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Examining seasonality and vertical variability of heavy metals contamination in Urban Lake Malaysia using discriminant analysis

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ABSTRACT

The aims of this study are threefold: (1) to determine the seasonal, vertical and lateral variations in heavy metals (Na, K, Al, Fe, Ba, Cu, Ni, Cd) contamination in Varsity Lake Malaysia, (2) if the significant seasonal variation were observed, derive a discriminant function metals contributed or had the greatest effect on the seasonal variation, and (3) assess the extent to which the water quality has degenerated based on three water quality guidelines. The water Sample analysis was performed by an inductively coupled plasma-mass spectrometry. Variation in heavy metal concentration was analysed using discriminant analysis method. The results of Wilks' Lambda *F*-test, canonical discriminant function showed strong significant seasonal variations for the metals with the rainy season having greater concentrations than in the dry season. While rainy season concentrations decreased in the order Na > K > Al > Fe > Ba > Cu > Ni > Cd, the dry season concentrations decreased in the order: Na > K > Fe > Al > Ba and Ni > Cu > Cd. The finding reveals a significant discriminant function and the metals with the most significant discriminant power were Na, Cu, and K, thus made the highest contribution (60%) to the seasonal variability. Though overall concentration was higher at 1.5-m depth, no significant vertical (depth) variation was observed. Overall, the summative metal concentration is highest in the inlet section of the lake, followed by the outlet sections. None of the metals exceeded the values for the Malaysian Interim National Water Quality Guidelines Class II and the United States Environmental Protection Agency criteria. Although Cd, Al and Fe, did exceed the Canadian Council of Ministers of Environment Guidelines, the water quality is still safe for macro aquatic life, no advanced treatment is required and hence good for recreational purposes.

Keywords: Heavy metals contamination; Water quality in Malaysia; Metals concentration; Discriminant analysis; Seasonal variation; Water pollution in Malaysia; Urban Lake pollution

1. Introduction

The contamination of water resources systems such as lakes and streams with heavy metals mainly results from waste and stormwater drainage that runs off into these water resources [1,2]. Urban stormwater-fed lakes are a major challenge to the government and water quality management institutions in Malaysia and around the world, and Varsity Lake Petaling Jaya, Malaysia, is an excellent example of an Urban Lake exposed to urban stormwater. The primary sources of water for Varsity Lake are underground water and urban stormwater pump. Whereas underground water may not constitute a significant contamination concern to the lake compared to urban

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stormwater since underground water is often buffered against acid rain and do not contain many organic contaminants, the main problem heavily lies with the urban stormwater. This worry comes from increasing literature evidence showing that urban stormwater discharged into lakes and rivers constitute significant sources of surface water pollution [3,4]. This concern stems from profound evidence that urban stormwater and effluents discharged into lakes and rivers are significant sources of water pollution and sediment contamination. More so, there is a widespread understanding that urban stormwater, to a great extent, is a potential source of anthropogenic heavy metals and organic nutrients contaminants. It was against this backdrop that St-Hilaire et al. (2016) argued that high concentrations of heavy metals in urban stormwater is considered one of the most critical surface water quality problems. This is mainly because heavy metals are ubiquitous in the environment, owing to their inability to undergo biological, physical or chemical degradation, thereby resulting in toxicity and persistence in the water bodies [5,6].

Studies by Sarika and Chandramohanakumar [7] have reported the danger posed to the urban water resources by the continuous discharge of unprocessed wastewaters and stormwater, spills and indiscriminate dumping of solid waste into the water resources. The impacts of these pollutants on the water quality and surrounding food chain have also been highlighted [8–10]. For example, when heavy metals go into an aquatic ecosystem, they are dispersed through the whole water column and eventually consumed by biota [11,12]. Additionally, heavy metal contaminants, even at low levels, can result in damage to the nervous system, reproductive impairments and cancer, following long periods of exposure. Increasingly, researchers and regulators rely much on elevated concentrations of these metals as one means to predict the risk posed by these metals in the environment.

