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Comparison of water level and eutrophication indicators during the wet and dry period in a eutrophic urban lake

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ABSTRACT

Eutrophication modifies lakes' ecological balances and threatens its viability. To date, eutrophication management strategies have been related to nutrient reduction in the lakes' water column. However, nutrient reduction strategies are complicated by the variations of the lake's water level, nutrient concentration, and eutrophication symptom, which are primarily known to be influenced by the local rainfall patterns. Therefore, this study aimed to compare the variability of water level, total phosphorus, and total chlorophyll-*a* concentrations in Slim River Lake during wet and dry seasons. In this study, water sampling and depth measurements were carried out from six sampling points for 1 year. Water samples were used to quantify total phosphorus and total chlorophyll-*a*. Our results showed that mean water levels in the studied lake ranged from 1.36 m to 5.46 m in the wet season and from 1.31 m to 5.41 m in the dry season, which implicated no significant difference ($p > .05$) between seasons in most sampling points. Total phosphorus present at concentrations exceeding 10 mg/L and showed small variations between wet and dry seasons. Mean total phosphorus concentrations varied from 10.55 mg/L to 26.66 mg/L in the wet season and 10.77 mg/L to 21.76 mg/L in the dry season and showed no significant difference between seasons. In addition, mean chlorophyll-*a* concentrations ranged from 14.35 mg/m^3 to 180.13 mg/m^3 and from 14.15 mg/m^3 to 39.27 mg/m^3 in wet and dry seasons, respectively. Chlorophyll-*a* concentrations showed significant differences ($p < .05$) between seasons in the deepest sampling points in the lake. The observed seasonal variations in total chlorophyll-*a* suggest the importance of algae monitoring during the wet season even when no apparent surge of phosphorus concentration is detected.

1. Introduction

Urban lakes can provide a diversity of ecosystem services and recreational activities to communities [1]. However, managing and maintaining lakes' water quality is demanding due to changes in land use and nutrient cycling [2]. Accumulation of nutrients from human activities, stormwater runoff, or urban water discharges leads to disruption in lakes' morphology, biology, and physicochemistry properties [3]. Together with altered hydrological profiles, the eutrophication phenomenon is threatening the viability and quality of most urban lakes globally [4,5].

Lake eutrophication is a natural process whereby anthropogenic phosphorus and nitrogen inputs into the water column can degrade lake water quality and affecting its aquatic ecosystems [3,6,7]. Specifically, eutrophication is triggered by the increased nutrients inputs from residential, industrials, and agricultural areas [6–8]. Algae blooms are the main effect of nutrient enrichment in the lakes [8]. Generally, eutrophication changes the structure and function of aquatic ecosystems, leads to the loss of aquatic biodiversity [9], and has negative impacts on human, social, and economic well-being [10].

Strategies used in controlling lake eutrophication, such as nutrient load reduction, are rather complicated. The nutrient discharge from different sources, together with variations in weather condition such as rainfall distribution, play an integral part in controlling nutrient loads into the lakes [11]. As suggested in earlier studies, rainfall and land use patterns were interconnected and could lead to an increment of nutrients in lakes [12,13]. Hashim et al. [13] also described that high intensities of rainfall produced surface runoff which brings along any nutrient into surface water that will affect sedimentation and water transparency.

At present, it remains a challenge for lake managers to propose effective strategies with consideration to both pollutant sources and seasonal variabilities in rainfall patterns [12]. As described in earlier studies, water inflow could change the water level, transport pollutants, and

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contribute to the variability of nutrient and phytoplankton concentrations [14,15]. Due to differences in lake morphology and climate variability, this study aimed to compare the variations of lake's water level, total phosphorus, and total phytoplankton biomass expressed as total chlorophyll-*a* during the wet and dry periods in a eutrophic urban lake.

2. Materials and methods

2.1. Site description and sampling

Slim River Lake (3° 49′ 26.688" N; 101° 24′ 30.6216" E) is located in Muallim district, Perak state, Malaysia (Fig. 1). This lake covers a total area of 8.28 ha with depth ranging from 1.31 m to 5.46 m. The catchment size of Slim River Lake is estimated at around 17.75 km^2. Slim River Lake is a eutrophic lake with high algae biomass [16].

