading and external loading of total phosphorus and total nitrogen with in-lake total phosphorus and total nitrogen concentrations. Analysis results were considered significant at $p<0.05$.

3. Results and Discussion

3.1 Physicochemical parameter

Water quality parameters, including water temperature, dissolved oxygen, pH, and turbidity were measured from May 2018 until April 2019 (Figure 3). The monthly mean water temperature in this lake ranged from 29.22 ºC to 35.10 ºC. The highest water temperature was recorded in May 2018, and the lowest was in August 2018. Meanwhile, the monthly mean dissolved oxygen in the Slim River Lake ranged from 3.13 mg/L to 6.36 mg/L. The dissolved oxygen across the sampling months indicated oxygen depletion at certain periods when the concentrations were below 5 mg/L. As suggested by Worako (2015), at least 5 mg/L of dissolved oxygen is required to maintain a healthy aquatic life. As for pH, the monthly mean values ranged from 5.98 to 7.92, and slightly acidic pH value was recorded in February 2019. The monthly mean water turbidity in Slim River Lake ranged from 0.76 to 2.98 NTU. The highest water turbidity was recorded in September 2018, and the lowest was in February 2019.

3.2 Internal and external total phosphorus and total nitrogen concentrations

In general, five dry periods have been identified throughout the study period. The identification of dry periods was essential for the internal total phosphorus and total nitrogen loading calculation. As suggested by Nürnberg *et al.* (2013a), the influence of internal phosphorus and nitrogen loading can be identified when measurements of total phosphorus and total nitrogen concentrations are made in the absence of external sources, which can be achieved during dry periods. Figure 4 shows monthly rainfall distribution within the Slim River Lake region from May 2018 to May 2019. Meanwhile, Figure 5 shows the average daily rainfall distribution, which also indicated five dry periods (P1-P5) with the average daily rainfall less than or equal to

3.8 mm per day. Period 1 started from early July until the end of July (18 days). Period 2 started from early August until the end of August (21 days). Meanwhile, Period 3 started from the end of November to early December (10 days), Period 4 started and ended in December (15 days), and lastly, Period 5 started from the middle of December to early January 2019 (14 days).