Urban stormwater in Petaling follows seasonal patterns. Thus, any contaminated stormwater emptying into lakes and rivers would have a concomitant influence on seasonal variability of heavy metal concentration and water quality conditions. In other words, owing to the seasonality, stormwater flows, concentrations of heavy metals in lakes and rivers are expected to fluctuate and change with seasonal fluctuations in stormwater flows. It becomes imperative, therefore, to investigate contamination of any stormwater-reliant lake from the perspective of seasonality. Regular monitoring and characterisation of the seasonal water status of a lake is a necessary part of lake management. It provides information on seasonal dynamics and changes in lake water quality conditions.

Many past studies investigating the seasonal variability of heavy metals in surface water have mainly adopted one-way ANOVA as their statistical analysis method. As a result, the findings from these studies have yielded limited information owing to the statistical limitations of one-way ANOVA. Yet, discriminant analysis which is an excellent alternative method is hardly used by researchers, notwithstanding its apparent advantages over one-way ANOVA. The few studies that utilised discriminant analysis only partially made use of its analytical statistics. As a result, their study lacks essential information.

This study investigates the heavy metal concentration (K, Cd, Al, Cu, Fe, Ba, Na and Ni) in the water of Varsity Lake, University of Malaya, Petaling Jaya, Malaysia, which is mostly used for recreational purposes such as canoeing by students, as well as habitat for some aquatic life. The purpose of this study is to apply a discriminant analytical method to determine: (1) whether there are significant seasonal and vertical variations in the heavy metal concentrations in Varsity Lake Malaysia; (2) determine if there is a significant discriminant function that differentiates wet and dry season variations, and identify the metals that contribute highest to the discriminant function, and thus, had the greatest response effects to the seasonal and vertical variation. It, therefore, tries to test the hypothesis of no significant seasonal variations in the heavy metals concentration and no significant discriminant function depicting such variations; (3) determine the vertical and lateral variation of the concentration of the metal and find out locations and columns of water most affected by contamination, and (4) the study further compared the results with water quality guidelines established in the literature and also examined the probable effects of elevated concentrations on the food chain.

2. Materials and methods

2.1. Study area

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 [13]. The lake is situated at the main gate of the University of Malaya, bordering 250.6 m in length, 85.3 m in width and a depth of 6 m. Overall, Peninsular Malaysia has a characteristic monsoon climate with two wet seasons related to the southwest monsoon (SWM), which occurs from May to September and the northeast monsoon (NEM), which takes place from November to March. The highest rainfall is observed during the transition period between the NEM (December to March) and SWM (June to September). Temperatures range from 21°C to 32°C. The precipitation patterns, however vary slightly among those states. Petaling Jaya and Kuala Lumpur record heavier rainfall in the months of November, December, October, September, March and April. In contrast, lighter rainfall is recorded in the months of January, February, May, June, July and August. December gets the highest mean monthly rainfall of 314 mm, which represents about 14% of the mean annual rainfall. On the other hand, February receives the lowest mean monthly rainfall of 115 mm that accounts for only about 5% of the mean annual rainfall. In this study, the sample of heavy metals was taken in September, October and December to represent and characterise wet season and in May, June and February to characterise dry season.

2.2. Sample collection and water quality evaluation

In this study, we selected 10 sampling positions were selected based primarily on their proximity to sources of water inlets and outlets of the lake as well as locations within the Lake Central and Lake Bay (close to the main road). The locations cover the northern, southern and central parts of the lake. The lake is deeper at the southern outlets area of the lake. These were denoted as stations 1–10, as shown in Table 1. 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. Heavy metals in the samples were analysed by inductively coupled plasma-mass spectrometry (PerkinElmer). The results from the present study were compared with 3 water quality guidelines as it relates to heavy metals: (1) the Canadian Council of Ministers of the Environment (CCME) guidelines for the protection of aquatic life. (2) United States Environmental Protection Agency (USEPA)-Criteria Maximum concentration. (3) The Malaysian Interim National Water Quality Guidelines Class II (INWQS).