Slim River Lake is an ex-mining lake and now well known as a famous fishing and recreational spot among the local community. Land use types around this lake are basically agricultural, recreational, and residential areas. Water enters Slim River Lake via direct rainfall recharge onto the lake surface or from surface runoff from the surrounding catchment. Additionally, this lake might also receive through-flow water from the adjacent Bernama river, which locates less than 100 m away.

Water sampling was conducted bi-monthly from May 2018 to April 2019. Water samples were collected from six sampling points (Fig. 2). Sampling points were located approximately five meters from the lake's shore and were accessed by boat. During each sampling, water samples were taken from 15 cm below the surface in triplicates. Water samples were collected using clean plastic bottles. All water samples were placed on ice and transported to the laboratory for further analysis.

2.2. Lake morphology characterization

Lake water level was measured bimonthly from the same six sampling points using levelling staff and recorded in metres (m). Then, the lake's bathymetric map was developed using Geographic Information System (GIS).

Fig. 1. Location of the study lake.

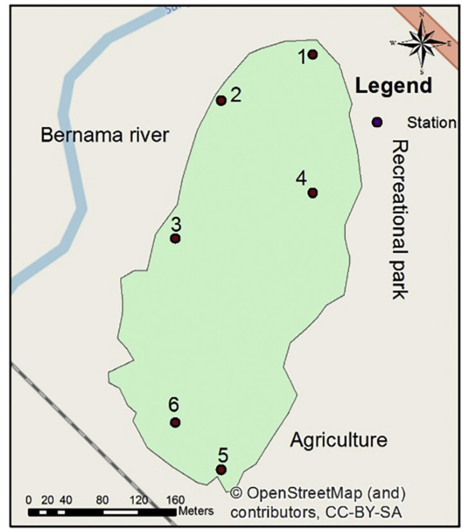

Fig. 2. Locations of sampling around Slim River Lake.

2.3. Rainfall data

Rainfall data recorded at a weather monitoring station (Felda Sg. Behrang) which located approximately 8.7 km from Slim River Lake was obtained from Malaysia Meteorological Department. The rainfall data were used to determine the wet and dry seasons. In this study, the wet season corresponded to the period where the area received at least 0.1 mm of rainfall amount daily. Meanwhile, the dry season includes the period when no rain occurs within consecutive days [12]. In this study, the wet season occurred from May 2018 until October 2018, while the dry season occurred from November 2018 until April 2019.

2.4. Total phosphorus and chlorophyll-a analyses

Total phosphorus analysis was carried out using the standard method [17]. Fifty milliliters water sample was analyzed using a persulfate digestion method followed by the ascorbic acid method [17]. Total chlorophyll-*a* in water samples were analyzed according to the standard method [17]. For the total chlorophyll-*a* analysis, 500 mL of water samples were filtered using 47 mm glass microfibre filters. Filter papers containing algal cells were placed in 10 mL of 90% acetone for extraction. Sonicator was used to break the algal cells during extraction. Next, the extracts were centrifuged for 5 min at 3800 rpm to eliminate the remaining cells and other debris. The absorbance of chlorophyll-*a* was measured using a spectrophotometer at 750 nm and 665 nm against 90% acetone blank before and after acidification with 0.1 mL of 1% hydrochloric acid (HCl), respectively.

2.5. Statistical analysis

Data were analyzed using the Statistical Package for Science Social (SPSS) program version 23. The monthly runoff volume was obtained from rainfall data in inch. Mean, standard error, and *t*-test were calculated for temperature, water level, total phosphorus, and chlorophyll-*a*. Data were log-transformed to meet the assumption of normality.

2.6. Geographic Information System (GIS) analysis

The bathymetric map of lake water level, total phosphorus, and chlorophyll-*a* was developed by using the inverse distance weighted (IDW) technique within the Geographic Information System (GIS) software.