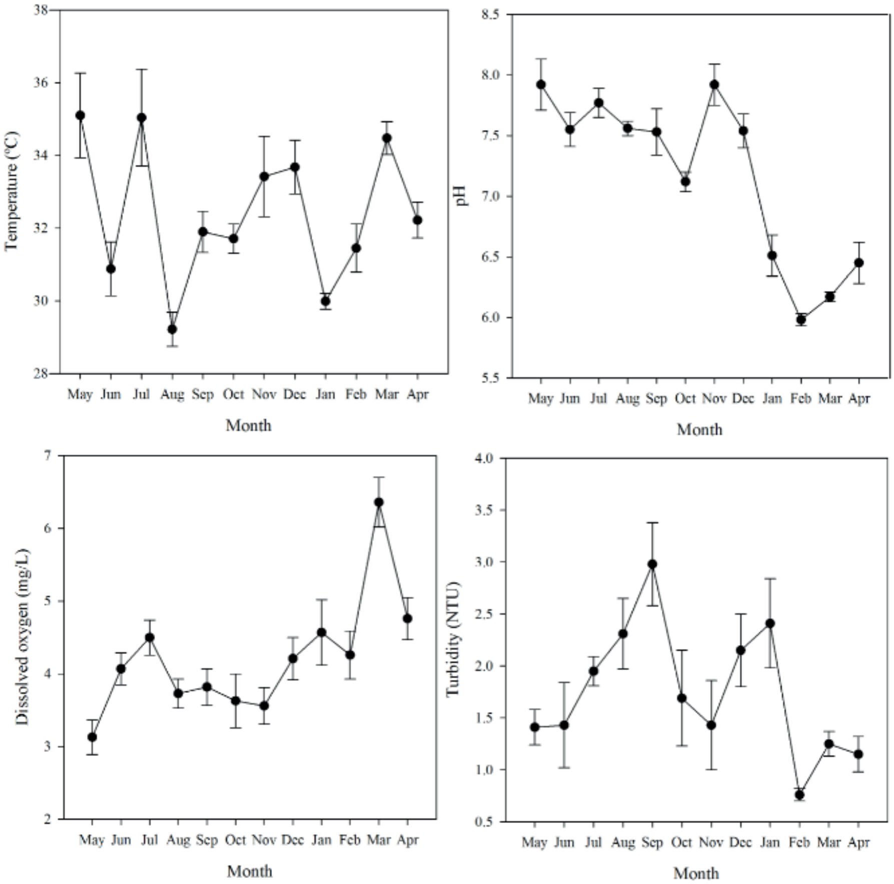

Figure 3. Monthly mean water temperature, pH, dissolved oxygen and turbidity in Slim River Lake

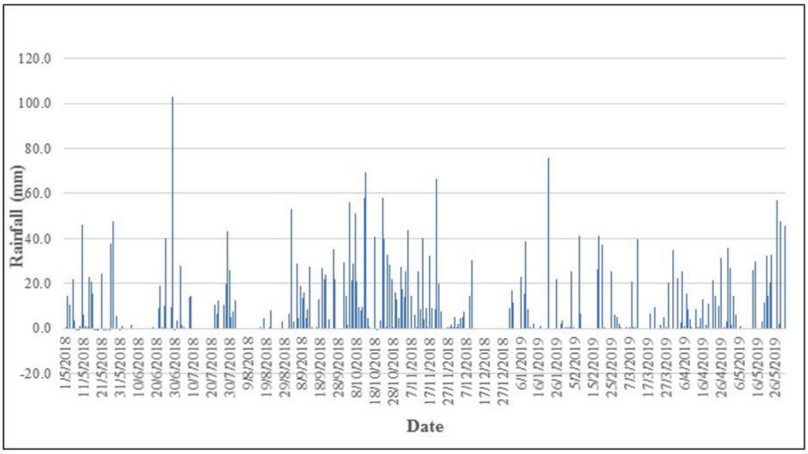

Figure 4. Monthly rainfall distribution in the Slim River Lake region

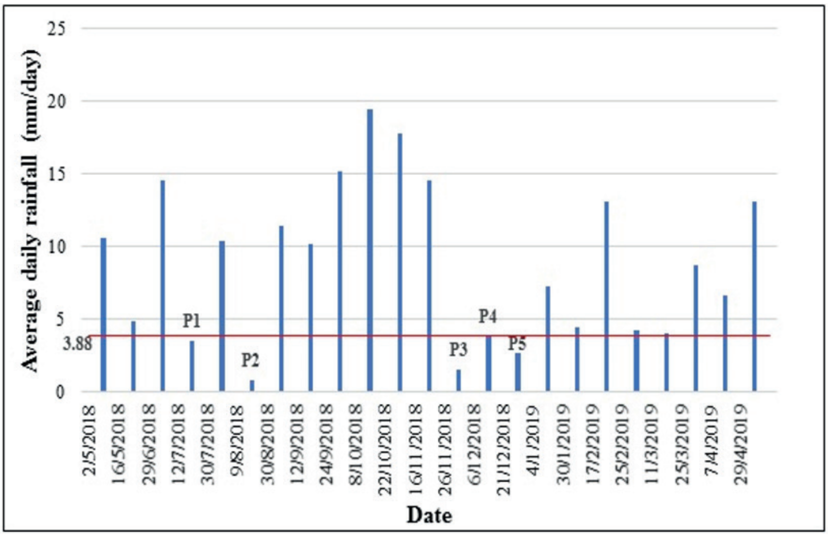

Figure 5. Average daily rainfall distribution in Slim River Lake region and five dry periods

Slim River Lake is a eutrophic lake which is exposed to different types of pollutants such as nutrients that impaired the lake water quality. Internal and external nutrients loading are known to damage the ecological balance of a shallow lake (Steinman *et al.,* 2009). It is widely reported that internal and external total phosphorus and total nitrogen loading into water bodies could vary across time and space (Nürnberg *et al.*, 2013b; Sondergaard *et al.,* 1993; Steinman *et al.,* 2009).

