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Urban lake physicochemical parameters seasonal and vertical variability within the context of ecological disturbance theory

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ABSTRACT

The aims of this study are threefold: (1) to determine the seasonal, vertical and lateral variations in the concentrations of physicochemical water quality parameters [pH, dissolved oxygen (DO), temperature, total dissolved solids (TDS), NH_3–N, PO_4, PO_4–P] in the Varsity Lake Malaysia, (2) derive a discriminant function that highlights the metals that contributed or had the greatest effect on the seasonal variation and (3) assess the extent to which the water quality has degenerated base on two water quality guidelines. The water samples were analysed using standard methods while the variations in physicochemical parameters concentration were analysed using discriminant analysis method. The results of Wilks' Lambda *F*-test and canonical discriminant function showed a highly significant seasonal variation in five parameters ($P < 0.001$; DO, pH, temperature, TDS, NH_3–N; and strong significant variation in two parameters ($P < 0.05$; PO_4, PO_4–P) with the wet season having greater concentrations. Based on the standardised discriminant function and structure matrix, DO, pH, and TDS were the parameters with the most significant discriminant power, thus made the highest effect on the seasonal differences in concentration. Significant vertical variations were detected for DO, pH, temperature and TDS. But NH_3–N and PO_4 concentrations did not vary significantly with depth. DO and pH failed the Malaysian National Water Quality, while Temperature out rightly failed the water quality guidelines. From the theoretical perspective, it is predicted that the lake will experience seasonal, vertical and lateral ecological disturbances. The parameters that contribute most to the ecological disturbances are DO, pH, PO_4 and PO_4–P.

Keywords: Physicochemical parameters; Malaysia water quality; Stormwater contamination; Seasonal water quality variability; Ecological disturbances; Urban lake pollution

1. Introduction

It is widely known in limnological studies that natural processes of precipitation, temperature, wind, geology, hydrology and anthropogenic activities (land use systems) exert influence on the physicochemical and microbiological water quality of the lake. But within a highly urbanized area with a high degree of imperviousness, anthropogenic influences may predominate or prevail over (but not offset) that of natural influences. This stems from the fact that hydrologically active impervious urban landscapes have numerous adverse ramifications on the water quality of urban lakes fed primarily by storm runoff and underground water High impervious surfaces not only alter the urban hydrological cycle through highs of runoff volume and erosivity, runoff coefficient, sediment load, peak flows and low base flow, rates of nutrient leaching and enrichment, but it also alters the local microclimate through its low albedo, low specific heat capacity, high thermal conductivity, and low evapotranspiration.

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These hydrological and microclimatic characteristics make urban lakes particularly vulnerable to seasonal changes and fluctuations in precipitation, water level, water temperature, and thermal stratification because these same hydro-climatic features subsequently influence the physicochemical water quality and quantity of biological productivity of the lake greatly [1–4].

Water temperature affects the rate of metabolic function and biological activities of aquatic organisms. Increased temperature raises the respiratory rate and oxygen consumption of aquatic organisms, which over an extended period can reduce their oxygen use efficiency and consequently lead to their impairment. Against this backdrop, many studies have established a direct relationship between water temperature and rate of metabolism [5]. As pointed out, a 10°C increase in water temperature will increase the metabolic functions of most fish by twofold while at temperature above 35°C their metabolic function will significantly drop and begin to show evidence of denature [6]. In the tropical areas, at temperatures below 21°C, most aquatic plants will experience restricted or dormant growth. The solubility of oxygen decreases with increasing temperature. Water temperatures affect the solubility and toxicity of some heavy metals. Solubility of metal such as cadmium, zinc and lead, as well as ammonia compounds, increase at elevated temperature conditions [7]. Water temperature affects conductivity; higher temperature increases both the ionic mobility and ionic concentration (known as total dissolved solids), which either path can potentially increase conductivity [8,9]. Water temperature is also known to influence pH via the quantity of ions concentration. An increase or decrease in temperature will have a corresponding effect on the ion concentrations and pH value [10].

Like temperature, dissolved oxygen is a critical physiochemical parameter that influences lake water quality dynamics in several ways. In fact, dissolved oxygen (DO) was so critically important in limnological assessment that some states in the United States (Kansas, Oklahoma States) single it out as listing criteria for lake impairment. For Kansas, lakes are listed as DO impaired if the frequency of DO levels dropping below 5 mg L^{-1} is more than once every 3 y. While in Oklahoma, a lake is depicted as impaired if DO concentration in 50% of the water column is less than 2 mg L^{-1} or if 10% of the surface samples have DO concentration below 4–5 mg L^{-1} [11]. There are natural reasons for dissolved oxygen variations, but the most worrying is the anthropogenic causes. Anthropogenic pollutions that contribute oxygen-demanding organic matter causes depletion in DO as the rapid utilization DO in the process of decomposition of organic matter reduce the concentration of DO, which results in impairment of aquatic life in the lake. Potential anthropogenic contributors to oxygen demanding substances in the urban setting include combined sewer overflows, automotive oils and greases, pet wastes, urban lawn grass mowing and grass clipping (at decomposition), urban agriculture water runoff, and ultimately stormwater runoff from high-intensity impervious surfaces that empty to the lake [12].

As a result, urban runoff has been seriously implicated as a major contributor to DO depletion in rivers and lakes in particular. As pointed out, the quality of urban runoff is comparable to that of treated sewage or may even be worse [13]. Studies have revealed that levels of biochemical oxygen demand (BOD) were directly related with the intensity of impervious surface within a watershed [14]. In another study, Lee and Jones-Lee [44] established a causal relationship between urban stormwater runoff in Joaquin River and a sharp drop in DO from 7 to 9 mg L^{-1} to about 3.5 mg L^{-1} and concomitant fish deaths. Stormwater runoffs over impervious surfaces are major sources of thermal pollution and DO depletion to the receiving lakes. It has been argued that the thermal conductivity of urban impervious surfaces (paved with asphalt, stone and concrete) is comparable to the rocky desert [15]. As a result, the thermal effects of elevated stormwater temperature flowing over impervious surfaces to the receiving lake include a decrease in DO level, fish death and influxes of invasive species. The adverse effect of urban stormwater runoff on the receiving lake can be in both short-term variations in physicochemical water quality during and after rainfall and long-term water physiochemical quality changes resulting from cumulative impacts of recurrent stormwater discharges from multiple sources.