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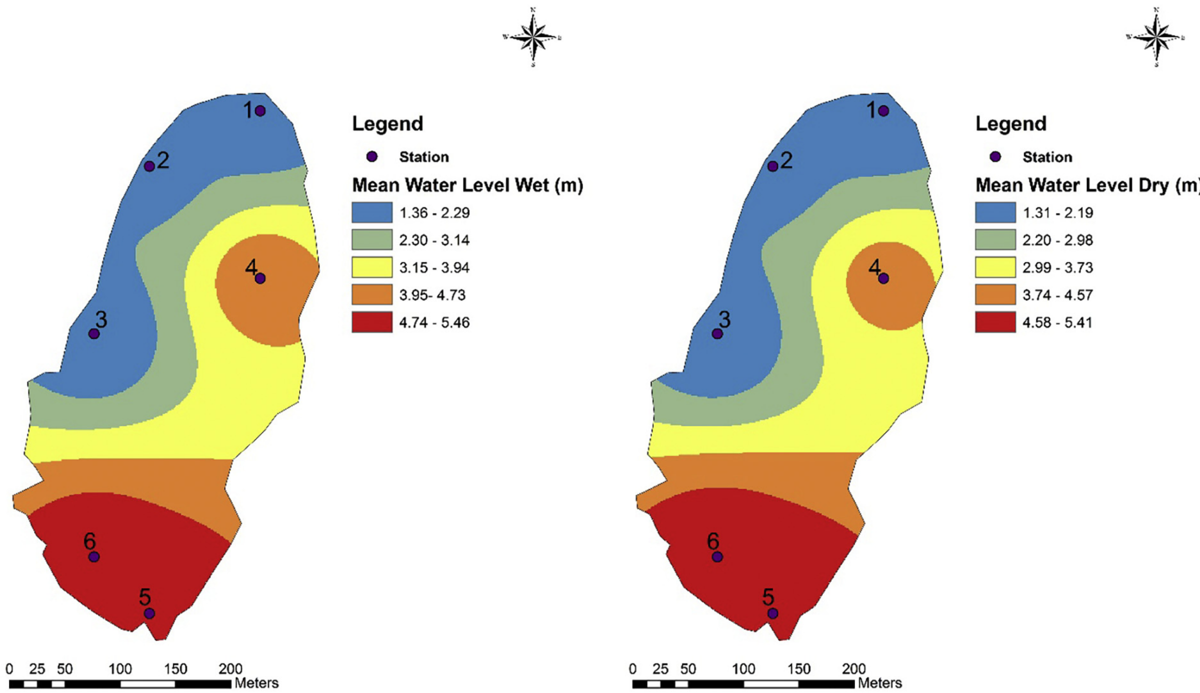

Fig. 3. Spatial distribution of mean water level during wet and dry seasons.

3. Results and discussion

In this present study, the water level was measured throughout the sampling period and discussed according to potential influencing factors such as water temperatures and precipitations or stormwater runoff quantity.

Slim River Lake is a shallow lake with water levels ranging between one to five meters during both wet and dry season. Fig. 3 shows the spatial distribution of mean water levels during both seasons. The water level in the Slim River Lake was shallower on the north sides (points 1, 2, and 3), which ranged between 1.31 m and 1.81 m and deeper on the south side (points 5 and 6), which ranged between 5.27 m and 5.46 m. When compared on a temporal basis, the water level in Slim River Lake only showed a small variation between wet and dry season in all sampling points (Table 1). During the wet season, the mean water level ranged between 1.36 m and 5.46 m while, in the dry season, it ranged between 1.31 m and 5.41 m. The water level showed no significant variation ($p > .05$) between the season in five sampling points and was not significantly different either ($p > .05$) when all data were combined. The only water level in point 4 showed significant changes ($p < .05$) between wet and dry seasons. This could be because of potentially higher water inflow (as stormwater runoff) during the wet season due to the higher slope observed at point 4.

In general, small and not significant changes in lake water level between the seasons could be explained by similar variation patterns observed for runoff volumes and water temperatures. Stormwater runoff volume showed no significant changes between wet and dry seasons. As shown in Table 2, the mean runoff volume ranged from 2.25 in. to 2.98 in., during the dry and wet seasons, respectively. There were no significant changes in runoff volume ($p > .05$) between both seasons. Similarly, to the runoff volumes, water temperatures also showed no significant changes during both seasons ($p > .05$), thus illustrating the insignificant effect of water evaporation on determining lake depth. As shown in Table 3, the mean water temperature ranged from 29.97 °C to 34.05 °C in the wet season while it ranged from 30.17 °C to 33.75 °C during dry seasons.