In this study, the internal total phosphorus and total nitrogen loading was calculated for each identified dry period. The positive internal loading values were defined as the release of sediment phosphorus. Meanwhile, the negative internal loading values were identified as phosphorus accumulation in sediment (Kowalczewska-Madura *et al.,* 2019b; Kowalczewska-Madura *et al.,* 2019c; Yang *et al.,* 2013). As shown in Figure 6, the internal total phosphorus and total nitrogen loading illustrate a similar pattern across five dry periods. Mean internal total phosphorus loading during the dry period ranged from 150.17 kg to 7,538.33 kg. The internal total phosphorus loading in the Slim River Lake was found higher compared to other studies, which reported that at least 99.6 kgP/season in summer (Kowalczewska-Madura *et al.,* 2014). Also, there were two periods (P2, P5) associated with phosphorus accumulation with values -200.50 kg and -5,375.00 kg. Meanwhile, the mean internal total nitrogen loading ranged from 2.72 kg to 42.23 kg. Nitrogen accumulation was also measured during the dry period 2, with a value of -4.06 kg.

These results suggest the potential sediment phosphorus and nitrogen release into the water column during the identified dry periods. The variations of phosphorus and nitrogen release from the sediment into the water column are known to be related to the changes in temperature or wind strength (Kowalczewska-Madura *et al.* 2019c). It has been reported that destratification and wind velocity could increase the phosphorus and nitrogen release from the sediment under aerobic conditions (Horppila *et al.,* 2017). Besides that, decomposition of organic matter also influences phosphorus release and accumulation in the lake (Katsev and Dittrich, 2013; Kowalczewska-Madura *et al.,*2019a). In contrast, the accumulation indicated by the observed negative internal loading values could be due to the presence of particle sedimentation in the water column or chemical adsorption of total phosphorus and total nitrogen to sediments (Steinman *et al.,* 2009).

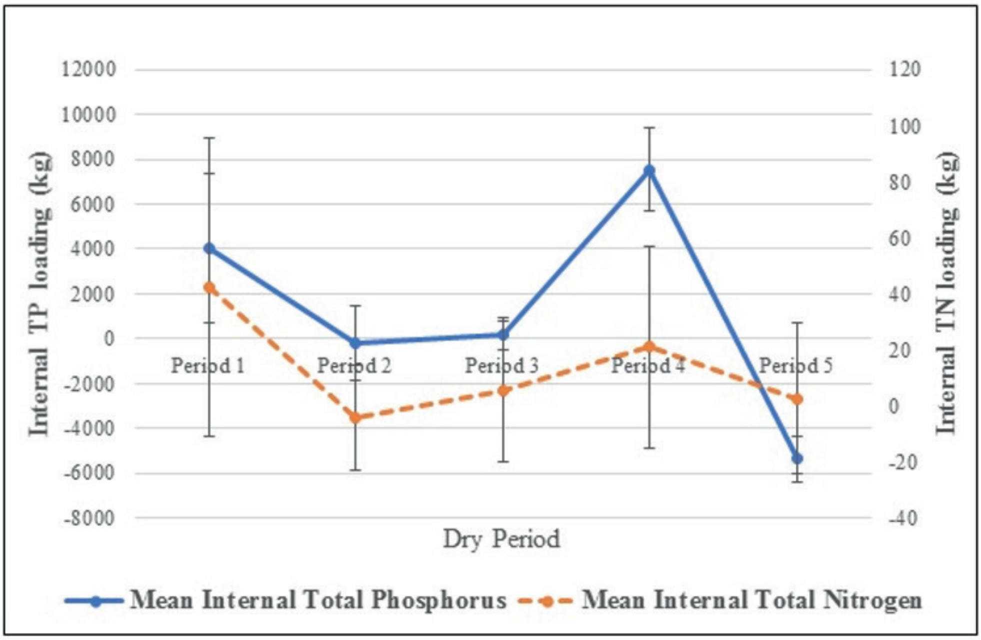

Figure 6. Internal total phosphorus and total nitrogen loading in Slim River Lake