Aquatic pH level is of cardinal importance in limnological assessment. pH level influences the dynamics of biological activities of lake aquatic life in several ways. The pH requirement for optimum fish productivity and survival is within the bounds of 6.5 to 9.0 [16]. Stress and mortality rates increase at variations below or above these limits though less sensitive amphibians like frogs can tolerate a lower pH levels of about 4.0. For lakes that are used for recreational purposes like swimming, pH levels above 11 or lower than 4 can cause skin and eye irritation, while pH below 2.5 can cause severe or permanent damage to the skin and organ linings [17]. Aquatic pH is also a determinant factor in the solubility and biological availability of chemical compounds (such as nitrogen and phosphorus) and heavy metals (e.g., lead, copper, cadmium) [18]. Changes in pH can increase the solubility of nutrients nitrogen and phosphorus, thus making it readily utilizable for plant and algal growth (WSDE, 1991), which increases DO demand. For heavy metals, low pH enhances their solubility, mobility and the risk of absorption (toxicity) by aquatic life [19]. However, the solubilising effect of pH depends on the lake's pH buffering capacity. Lakes naturally may have carbonate materials or chemical shock absorbers such as calcium carbonate that can mix with hydrogen ions to neutralize and resist small or localized changes in pH [20]. Natural and anthropogenic factors also influence pH variations. Anthropogenic point sources include industrial runoff, urban agricultural runoff, wastewater discharges from clusters of restaurants containing detergents. Urban stormwater carrying high load pollutants can significantly contribute to pH variation in the receiving lake. This will be aggravated if the stormwater running into the lake contains acid rain (rain with pH lower than 5.0). Stormwater containing elevated acid rain can potentially make the receiving lake lose their pH buffering capacity. As Michaud [12] pointed out, lakes receiving too much acid rain lose their buffering capacity for pH. This is particularly relevant in the study area as Petaling Jaya where Varsity Lake is located, is notorious for acid rain.

Excess nutrients such as phosphorus and nitrogen are major concerns in lake water quality management as most lakes' ecological problems are caused by eutrophication associated with nutrients overload. Runoff rich in phosphorus and nitrogen can lead to phytoplankton growth and algae blooms which can potentially turn a lake that was initially oligotrophic – (high in DO) into a eutrophic lake (deficient in DO). Eutrophication is a major source of lake aquatic life impairments and toxicity because toxin secreted by cyanobacteria in the process has the ability to impair aquatic life productivity and maintenance [21].

Regular monitoring of the physiochemical water status of a lake is a necessary part of lake management. It provides early warning limnological data and information on measurable changes or deviations from the lake's natural physical and chemical water quality condition. In Malaysia, particularly on the Varsity Lake, there is a dearth of studies characterising spatiotemporal water quality of lakes. Though the only study on water quality of Varsity Lake by Aqeel Ashraf et al. [22] reported that the lake is polluted in terms of total dissolved solids (TDS), BOD, temperature, oil and grease and nitrate concentration beyond permissible standard limits, the analysis was based on only three months samples (October, December and February). So, it may be said the study did not capture enough the seasonal or temporal variations of the physicochemical parameters. Moreover, their study did not examine variations of the water quality parameters according to depth.

The aims of this study are: (1) to determine if there are significant seasonal variations in the concentrations of physicochemical water quality parameters (pH, DO, Temperature, TDS, NH_3–N, PO_4) in the Varsity Lake Malaysia. Thus, given these variables, is there a significant discriminant function that differentiates wet and dry season variations. It, therefore, tries to test the hypothesis of zero seasonal variations in physicochemical water quality parameters and no significant discriminant function; (2) determine the physicochemical parameters that contributed or had the greatest effects on the seasonal variation; (3) determine the vertical and lateral variation of the parameters concentration and find out locations and columns of water most affected by pollution; (4) assess the extent to which the water quality has degenerated based on two water quality guidelines – Malaysian Interim National Water Quality Guidelines (INWQS) and the Canadian Council of Minister of Environment, 1999; (5) analyse the implications of the physicochemical parameters variations and contaminations within the context of ecological disturbance theory.

2. Physicochemical parameters as trigger forces of lake ecological disturbance from the perspective of ecological disturbance theory

Ecological disturbance theorists have not only labelled ecological disturbance a key restructuring and rebalancing force in ecological systems, it is a major threat to the ecological integrity of most aquatic communities [23–25]. Ecological disturbance takes place when potentially damaging force applies to habitat occupied by a population, community, or ecosystem, and the magnitude of such forces may be to the extent that organisms may be killed or displaced, or depleted [26]. Ecological disturbance can also be described as a causal agent which results in perturbation, stress or effect change on system state, which as a consequence can lead to destruction, dis-composition, or suppression of biotic life [27]. As a result, various forms of ecological disturbances effects are discernible: the lethal effect where the dominant effect is massive mortality and reduction in the quantity of existing biotic lives; biotic lives dis-composition effect, which results in relatively low biological life reduction through selective elimination and displacement; suppression effect from inhibited energy flow; and biotic live stress effect which is stress-induced disturbance resulting from biological life deviation from the natural state. Overall, the perturbative effect of disturbance may be transitory (temporary), after which normalcy resumes or permanent or long-lasting.

Physicochemical water quality parameters such as temperature, dissolved oxygen (DO), pH, total dissolved solids, ammoniacal nitrogen (NH_3–N), phosphate (PO_4), constitute major causal agents of ecological disturbance in surface water systems. The physicochemical and biochemical reactions of the parameters catalysed into series of physiological disturbance effects such as "the biotic lives lethal effect" with massive mortality and reduction in the quantity of biotic lives or "biotic live stress effect" resulting in biological lives deviation from their natural state.

In ecological disturbance theory, the actual extent of disturbance effects will depend on the disturbance regime attributes such as frequency, magnitude or severity intensity of the physicochemical water quality parameters. In other words, high magnitude frequently occurring disturbance events are likely to cause more disturbance effects than low magnitude frequently occurring disturbance events. Nevertheless, short-term high magnitude disturbance events can cause severe large scale disturbance effects. For example, single day to 4 days dredging of a lake can lead to sediment plume, which can simultaneously act as a physical stressor to biotic lives through increased turbidity and reduced visibility and as chemical stressor through hypoxia-related oxygen depletion. Similarly, infrequent, intermittent combined sewer overflows discharging into a lake or intermittent wet season urban stormwater loaded with excess nutrients such as nitrogen and phosphate can cause frequent hypoxia conditions of oxygen deficiency that can sometimes have severe stress effects on aquatic organisms. As a researcher pointed out, intermittent exposure can be more toxic to the aquatic community than continuous.