2.3. 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 heavy metal concentration: dry season concentration and wet season concentration, it also seeks to identify the most dominant metal 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 (Hair et al., 1987). 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:

$$Z = W1X1 + W2X2 + W3X3..... + WnXn \quad (1)$$

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 (SDFC), 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 Wilks' Lambda (called the model Wilks' Lambda is used to test the goodness-of-fit of the model. The larger the value of Wilks' Lambda, the more the within-groups variation. Discriminant analysis was applied to test the hypothesis that there is of no significant seasonal and vertical variations in the heavy metals' concentration and no significant discriminant function depicting such variations.

3. Results

3.1. Comparing total mean metal concentrations with 3 established water quality guidelines

The total mean concentrations of metals in the two seasons were compared with the CCME, USEPA and INWQS. The results (Table 2) showed that the total mean concentration of Cd (0.247 μg L^{-1}) exceeded the CCME guideline values but was below the USEPA and INWQS guideline values, respectively. The results also showed that both Al and Fe with total mean concentrations of 502 and 453 μg L^{-1}, exceeded the CCME guideline values but were below the USEPA and INWQS guideline values respectively, while Cu with a total mean concentration of (4 μg L^{-1}) was within the range of values for the CCME and below the range of values for both USEPA and INWQS guidelines respectively. Conversely, Ba (110 μg L^{-1}) and Ni (0.5 μg L^{-1}) were below the INWQS and below all the guideline values, respectively.

The percentage increases in heavy metal concentrations over the guideline values were also calculated. The results showed that the total mean concentration of metals only increased above the CCME guideline values; Cd increased

Table 1
Sampling positions

Serial No.	Position		
	Latitude	Longitude	Close proximity to
Location 1	03 07 11. 14242	101 39 22. 46321	Proximity storm water inlets 1
Location 2	03 07 10. 78242	101 39 23. 06321	Proximity storm water inlets 2
Location 3	03 07 10. 36242	101 39 23. 86321	Proximity storm water inlets 3
Location 4	03 07 09. 70242	101 39 25. 06321	Proximity 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

by 93%, Al increased by 80%, while Fe increased by 33.8%. However, there was no increase over the USEPA and INWQS guideline values.

3.2. Seasonal variation in heavy metal concentrations

Total and seasonal variation in heavy metal concentrations is represented in (Table 3). The total mean concentration for the eight metals were found to be in the order of Na > K > Al > Fe > Ba > Cu > Ni > Cd. The results showed a consistent trend in metal concentration with respect to seasons. The mean concentrations of all the eight metals investigated were greater in the rainy season than in the dry season. The rainy season concentrations decreased in the order: Na > K > Al > Fe > Ba > Cu > Ni > Cd (3.93 > 2.74 > 0.70 > 0.52 > 0.02 > 0.01 > 0.001 > 0.0004 mg L^{-1},respectively while the dry season concentrations decreased in the order: Na > K > Fe > Al > Ba and Ni > Cu > Cd (2.02 > 2.00 > 0.36 > 0.20 > 0.0002 and 0.0002 mg L^{-1} > 0.00003 mg L^{-1} > below detection limit, respectively).

The Wilks' Lambda univariate (ANOVA) F-test for equality of group means was used to identify heavy metal concentrations that differed significantly between the two seasons. From the results (Table 3), it can be seen that the following heavy metals, (K, λ = 0.592, F = 102.08) (Cd, λ = 0.796, F = 37.85) (Al, λ = 0.845, F = 27.22) (Cu, λ = 0.472, F = 165.31) (Na, λ = 0.448, F = 182.57) (Ba, λ = 0.720, F = 57.59) (Ni, λ = 0.798, F = 37.52) exhibited significant mean differences at P < 0.001 level of significance, while (Fe, λ = 0.958, F = 6.43), exhibited significant mean differences

Table 2
Comparing total mean metal concentrations measured in the study with 3 established water quality guidelines