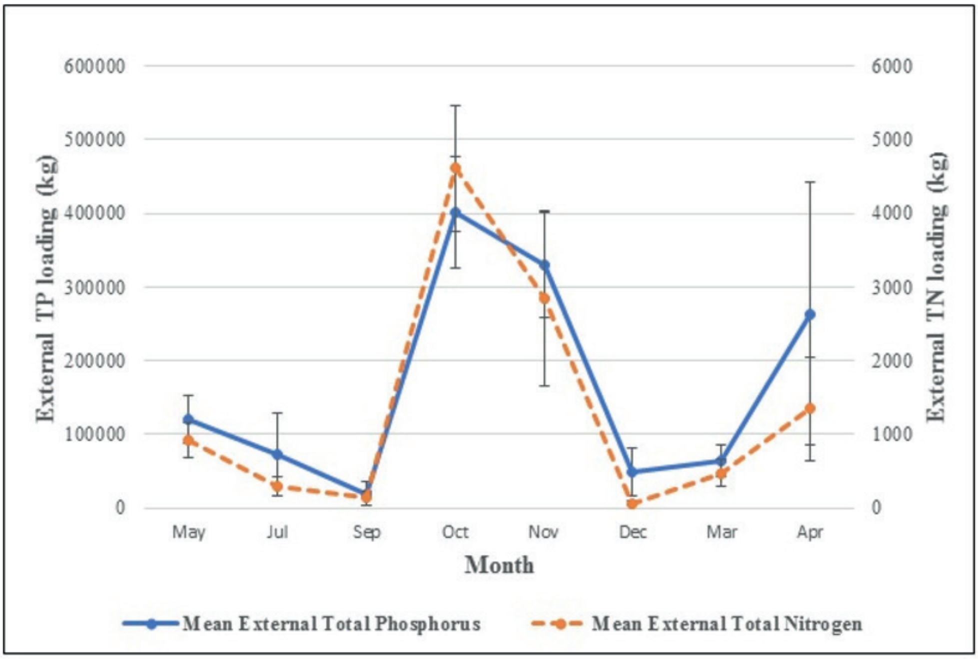

Figure 7. External total phosphorus and total nitrogen loading in Slim River Lake

In addition to the internal source, the results also suggest a significant amount of external total phosphorus and total nitrogen. The monthly mean external total phosphorus and total nitrogen loading are shown in Figure 7. In general, the external total phosphorus and total nitrogen loading showed a similar pattern throughout the sampling period. Monthly mean external total phosphorus loading ranged from 19,800.00 kg to 401,500.00 kg. High external total phosphorus loading might be associated with the manure of livestock breeding such as cows, storm water drain, and recreational activities such as kayaking and fishing in Slim River Lake (Aeriyanie *et al.,* 2020; Tibebe *et al.,* 2019). Meanwhile, monthly mean external total nitrogen loading ranged from 67.81 kg to 4,611.67 kg. The highest external total phosphorus and total nitrogen loading were recorded in October 2018, which related to the period with the highest amount of rainfall. This result indicated that phosphorus and nitrogen accumulated in the terrestrial ecosystem during dry periods were brought into the lake ecosystem during a period of high rainfall intensity. Subsequently, a lower amount of phosphorus and nitrogen concentration is expected after a series of rainfall (Zuraini *et al.,* 2018).

The study data also shows that the internal and external total phosphorus loading in the Slim River Lake were higher when compared to its internal and external total nitrogen loading. It has been suggested that land use, soil erosion, fertilizer, and macrophyte cover might increase phosphorus load into a lake (Ekholm and Lehtoranta, 2012; Ghani *et al.,* 2019; Markogianni *et al.,* 2016; Wang *et al.,* 2018). For example, oil palm plantations adjacent to the Slim River Lake could lead to high phosphorus losses. Ghani *et al.* (2019) has reported that at least 4.5 k ton P/year of phosphorus load could be introduced from fertilizers used at oil palm plantation. Furthermore, climate change (Vystavna *et al.,* 2017) and higher atmospheric deposition of phosphorus could also lead to increased phosphorus in lake water despite higher atmospheric nitrogen, which then changing the phosphorus limitation to nitrogen limitation in the lake (Camarero and Catalan, 2012).