In ecological disturbance theoretical tradition, interpretation of ecological disturbance explicitly requires a quantitative reference baseline conditions or values. As Rykiel [27] pointed out, without a defined reference state (quantitative baseline values), the occurrence of a disturbance, perturbation or stress cannot be detected or measured. In a similar tone, Villnäs [28] stressed that a reference state must be defined in order to interpret the meaning of ecological disturbance. In the study, The Malaysian Interim National Water Quality Guidelines (INWQS) for aquatic life species will be used as a proxy reference baseline for gauging and interpreting potential ecological disturbance.

3. Materials and methods

3.1. Study area and sample collection

The Varsity Lake is located at latitude 3° 25′ 27.52′′N and longitude 101° 25′ 53.89′′E and at an altitude 558 m above average sea level. The lake is situated at the main gate of the University of Malaya, bordering 250.6 m length, 85.3 m width and a depth of 6 m. The lake's watershed comprises high density residential and commercial areas with high vehicular traffic. But the immediate vicinity within the watershed are institutional structures such colleges including engineering colleges with metal construction workshops, students' hostels, canteens, administration centre and ongoing construction activities. The lake gets its water mainly from stormwater runoff from its watershed and underground water that is pumped only during the dry season when the water level is low. In this study, stormwater flowing into the Varsity Lake is considered as both diffuse and point sources of pollution. Though the stormwater initially flows overland surface, it afterwards flow through concentrated channels in the watershed before discharging into the lake via stormwater inlets. MADEP (1997) had noted that under US-EPA, urban stormwater flowing into conveyance systems such as channels, pipes or ditches are considered as point sources of pollution. In this study, 10 sampling positions were chosen based on their proximity to stormwater inlets (3) and outlets (3) or within the Lake Central (2) and Lake Bay (1). These were denoted as locations 1–10, as shown in Table 1. According to Meybeck et al. [48], lakes with inlets and bays require a minimum of 3 samples, but for adequate description, the optimum samples should be 10 or more.

The locations cover the northern, southern and central parts of the lake. The lake is deeper at the southern outlets' area. All water samples were taken from 3 depth intervals, 0.5, 1 and 1.5 m and were immediately transferred into prewashed 100 mL scotch bottles, acidified to pH < 2 with 2 mL Aristar® HNO_3 (70%) and labelled. Samples were sealed and stored in a 4°C refrigerator. The physicochemical parameters were determined as follows: pH, temperature and TDS were determined in situ by YSI model 449D multisensor probe. Dissolved oxygen was determined by Winkler's Titration, the nutrients (NO_3–N and PO_4) were determined using a portable Lamoth Smart2 colourimeter [29].

3.2. Statistical analysis

The analytical statistics adopted for this study is discriminant analysis. The justification for its use lies in the fact the study not only involves testing group mean differences or variation between two groups of physicochemical parameters concentration: dry season concentration and wet season concentration, it also seeks to identify the most dominant physicochemical parameters accounting for the variation. Discriminant analysis is an appropriate statistical technique for testing for equality of group means and building a predictive model of group variance based on a set of observed discriminant variables. It is a linear combination of two or more variables (discriminant function) that discriminate best between groups. The relationship is expressed as the ratio of between-group to within-group variances. The linear combination is derived from the following equation:

$$Z = W_1X_1 + W_2X_2 + W_3X_3 .... + W_nX_n \quad (1)$$

where Z = the discriminant score; W = the discriminant weights (discriminant coefficients); X = the independent discriminant variables.

Discriminant analysis provides descriptive statistics (total mean and group mean) and inferential statistics for identifying and analysing group differences. Inferential statistics include F-test for Wilks' Lambda, model Wilks' Lambda, standardized canonical discriminant function coefficients (SCDFC), canonical correlation, and functions at group centroids. ANOVA (F) for univariate Wilks' Lambda test if there are significant group mean differences. In other words, F for Wilks' Lambda provides useful statistics to identify variables that make significant differentiation between or among groups. The multivariate

Table 1
Sampling positions

Serial No.	Position		
	Latitude	Longitude	Close proximity to
Location 1	03 07 11. 14242	101 39 22. 46321	Proximity to storm water inlets 1
Location 2	03 07 10. 78242	101 39 23. 06321	Proximity to storm water inlets 2
Location 3	03 07 10. 36242	101 39 23. 86321	Proximity to storm water inlets 3
Location 4	03 07 09. 70242	101 39 25. 06321	Proximity to storm water inlets 4
Location 5	03 07 09. 58242	101 39 26. 66321	Within the Lake Central 1
Location 6	03 07 09. 76242	101 39 27. 16321	Within the Lake Central 2
Location 7	03 07 09. 28242	101 39 29. 96321	Lake Bay (close to main road)
Location 8	03 07 08. 26242	101 39 29. 96321	Proximity to water outlets 1
Location 9	03 07 09. 46242	101 39 30. 96321	Proximity to water outlets 2
Location 10	03 07 09. 70242	101 39 31. 26321	Proximity to water outlets 3

Wilks' Lambda (called the model Wilks' Lambda is used to test the goodness-of-fit of the model. The larger the value, the more the within-group variation. Thus, the discriminant analysis provides the statistics used to test and verify the research hypotheses.