In terms of total phosphorus, high concentrations were recorded in both seasons. In general, total phosphorus concentrations exceeded 10 mg/L throughout the study period and indicated persistent eutrophication in this lake. Fig. 4 shows the spatial distribution of total phosphorus in both seasons. Higher total phosphorus concentrations were recorded in the deeper part on the southern side of the lake (point 5) compared to the shallower northern side. Moreover, when compared on the temporal basis, total phosphorus in this lake showed only a small variation between wet and dry seasons in most sampling points (Table 4). The mean total phosphorus concentrations in the wet season

Table 1
Lake water level during wet and dry seasons.

Station	Water level (m) during wet season	Water level (m) during dry season	t-test
	Mean ± SE	Mean ± SE	
1	1.56 ± 0.14	1.51 ± 0.12	t(21) = 0.30, $p > .05$
2	1.81 ± 0.14	1.76 ± 0.12	t(21) = 0.29, $p > .05$
3	1.36 ± 0.14	1.31 ± 0.12	t(21) = 0.32, $p > .05$
4	4.58 ± 0.14	4.12 ± 0.12	**t(21) = 2.57, $p < .05$**
5	5.46 ± 0.14	5.41 ± 0.12	t(21) = 0.28, $p > .05$
6	5.32 ± 0.14	5.27 ± 0.12	t(21) = 0.28, $p > .05$
Mean ± SE	3.35 ± 0.23	3.23 ± 0.21	t(136) = 0.38, $p > .05$

Note: t(degree of freedom).

Table 2
Monthly runoff volume in Slim River Lake.

Month (wet)	Runoff volume (inch) during wet season	Month (Dry)	Runoff volume (inch) during dry season
May 2018	2.97	November 2018	4.08
June 2018	2.05	December 2018	0.73
July 2018	2.08	January 2019	2.34
August 2018	0.39	February 2019	2.31
September 2018	3.53	March 2019	1.51
October 2018	6.83	April 2019	2.50
Mean ± SE	2.98 ± 0.89	Mean ± SE	2.25 ± 0.46
t-test (between seasons)	t(10) = 0.73, $p > .05$		

Note: t(degree of freedom).

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Table 3
Water temperature (°C) in wet and dry seasons.

Station	Temperature (Wet season) Mean ± SE	Temperature (Dry season) Mean ± SE	t-test
1	34.05 ± 0.98	33.75 ± 0.79	t(21) = 0.23, $p > .05$
2	33.74 ± 1.32	33.38 ± 1.05	t(21) = 0.19, $p > .05$
3	32.11 ± 0.92	32.75 ± 0.64	t(21) = −0.62, $p > .05$
4	33.29 ± 1.22	32.94 ± 0.69	t(21) = 0.18, $p > .05$
5	29.97 ± 0.95	30.17 ± 0.46	t(21) = −0.31, $p > .05$
6	31.46 ± 0.68	32.26 ± 0.61	t(21) = −0.90, $p > .05$
Mean ± SE	32.44 ± 0.44	32.54 ± 0.32	t(136) = −0.35, $p > .05$

Note: t(degree of freedom).

Table 4
Total phosphorus (mg/L) during wet and dry seasons.

Station	Total phosphorus (Wet season) Mean ± SE	Total phosphorus (Dry season) Mean ± SE	t-test
1	10.58 ± 4.48	10.77 ± 2.43	t(17) = −0.13, $p > .05$
2	10.55 ± 5.81	11.40 ± 2.40	t(18) = −1.44, $p > .05$
3	10.91 ± 4.31	13.65 ± 3.50	t(19) = −1.18, $p > .05$
4	14.43 ± 7.22	11.73 ± 2.28	t(19) = −0.74, $p > .05$
5	26.66 ± 9.55	21.76 ± 5.03	t(18) = −0.41, $p > .05$
6	26.50 ± 7.92	15.07 ± 3.36	t(19) = 0.53, $p > .05$
Mean ± SE	16.61 ± 2.82	14.06 ± 1.38	t(124) = 0.87, $p > .05$

Note: t(degree of freedom).

ranged between 10.55 mg/L and 26.66 mg/L while it ranged between 10.77 mg/L and 21.76 mg/L in the dry season. Total phosphorus concentrations during wet season were slightly higher when compared to the dry season only at points 4, 5, and 6. Overall, total phosphorus concentrations in Slim River Lake were not significantly different ($p > .05$) between wet and dry seasons.