The monthly mean total phosphorus and total nitrogen concentrations in the water column, termed as mean in-lake concentrations, are shown in Figure 8. In general, in-lake total phosphorus and total nitrogen concentrations fluctuate throughout the study period. Mean in-lake total phosphorus concentration ranged from

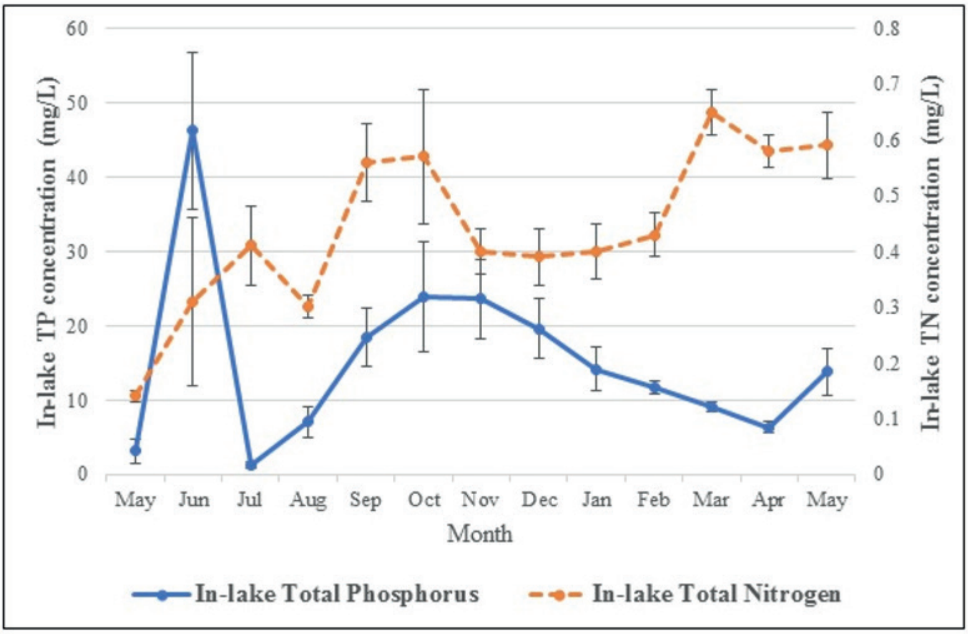

Figure 8. Monthly mean in-lake total phosphorus and total nitrogen concentration in Slim River Lake

1.2 mg/L to 46.22 mg/L. The highest mean in-lake total phosphorus was recorded in June 2018. High total phosphorus concentration throughout the sampling period indicated persistent eutrophication in the Slim River Lake (Aeriyanie *et al.,* 2020). Meanwhile, mean in-lake total nitrogen ranged from 0.14 mg/L to 0.65 mg/L, and the highest value was recorded in March 2019.

The fluctuations of in-lake total phosphorus and total nitrogen concentrations can be explained by the variations of internal total phosphorus and total nitrogen loading. Based on the Pearson correlation coefficient analysis, in-lake total phosphorus concentrations were significantly correlated to the internal total phosphorus loading ($r = 0.82$, $p < 0.01$). Similarly, mean in-lake total nitrogen concentrations were also significantly correlated to the internal total nitrogen loading ($r = 0.60$, $p < 0.05$). In contrast, the external total phosphorus and total nitrogen loading were not significantly correlated with the in-lake of total phosphorus and total nitrogen concentrations (Table 1).