4. Results

4.1. Seasonal variation in physicochemical parameters concentrations

Seasonal variation in physicochemical parameters concentrations is represented in (Table 2). Variance analysis within the univariate ANOVA (*F*) test of equality of group means was used to identify physicochemical parameters that differed significantly between the two seasons. The results showed that four parameters (pH, DO, temperature and TDS) recorded significantly greater concentrations in the wet season compared to the dry season. On the other hand, three parameters (NH_3–N, PO_4 and PO_4–P) were significantly more significant in the dry season than in the wet season. For statistical details, four of the parameters; (pH, $\lambda = 0.776$, $F = 40.01$) (DO, $\lambda = 0.477$, $F = 152.71$) (TDS, $\lambda = 0.835$, $F = 27.37$) (NH_3–N, $\lambda = 0.845$, $F = 25.50$) exhibited very high significant mean differences at $P < 0.001$ level of significance, while (temperature, $\lambda = 0.935$, $F = 9.74$) (phosphate, $\lambda = 0.969$, $F = 4.41$) phosphate phosphorus, $\lambda = 0.971$, $F = 4.39$) exhibited strong significant mean differences at $P < 0.05$ level of significance. Consequent upon the univariate ANOVA (*F*) test, we can reject the null hypothesis and accept the alternative that there are significant seasonal variations in physicochemical water quality parameters with evidence from the group means indicating greater concentration in the wet season for four parameters (pH, DO, temperature and TDS) than in the dry season and more significant dry season concentration for three parameters (NH_3–N, PO_4 and PO_4–P).

4.1.1. Predicting physicochemical parameters concentrations in Varsity Lake with respect to seasons

In this study, we aim to identify the most significant physicochemical parameters that best distinguishes between water quality in wet and dry seasons. Thus, this will help predict at what season physicochemical parameters will be highest based on their variable concentrations. Table 3 shows that after series of iterations, six out of the seven parameters entered the model in the following order of magnitude of stepwise Wilks' Lambda: DO > pH > TDS > NH_3–N > temperature > PO_4. The results also showed the standardized canonical discriminant function coefficients (SCDFC) used to assess each physicochemical parameter's unique contribution to discriminant function. It follows that the parameter in the model with the greatest discriminatory power for the seasonal variations were DO ($\beta = 0.958$ and within-group correlation = 0.638 at $P < 0.001$); pH ($\beta = 0.151$ and within-group correlation = 0.326 at $P < 0.001$); TDS ($\beta = 0.849$ and within-group correlation = 0.270 at $P < 0.002$), NH_3–N ($\beta = -0.402$ and within-group correlation = –0.261 at $P < 0.001$) temperature ($\beta = -0.047$ and within-group correlation = 0.161 at $P < 0.001$), PO_4 ($\beta = -0.125$ and within-group correlation = –0.108 at $P < 0.05$). This also implies that these parameters had greater influence in differentiating the wet and dry season water quality variations.

The function at group centroid determines the optimal *Z*-value on which the physicochemical parameters could be classified as having a greater probability of having a higher concentration in wet or dry seasons. The table reveals that at the group centroids, physicochemical parameters concentration in the wet season had a *Z*-value of 1.41, while the concentration in the dry season had a *Z*-value of –1.896. This suggests that a parameter having a *Z*-value in the direction of 1.41 is grouped into wet season, while a physicochemical parameter with a *Z*-value in the direction of –1.896 is grouped into the dry season. Using the SCDFC,

Table 2
Group mean differences and test of equality of group means

Variables	Total (mean) concentration for dry and wet season (mg kg^{-1})	Group means			Tests of equality of group means		
		Dry season	Wet season	Mean diff.	Wilks' Lambda	F^a	Sig.
pH	6.6 (0.81)	6.2 (0.62)	6.9 (0.8)	0.7	0.776	40.011	0.000
DO	4.96 (2.32)	2.9 (1.31)	6.1 (1.61)	3.2	0.477	152.71	0.000
Temp	29.90 (1.17)	29.50 (1.4))	30 (0.89)	0.5	0.935	9.74	0.002
TDS	221.70 (37.60)	203 (32.2)	234.65 (37.66)	31.65	0.835	27.37	0.000
NH_3–N	0.21 (0.41)	0.4 (0.49)	0.07 (0.26)	–0.33	0.845	25.50	0.000
PO_4	0.22 (0.73)	0.38 (1.1)	0.12 (0.29)	–0.26	0.969	4.41	0.031
*PO_4–P	0.071 (0.801)	0.123 (0.64)	0.038 (0.36)	–0.09	0.971	4.39	0.038

Diff 1 = 1 Diff 2 = 139; Figures () = Standard deviation; *Value derived from PO_4 and not included in DA.

Table 3
Predictive model of seasonal variation in physicochemical parameters in water of Varsity Lake

Variables (entered/removed)		Model Wilks' Lambda				Exact F			
Step	Water quality parameters	Statistic	df1	df2	df3	Statistic	df1	df2	Sig.
1	DO	0.477	1	1	139	152.71	1	139	0.000
2	pH	0.776	2	1	139	40.01	2	139	0.000
3	TDS	0.835	3	1	139	27.37	3	139	0.002
4	NH_3–N	0.845	4	1	139	25.50	4	139	0.000
5	Temp	0.935	5	1	139	9.74	5	139	0.000
6	PO_4	0.969	6	1	139	4.41	6	139	0.038

Standardized canonical discriminant function coefficients (SCDFC)			
	Function 1	Impact ranking	Structure matrix (within group correlation)
DO	0.958	1	0.638
TDS	0.849	2	0.326
pH	0.151	3	0.270
NH_3–N	–0.402	4	–0.261
Temp	0.125	5	0.161
PO_4	–0.047	6	–0.108
Functions at group centroids			
Dry season	–1.896		
Wet season	1.41		
Model validation statistics			
Canonical correlation (CCr)	0.854		
CCr^2	0.73		
Eigenvalue	2.702		
Wilks' Lambda	0.27		
Sig.	0.000		
Chi-square (df = 10)	178.001		
Classification accuracy (hit ratio)	95.7%		

deriving the final discriminant score (Z score) for classification of the groups will take the following form:

$$Z = 0.958 \times \text{dissolved oxygen (DO)} + 0.849 \times \text{total dissolved solids (TDS)} + 0.151 \times \text{pH} + -0.402 \times \text{ammonical nitrogen } (NH_3\text{–N}) + 0.125 \times \text{temperature} + -0.047 \times \text{phosphate } (PO_4) \quad (2)$$

Taking the cut-off value or mid-point for wet or dry seasons to be zero, movement above zero is predicted to be a move towards greater wet season concentration, while a movement below zero is predicted to be a move towards greater dry season concentration.