Following similar patterns with total phosphorus concentrations, high total chlorophyll-*a* concentrations were also recorded in Slim River Lake in both seasons. Total chlorophyll-*a* concentrations exceeded 10 mg/m^3 throughout the study period and indicated the presence of high phytoplankton biomass in this lake. Fig. 5 shows a spatial distribution of mean chlorophyll-*a* concentration, and Table 5 shown chlorophyll-*a* concentration at Slim River Lake during the wet and dry season. Similar to the total phosphorus, higher total chlorophyll-*a* concentrations were recorded on the southern side of the lake compared to the northern side. Moreover, when compared on the temporal basis, total chlorophyll-*a* concentrations in this lake were generally higher in the wet season than the dry season in all sampling points (Table 5). The mean chlorophyll-*a* concentrations ranged between 14.35 mg/m^3 and 180.13 mg/m^3 in the wet season while it ranged between 14.15 mg/m^3 and 39.27 mg/m^3 in the dry season. In general, there was significant difference in total chlorophyll-*a* concentrations between seasons when all data were combined. However, when compared on point basis, only total chlorophyll-*a* concentrations recorded at points 4, 5, and 6 were significantly different between the wet and dry season ($p < .05$).

Overall, our results illustrate that rainfall amount, stormwater runoff volumes and water temperatures may not significantly influence the water level in Slim River Lake. However, it is important to understand the factors influencing the water level which is useful in evaluating nutrient loads into the lake ecosystem [18]. Changes to water levels will eventually affect nutrient concentrations and contribute to changes in the growth of phytoplankton [19]. It has been suggested that lake water level fluctuates due to precipitation, runoff, evaporation, and outflow [20]. High water temperature caused increase evaporation that might reduce the water level. However, in this study, uniform water temperatures and runoff volumes were recorded during both seasons ($p > .05$). These observations suggest that the fluctuations in the water level in this lake might depend more on the water through flow from the nearby river which located less than 100 m from the lake.

As suggested by our observations, variations in the lake's water level reflected the variations in total phosphorus concentrations, and both