Based on the results presented in Table 1, internal total phosphorus and total nitrogen loading might be a crucial factor that impaired the lake water quality. Similar findings were also reported in Kowalczewska-Madura *et al.* (2018) and Ostrofsky and Marbach (2019). Internal total phosphorus and total nitrogen loading could contribute to a significant amount of in-lake total phosphorus and total nitrogen during the dry period (Kowalczewska-Madura and Goldyn, 2011; Steinman *et al.,* 2009). The fluctuation of in-lake total phosphorus and total nitrogen during dry periods in a eutrophic shallow lake indicated the release of phosphorus from lake sediments (Matisoff *et al.,* 2017; Søndergaard *et al.,* 1999; Søndergaard *et al.,* 2013). A few factors are known to regulate the release rates of phosphorus and nitrogen. Phosphorus and nitrogen release rates increased with the increase in water temperatures (Dondajewska *et al.,* 2019). Water temperature influences on the internal nutrient loading have been established by Gudasz *et al.* (2015) and Wu *et al.* (2014), which suggest a significant role of temperature for organic matter decomposition. Moreover, phosphorus and nitrogen release rates from sediments could also differ between lakes as there are differences in temperature, water mixing, oxygen concentration, or intensification of organic matter (Chaichana and Dampin, 2016; Kowalczewska-Madura *et al.,* 2019c).

On the other issue, the results also suggest that in-lake total nitrogen concentrations in Slim River Lake were much lower when compared to the in-lake total phosphorus concentrations. These variations could indicate that there is less intensive nitrogen release from sediments. As nitrogen concentration is primarily controlled by organic matter decomposition in the sediments, interaction or mobilization of nitrogen to the water column is relatively slow. This might be due to nitrogen-fixing cyanobacteria, which incorporate nitrogen into organic matter or nitrogen might release as a gas into the atmosphere. Hence, it could result in low concentrations of in-lake nitrogen (Jarosiewicz, 2009).

Table 1. The Pearson correlation coefficient (r) between internal and external total phosphorus and total nitrogen loading with in-lake total phosphorus and total nitrogen concentrations

	In-lake total phosphorus	**In-lake total nitrogen**
Internal total phosphorus loading	0.82*	
External total phosphorus loading	0.15	
Internal total nitrogen loading		0.60*
External total nitrogen loading		0.06

*significant at p<0.05

Additionally, the internal nutrients loading pattern into a lake could be indirectly influenced by the surrounding land use. In Slim River Lake, high in-lake total phosphorus and total nitrogen concentrations might be due to high phosphorus and nitrogen released from the sediment. Agricultural land and livestock breeding surrounding Slim River Lake could cause more nutrients being mobilized into lake sediment, thus creating long-term phosphorus and nitrogen accumulation. The accumulated nutrients then act as an internal source of in-lake total phosphorus and total nitrogen concentrations. Similar to this study, Lee and Oh (2018) and Strokal *et al.* (2016) also stated that the release rate of nutrients or nutrient concentration in the lake water could be higher when the pollutant sources came from livestock or agricultural sources as compared to sewage sources.

External nutrients loading was also known to cause significant damage to the aquatic systems such as algal blooms, loss of biodiversity, and increased sedimentation rates (Shuhaimi-Othman *et al.,* 2008; Steinman *et al.,* 2015). In this present study, no significant correlation was observed between the external loading and in-lake total phosphorus and total nitrogen concentrations. These results could be due to flushing and dilution effects, which might decrease in-lake total phosphorus and total nitrogen concentrations. In contrast, flushing and dilution effects were not applicable during the dry period. Additionally, Jeppesen *et al.* (2005) and Hou *et al.* (2013) have also suggested that nitrogen loss during the denitrification process could exceed the amount of nitrogen entered into a lake through external loading, thus explained the observed insignificant correlation between the external loading towards in-lake nitrogen concentrations.

4. Conclusions

In conclusion, this study represents the first effort to quantify the internal and external loading of total phosphorus and total nitrogen into the Slim River Lake. The results emphasized the contribution of internal total phosphorus and total nitrogen loading toward in-lake total phosphorus and total nitrogen concentrations during the dry period. Further studies such as mesocosm experiments regarding sediment core, forms of phosphorus and nitrogen, or environmental influence in the release rate of nutrients from sediments should be considered. Besides that, a long-term study might be needed to fully understand the impact of external nutrients loading on eutrophication progression in this lake. This is due to the fact that storm water runoff also continuously transports nutrients from the catchment area, and a preventive technique such as filtration and settling should also be considered. Therefore, holistic strategies that include internal and external nutrients loading management should be primarily discussed to restore Slim River Lake.

Acknowledgments

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