The result (Table 3) also showed the canonical correlation (CCr), which represents the correlation between the predictors and the discriminant function. It provides a general index for assessing the fit of the model. The CCr value of 0.73 implies that the model has explained 73% (CCr^2) of the variation in group difference. The model's Wilks' Lambda (λ) indicates the statistical significance of the discriminant function. The table showed a significant discriminant function ($\lambda = 0.27$; $\chi^2_{(df = 6)} = 178.001$ at $P < 0.001$). As a result, we reject the null hypotheses and conclude that there is a significant discriminating function that differentiates the six physicochemical parameters in the wet and dry seasons. The model achieved a hit ratio of 95.7%, implying that 95.7% of the mean wet and dry seasons physicochemical parameters concentrations were correctly predicted.

4.2. Comparing physicochemical parameters with depth data (vertical variability)

Vertical variations in physicochemical parameters are represented in (Table 4 and Fig. 1). The results showed that pH was slightly acidic, with the 1.5 m depth having the least pH value of 6.2, while the 0.5 and 1 m had similar normal pH values of 6.9 and 6.7. Similarly, the 1.5 m depth had the least concentration of DO, with concentrations decreasing in the order, 0.5 m > 1 m > 1.5 m; (5.7 mg L^{-1} > 4.2 mg L^{-1} > 3.3 mg L^{-1}). Temperature also followed a similar pattern of decrease with depth; 0.5 m > 1 m > 1.5 m (30°C > 29.63°C > 29.40°C). Conversely, the TDS were greater with increased depth; 0.5 m < 1 m < 1.5 m; (213.12 mg L^{-1} < 222.27 mg L^{-1} < 236 mg L^{-1}). (NH_3–N and PO_4 also showed greater concentrations at the 1.5 m depth.

The analysis of variance results under the test of equality of group means was used to identify physicochemical parameters that differed significantly among the 3 depths. From the results (Table 5), it can be seen that four of the

Table 4
Total means, group mean, and test of equality of group means depths concentrations

Water quality parameters	Total mean for 3 depths	Group means depths concentrations			Test of equality of group means		
		0.5 m	1 m	1.5 m	Wilks' Lambda	*F*	Significance
pH	6.6 (0.83)	6.9 (0.91)	6.7 (0.78)	6.2 (0.71)	0.92	5.57	0.005
DO	4.40 (2.02)	5.7 (1.95)	4.20 (1.85)	3.3 (1.48)	0.76	19.60	0.000
Temp	29.66 (1.14)	30 (1.18)	29.63 (1.09)	29.40 (1.1)	0.95	3.45	0.035
TDS	223.94 (38.14)	213.12 (34.43)	222.27 (37.99)	236.11 (39.10)	0.94	4.02	0.02
NH_3–N	0.24 (0.43)	0.2 (0.4)	0.27 (0.45)	0.26 (0.45)	0.99	0.34	0.72
PO_4	0.19 (0.52)	0.2 (0.46)	0.15 (0.42)	0.25 (0.65)	0.99	0.45	0.64
PO_4–P	0.062 (0.62)	0.065 (0.43)	0.048 (0.33)	0.081 (0.48)	0.99	0.29	0.6.8

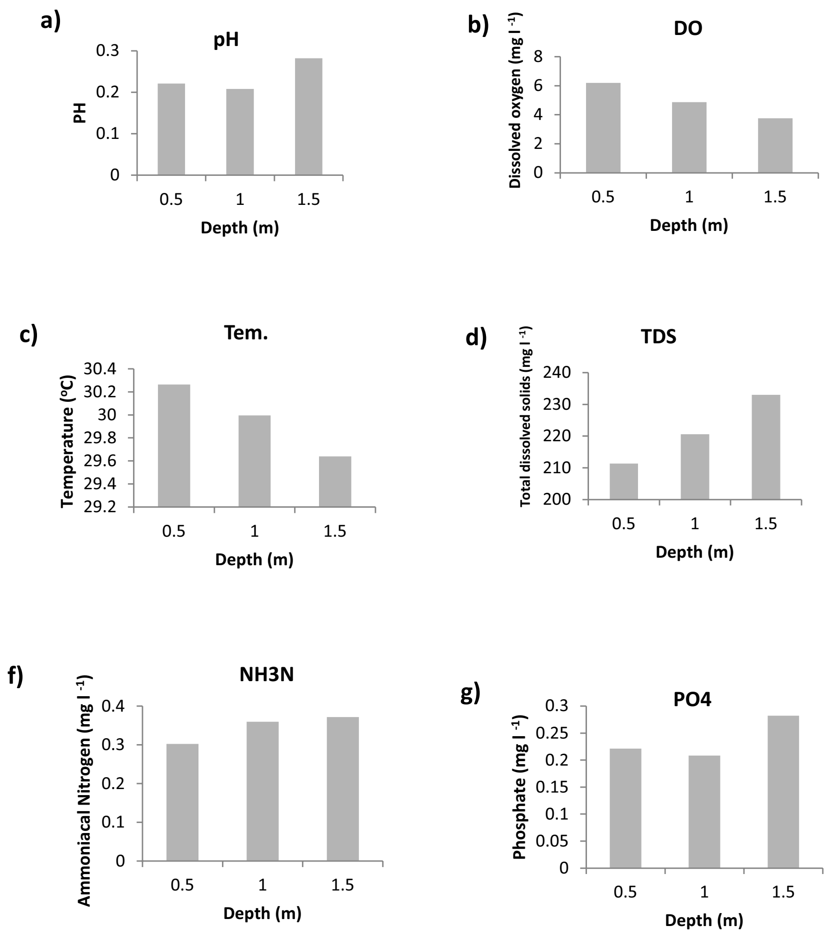

Fig. 1. Variations of physicochemical parameters with depth.