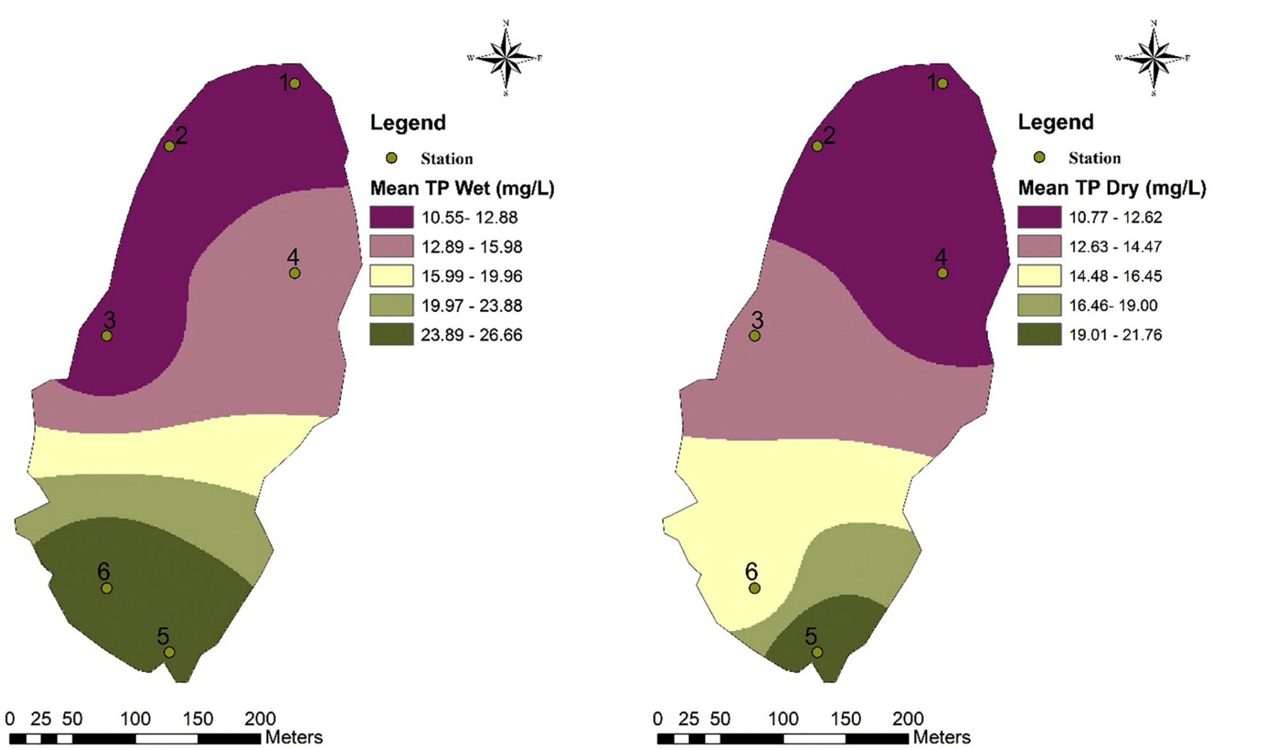

Fig. 4. Spatial distribution of mean total phosphorus during wet and dry seasons.

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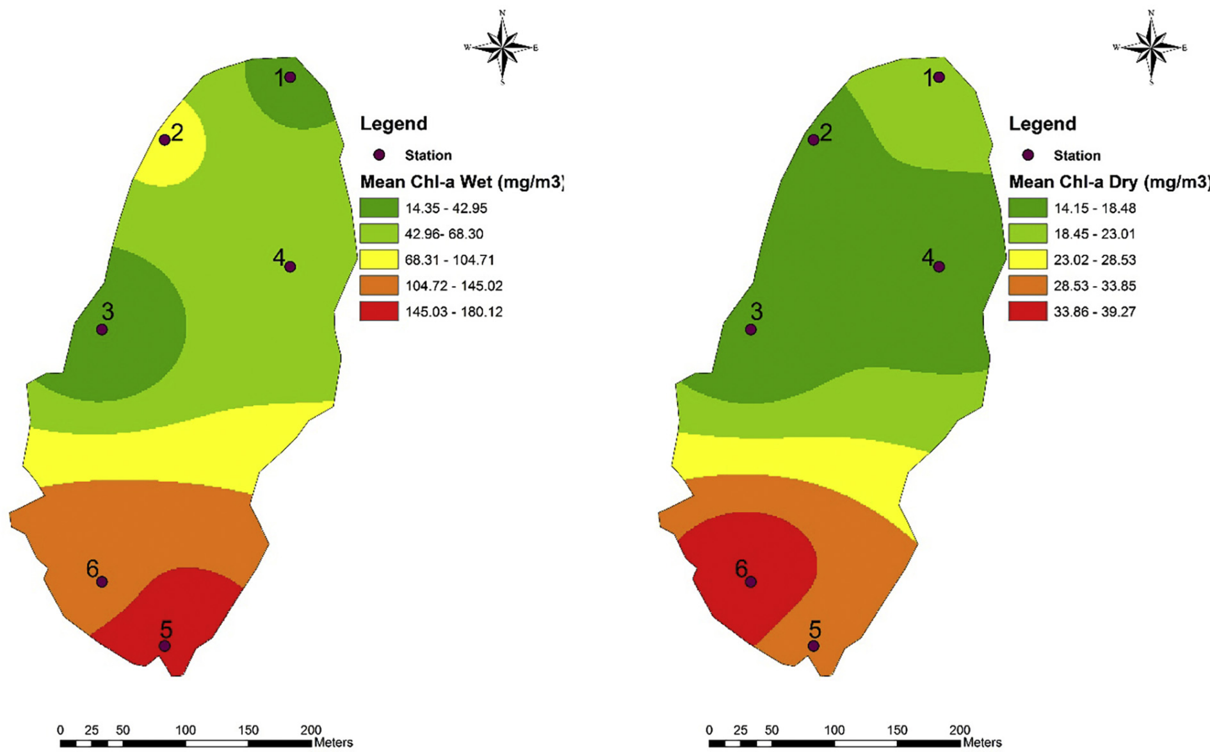

Fig. 5. Spatial distribution of mean chlorophyll-*a* (mg/m^3) in wet and dry seasons.

were not influenced by the season. Even though total phosphorus was not influenced by the season, this nutrient was present in high concentrations throughout the sampling period, thus illustrating persistent eutrophication in the studied lake. It has been acknowledged that variations in rainfall distribution can have an impact on nutrient concentrations in lakes [21,22]. Also, higher rainfall intensity during the wet season at certain sampling points (e.g. points 4–6), external phosphorus may contribute to the increased concentration in this lake. Additionally, the livestock farming and recreational parks adjacent to points 4, 5, and 6 may contribute to the external phosphorus loading into the lake. It has been reported in Sinang et al. [16] that high phosphorus in Slim River Lake could be due to surface runoff and waste from an adjacent farm. Anteneh et al. [23] also suggested that anthropogenic factors might be the primary factor in deteriorating receiving water quality. Therefore, higher accumulation of phosphorus in this lake is expected if the land use remains unchanged in the longer term.