Table 5
Comparing total mean physical quality parameters and metal concentrations measured in the study with 2 established water quality guidelines

Water quality parameter	Total metal concentrations for dry and wet seasons at study locations respectively	CCME standards		INWQS for Malaysia	
		Overall	Aquatic	Class I	Class IIA
pH	6.6 (0.81)	8.5–9	5–9	6.5–8.5	6–9
Dissolved oxygen	4.96 (2.32)	NA	NA	7	5–7
Temp	29.90 (1.17)	15	15	NA	29.0
Total dissolved solids	221.70 (37.60)	500	500	500	1,000
Ammoniacal nitrogen (NH_3–N)	0.21 (0.41)	1.37	1.37	0.1	0.3
Phosphate (PO_4)	0.22 (0.73)	NA	NA	0.10–0.20	NA
Phosphate phosphorus (PO_4–P)	0.071	<0.02	*Trigger ranges	0.05	NA

NA: not available;
*<0.004 (ultra-oligotrophic); 0.004–0.010 (oligotrophic); 0.010–0.020 (mesotrophic); 0.020–0.035 (meso-eutrophic); 0.035–0.0100 (eutrophic); >0.100 (hyper-eutrophic);
Baginda and Zainudin [36]; Canadian Council of Ministers of the Environment (CCME) [39].

physicochemical parameters investigated, (pH, λ = 0.916, F = 5.57) (DO, λ = 0.755, F = 19.60) (temperature, λ = 0.945, F = 3.45) (TDS, λ = 0.0.938, F = 4.02) were varied significantly at P < 0.005, 0.001, 0.05, respectively for the three depths. Conversely, NH_3–N and PO_4 were similar for the 3 depths (NH_3–N, λ = 0.99, F = 0.34) (PO_4, λ = 0.99, F = 0.45) with P = 0.72 and 0.64 respectively. We can therefore reject the null hypotheses and accept the alternative hypotheses that pH, DO, temperature, and TDS in the Varsity Lake vary significantly with depth, with the 0.5 and 1 m depths having greater values of physicochemical parameters than the 1.5 m depth. However, for the NH_3–N and PO_4, we can accept the null hypotheses that there are no differences in their concentrations in the Varsity Lake with depth. In descriptive terms, PO_4–P total mean depth concentration is 0.062, while the group mean depths concentrations for 0.5, 1, 1 and 1.5 m are 0.065, 0.048 and 0.081, respectively.

4.4. Comparing the effect of location on physicochemical parameters (lateral variability)

The effects of locations with physicochemical parameters are represented in (Fig. 2a–c). The results (Fig. 2a) showed that the lowest pH value was recorded at location 1 (proximity to stormwater inlets 1), with the pH increasing up at location 3 (proximity to stormwater inlets 3), which had the highest pH value. In contrast, the results (Fig. 2b) showed that TDS was highest at locations 1 (proximity to stormwater inlets 1) and locations 2 (proximity to stormwater inlets 2. This was followed by location 10 (proximity to stormwater outlets 1. while location 4 (proximity to stormwater inlets 4) had the least TDS. The results (Fig. 2c) showed that DO values within locations were comparable to one another. The highest DO was found at location 5 (Within the Lake Central 1), while location 1 had the lowest DO. The results (Fig. 2b and c) showed that the lowest concentration of nutrients (NO_3–N, PO_4 and PO_4–P) were recorded at location 10 while the highest concentration of nutrients NO_3–N (Fig. 2b) was recorded at location 1 (proximity to stormwater inlets1), whereas the highest concentration of PO_4 (Fig. 2c) and PO_4–P were recorded at location 5.

4.5. Comparing total mean physical quality parameters concentrations measured in the study with 2 established water quality guidelines

The results (Table 5) showed that the total mean pH value and TDS were within an acceptable range when compared to the two standard guideline values, while the total mean DO and NH_3–N) were below the standard guideline values. However, the total mean temperature exceeded both standard guideline values. The phosphorus (PO_4–P) obtained is above the Canadian Council of Ministers of the Environment (CCME) and Malaysia standards (The Putrajaya Ambient Lake Water Quality Standards).

4. Discussion

Physicochemical parameters are critically important when evaluating water quality as they can be used to designate water samples as physiochemically fresh, slightly polluted and polluted. In this study, the following physicochemical parameters were investigated: pH, DO, TDS, temperature, NH_3–N and PO_4.

4.1. pH

The pH value in the Varsity Lake was significantly higher in the wet season (6.9) than in the dry season (6.2), with a total mean value of 6.6. The total mean and wet season pH values obtained in this study were within the range of pH values recommended by the CCME, 1999 and the INWQS. But the dry season concentration is slightly acidic and below the range. From the perspective of ecological disturbance, it could be said that based on the total mean concentration, pH does not pose a noticeable ecological disturbance. But in the dry season, pH is expected to pose slight stress disturbance to aquatic biotas like

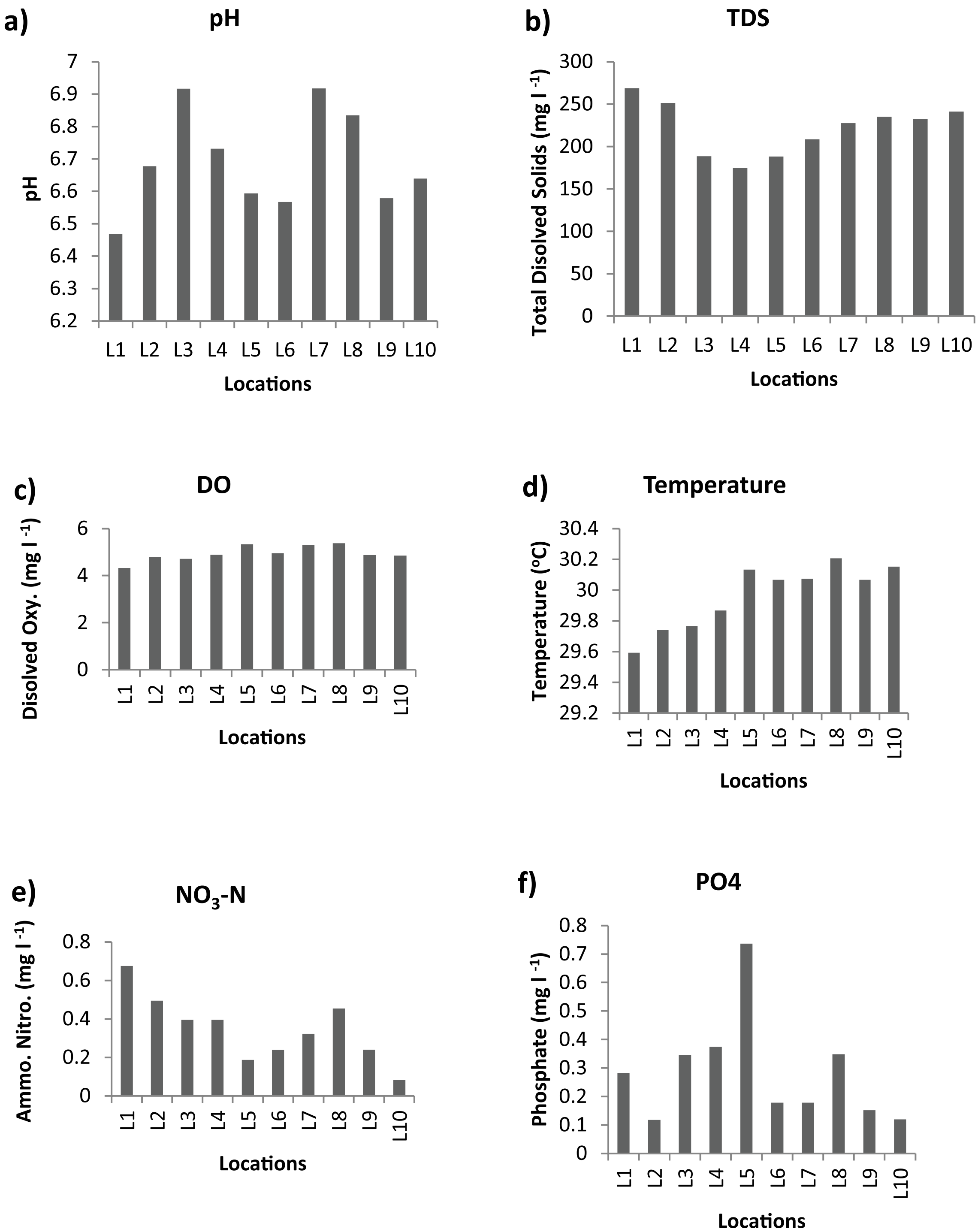

Fig. 2. Lateral variations of physicochemical parameters.

fish and invertebrates. Similarly, studies have found that pH values in the range of 6.5–9 is an index for increased fish habitation [30,31]. Barreto et al. [32] also found lower pH values in the dry than in the wet season, which they attributed to greater organic matter content in the Lake as a result of decomposition, which in turn generates fulvic acid that lower the pH of the water.

4.2. Temperature

The water temperature in the Varsity Lake was significantly higher in the wet season (30°C) than in the dry season (29.5°C), with a mean temperature of 29.90°C. The mean temperature was higher than the temperature value of 29°C for Class IIA. Although the mean temperature was also higher than the ranges for the CCME guidelines (15°C), but this is negligible due to differences in climatic conditions. The effect of elevated temperature had been highlighted, for example, Michaud [12] reported that most aquatic organisms are cold-blooded, that is, they lack mechanisms to control their body temperature; as a result, any increase in temperature will adversely affect their activities. In this study, temperatures were higher in the wet than in the dry season. This may be due to the cumulative thermal effects of elevated stormwater temperature flowing over impervious surfaces and discharging into the Varsity Lake during the wet season.

4.3. Dissolved oxygen

In this study, DO was found to have the most significant influence in differentiating between the two seasons concentrations. DO concentration in the Varsity Lake was significantly greater in the wet season than in the dry season by a factor of 2.1, with a mean concentration of 4.96 mg L^{-1}. The mean concentration is below the range of concentrations for Class I and II of the INWQS. Though the wet season concentration is within the range of Class 1, it is below the acceptable limit for Class II. This implies that conventional treatment is required for Class II utilisation. However, the DO concentration during the dry season calls for real concern as it is below the acceptable limits of both classes. Based on the mean total value, DO will constitute ecological disturbances to aquatic life as generally, DO below 5.0 subject's aquatic organisms to ecological disturbance. The ecological disturbance is expected to be severe in the dry season when DO is at the level of 2.9 mg.

Barreto et al. [32] reported decreased DO in the dry season than in the wet season. The lower dissolved oxygen concentrations can be attributed to cumulative effects the elevated water temperature, decomposition of organic matter. Other investigators have attributed low DO levels to reduced wave actions during sampling and discharges from sewages which can affect aquatic life. This is in line with the results obtained in this study as both wind and wave actions are more pronounced during wet than dry seasons. As a result, the influx of air is reduced during the dry season, which may reduce DO concentrations.

4.4. Total dissolved solids

The total suspended solids (TDS) was significantly higher in the wet season than in the dry season by a factor of 1.2, with a mean of 221.70 mg L^{-1}. The value is within the range recommended by both CCME and the INWQS values. As such, TDS will not contribute significantly to ecological disturbance. However, this is below the TDS value reported by Aqeel Ashraf et al. [22].

4.5. Nutrients: ammoniacal nitrogen (NH_3–N)

The concentration of NH_3–N was greater in the dry season than in the wet season by a factor of 5.7, with a mean concentration of 0.21 mg L^{-1}. This was lower than both the CCME, 1999 and Class IIA INWQS guideline values. However, the values were greater than the Class I INWQS. Addo et al. [30] had reported that nitrate levels are used to monitor organic contamination in water bodies. This finding implies that based on the mean concentration, NH_3–N alone will constitute an insignificant source of ecological disturbance.

4.6. Phosphate (PO_4)

The concentration of phosphate obtained in the dry season was greater than that obtained in the wet season by a factor of 3.2, with a mean concentration of 0.22 mg L^{-1}. Similar mean phosphorus concentrations (0.22 mg L^{-1}) were also obtained by Addo et al. [30] who reported that phosphorus concentration is used as an index of anthropogenic contamination. Although the two water quality guidelines used for comparison in this study did not have any available data as regards the permissible levels of phosphorus, the recoded value for the Varsity Lake is nevertheless much above the range (0.005 to 0.02 mg L^{-1}) reported by a researcher as background concentrations for unpolluted waters. The (PO_4–P) obtained (0.0710 is higher than the CCME and Malaysia standard (The Putrajaya Ambient Lake Water Quality Standards) [33]. The obtained value is within range eutrophic anoxia condition is triggered.