Our findings also suggest a potentially significant influence of internal phosphorus load in the study lake. As discussed in Gran'eli [24], the shallow lake system is basically more vulnerable to degradation from internal phosphorus loading [24–28]. This is due to the fact that shallow lake received stormwater runoff that transport phosphorus which then

Table 5
Chlorophyll-*a* (mg/m^3) in wet and dry seasons.

Station	Chlorophyll-*a* (Wet season)	Chlorophyll-*a* (Dry season)	t-test
	Mean ± SE	Mean ± SE	
1	35.50 ± 13.50	21.62 ± 7.89	$t(21) = 1.09, p > .05$
2	75.20 ± 42.86	17.21 ± 3.77	$t(21) = 0.60, p > .05$
3	14.35 ± 4.80	14.15 ± 4.05	$t(21) = -0.37, p > .05$
4	51.15 ± 21.69	15.03 ± 3.92	$\mathbf{t(21) = 2.09, p < .05}$
5	180.13 ± 60.09	30.63 ± 8.23	$\mathbf{t(21) = 2.09, p < .05}$
6	133.90 ± 42.11	39.27 ± 12.86	$\mathbf{t(21) = 2.47, p < .05}$
Mean ± SE	81.70 ± 15.93	22.99 ± 3.16	$\mathbf{t(136) = 3.76, p < .05}$

Note: t(degree of freedom).

accumulated in the sediment, which is also known to contain high organic matter [28–30]. As suggested by Hou et al. [31], persistent high temperatures in both seasons could enhance the growth of phytoplankton. Phytoplankton decomposition will later release the biologically available fraction of phosphorus into the water column [32]. Additionally, the sediment phosphorus can be released back into the water column by decomposition of organic matters [29].

It is also widely accepted that persistently high phosphorus in the lake water column can create a severe disturbance due to high phytoplankton biomass [33–35]. In this study, a significant seasonal influence was observed for total phytoplankton biomass even though not for total phosphorus. Thus, this result suggests the influence of other environmental factors in controlling the growth of phytoplankton. As suggested by Sun et al. [36] and Hou et al. [31], phytoplankton growth can be affected by temperature, whereby different varieties of phytoplankton can dominate in different seasons. In addition, Zheng et al. [15], clarified that chlorophyll-*a* and the water level did not show any relation, yet chlorophyll-*a* were more influenced by water temperature, light, suspended matter, and algal biomass. It is apparent that high water temperature during wet and dry seasons in this study lake accelerate the growth of phytoplankton [21]. Moreover, Qiu et al. [37] and Okech et al. [38] highlighted that high accumulation of phytoplankton biomass, particularly cyanobacteria, is more likely to occur in the wet period even with slight changes in nutrient conditions. In the dry period, a high concentration of chlorophyll-*a* might be caused by ion concentrations due to increased evaporation in the lake [38] or less dilution effects that might increase the phosphorus levels in the lake [39]. Therefore, phytoplankton biomass in a eutrophic lake should also be monitored in the wet season even when no apparent surge of phosphorus concentration is detected.

4. Conclusion

This present study was conducted to investigate the variation of water level, total phosphorus, and total chlorophyll-*a* during wet and dry seasons in Slim River Lake. Our results suggested no significant changes in the water level between wet and dry seasons. Similarly, no significant seasonal variation was observed in the lake's total phosphorus concentrations. In contrast, a significant seasonal variation was observed for total chlorophyll-*a* concentration in the study lake. The observed variability of these factors might not only relate to rainfall patterns but might also connect to other factors such as land use. Additionally, our study results suggested the importance of health risk assessment associated with the presence of high algal biomass to be monitored regularly. Specifically, for the studied lake, persistent high concentrations in total phosphorus and phytoplankton biomass highlighted an urgent need to establish measures for lake rehabilitation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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