From the perspective of vertical variations, pH, DO, and temperature exhibited similar decrease patterns with depth. In contrast, TDS, NH_3–N, PO_4 all increased with depth. The results of the discriminant analysis also showed that pH at $P < 0.001$, DO at $P < 0.005$, TDS at $P < 0.035$ and temperature at $P < 0.02$, all varied significantly with depth, with the 0.5 m (surface having significantly greater concentrations compared to the 1 and 1.5 m respectively. An ecological disturbance will increase with increasing depth as DO decreases with depth. DO below 3.4 mg could lead to a state of anoxia that could trigger sublethal ecological disturbance effect in the form of aquatic life growth impairment and reduced reproduction. As such, the 3.3 mg DO at 1.5-m depth can lead to hypoxia conditions that could trigger lethal ecological effects on aquatic biota. The vertical variation in DO could lead to a restricted movement which is also a form of an ecological disturbance where aquatic organisms remain at the top surface column with tolerable DO and avoid anoxia condition at the lower surface.

Conversely, NH_3–N at $P > 0.64$ and PO_4 at $P > 0.72$ were statistically similar with depth. Although, both nutrients still showed greater concentrations at the 1.5 m (bottom) depth. It was not statistically significant. Consequently, the potential ecological disturbance caused by the nutrient, particularly PO_4 will not vary with depths. The TDS was rather significantly greater at the 1.5 m depth than the 1 and 0.5 m depths, respectively. Consistent with our result, Barreto et al. [32] found greater DO concentrations at the Lake surface (5.6 mg L^{-1}) is higher compared to the subsurface (>1 m depth); (1.4 mg L^{-1}). Also, Mwamburi [34], in their study at Lake Sare, found that both temperature and DO were greater at the surface than the bottom at Lake Kanyaboli; they also found that pH was greater at the surface compared to the bottom [34–40]. The higher pH values at the surface were attributed to higher evaporation rates that lead to an increase in the concentration of excess soluble salts in water. On lateral variation, the least pH and DO values were recorded at location 1 (proximity to stormwater inlets 1) close to the Faculty of Engineering and student's canteen. Similar results were obtained by Aqeel Ashraf et al. [22], who recorded the lowest pH and DO values at sites near the engineering faculty in their study on the water quality in the Varsity Lake. At all the locations, both pH and DO values were below the water quality guideline values [41–45]. Thus, ecological disturbances resulting from low pH and DO are expected at all ten locations. The TDS were highest at location 1, followed by location 2 (proximity to stormwater inlets 2) [46–50]. In this study, TDS were within the guideline values at all the locations. The least temperature was recorded at location 1, with location 8 having the highest temperature. The lowest concentration of nutrients, NO_3–N and PO_4, was recorded at location 10 (proximity to stormwater outlets 1), while the highest concentration of NO_3–N was recorded at location 1, and the highest concentration of PO_4, was recorded at location 5 (Within the Lake Central). Based on PO_4–P concentration, the Lake may not be described as oligotrophic. The PO_4–P concentration in the lake ranged from 0.038 to 0.238, with 60% of the locations (1,2,6,7,9,10) within the range that is described as eutrophic or concentration level at which algae and plant growth are stimulated while at 40% of the locations (3–5,8) is within the range that is described as hyper-eutrophic or level of accelerated algae plant growth and consequential problems. Consequently, in 100% of the locations, PO_4–P concentrations will lead to ecological disturbances [50–58]. PO_4–P induced ecological disturbance will be particularly severe in 40% of the locations (3–5,8). The concentration of NH_3–N was below the CCME, 1999 guideline values at all the locations but was above Class IIA of the INWQS at 60% of the locations (1–4, 7 and 8). Nitrates hinder the oxygen-carrying capacity of blood in aquatic organisms as well as proper salt balance. The authors also reported that elevated concentrations of nutrients (NO_3–N and PO_4) can lead to the proliferation of plants and algae, which in turn reduces oxygen levels in the water.

5. Conclusions

Information on concentrations and variations of physicochemical water quality parameters are crucial for the effective management of the aquatic environment. This study is set out to determine the seasonal, vertical and lateral variations in physicochemical water quality parameters in Varsity Lake Malaysia. Discriminant analysis provided clear evidence of significant seasonal concentration variation in the parameters investigated. There was a significant discriminant function that accounted for and differentiated between wet and dry seasons concentrations. Wet season concentrations were significantly greater than in the dry season concentrations. Deducing from the structure correlations and canonical discriminant function coefficients, DO, pH, and TDS were the parameters that correlated best with the discriminant function and registered the highest discriminant power, thus making the most significant differences in the seasonal variation. From the perspective of vertical variation, DO, pH, TDS and temperature varied significantly with depths, but NH_3–N, PO_4 did not. pH, DO and temperature concentration decreased in the order of 0.5 m > 1 m > 1.5 m. The reverse was TDS concentration as it increased in the order of depth of 0.5 m < 1 m > 1.5 m. NH_3–N and PO_4 did not show a clear pattern, but their 1.5 m concentration was higher than the total mean concentration. The comparisons with two water quality guidelines showed that DO and pH (in the dry season slightly) failed the Malaysian Interim National Water Quality Guidelines (INWQS). Based on dry season concentration and the three depths, it may be said that overall, the lake is DO impaired and aquatic life (fish) production impairment is expected. While the surface water column at 0.5-m depth is slightly DO impaired, the subsurface columns, particularly the 1.5 m depths, may be described as severely impaired by DO, and aquatic life production impairment and mortality are highly possible. Based on the analysis of discriminant functions at group centroids, it is predicted that in the Varsity Lake, there is a greater probability for the concentrations of DO, pH, TDS and water Temperature to be higher in the wet season than in the dry season while the reverse prediction will be the case for NH_3–N and PO_4. By dint of PO_4–P concentration, it can be inferred that vertically and laterally, the Lake can overall be depicted as eutrophic and hence, very rich in nutrients with high biological productivity. More so, in the dry season and in the benthic water column (1.5 m depth), the lake is characteristically hyper-eutrophic, as a result highly productive owing to excessive nutrient load. From the theoretical perspective, it is predicted that the lake will experience seasonal, vertical and lateral ecological disturbances. The seasonal ecological disturbance will be higher in the dry season, while the vertical ecological disturbance will be higher at the subsurface water columns of 1 m depth and 1.5 m depth. The physicochemical water quality parameters that contribute most to the ecological disturbances are DO, pH, PO_4 and PO_4–P. It is recommended that future physicochemical water quality studies of the Varsity Lake should include other parameters, particularly biochemical oxygen demand (BOD) and chemical oxygen demand, to better characterise the physicochemical water quality of the lake.

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