Metal	Total concentrations for dry and wet seasons at study location (μg L^{-1})	CCME – Protection of aquatic life (μg L^{-1})	USEPA – Criteria maximum concentration (CMC) μg L^{-1}	INWQS Class II (μg L^{-1})
K	2,440	–	–	–
Cd	0.247	0.017	2.0	10
Al	502	5–100	750	–
Cu	4	2–4	13	20
Fe	453	300	–	1,000
Na	3,170	200,000	–	–
Ba	110	–	–	1,000
Ni	0.5	25–150	470	50

Sources: Canadian Council of Ministers of the Environment (CCME) [20]; Tong and Goh [23]; USEPA (United States Environmental Protection Agency) [24].

Table 3
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.
K	2.44 (0.572)	2.00 (0.026)	2.74 (0.57)	0.74	0.592	102.08	0.000
Cd	0.000247 (0.00045)	0.0001 (0.00)	0.00041 (0.00052)	0.00	0.796	37.85	0.000
Al	0.503 (0.627)	0.201 (0.514)	0.704 (0.62)	0.503	0.845	27.22	0.000
Cu	0.00405 (0.0045)	0.00033 (0.0026)	0.0067 (0.0040)	–0.006.7	0.472	165.31	0.000
Fe	0.453 (0.385)	0.357 (0.513)	0.517 (0.251)	0.16	0.958	6.43	0.012
Na	3.167 (1.27)	2.016 (0.129)	3.93 (1.094)	1.914	0.448	182.57	0.000
Ba	0.011 (0.017)	0.00017 (0.0013)	0.019 (0.019)	0.019	0.720	57.59	0.000
Ni	0.0005 (0.0009)	0.00017 (0.0013)	0.0008 (0.001)	0.0007.83	0.798	37.52	0.000

Diff 1 = 1 Diff 2 = 148; Figures in () = Standard deviation.

at $P < 0.01$ level of significance within the two seasons respectively. We can therefore reject the null hypotheses that there is no significant difference between the concentration of heavy metals in the Varsity Lake in the dry and rainy seasons and accept the alternative hypotheses that the concentration of heavy metals in the Varsity Lake is greater in the rainy season than in the dry season.

3.2.1. Predicting heavy metal concentrations in Varsity Lake

In this study, we aim to identify the most significant heavy metal concentration with the highest discriminant power and, therefore, best distinguishes between concentrations in rainy and dry seasons. Thus, this will help to predict at what season heavy metal concentrations will be highest based on their variable concentrations. Table 4 showed that seven out of the eight metals measured (Na, Cu, K, Ba, Cd, Ni, and Al) entered the model at a $P < 0.01$ level of significance. Thus, seven heavy metals entered the model with significant discriminatory power, which serves as an effective means of distinguishing between the two seasons on the concentration of heavy metals. The table also showed the standardized discriminant function coefficients used to assess each metal's unique contribution to the discriminant function. It follows that the heavy metal in the model with the greatest discriminatory power in both the rainy and dry seasons were Na (β = 1.423 and within-group correlation = 0.490 at $P < 0.01$); Cu (β = 0.674 and within-group correlation = 0.466 at $P < 0.05$); K (β = 1.033 and within-group correlation = 0.366 at $P < 0.01$), Ba (β = 0.318 and within-group correlation = 0.275 at $P < 0.05$) Cd (β = 0.442 and within-group correlation = 0.223 at $P < 0.01$) Ni (β = 0.272 and within-group correlation = 0.222 at $P < 0.01$) Al (β = 0.189 and within-group correlation = 0.189 at $P < 0.01$). This also implies that these heavy metals had a greater influence in distinguishing between the rainy and dry season concentrations.

The functions at the group centroid are used mainly for the classification and depiction of a group membership. It determines the optimal Z-value on which

Table 4
Predictive model of heavy metal conce tions in water of Varsity Lake

Variables (entered/removed)		Model Wilks' Lambda				Exact *F*			
Step	Heavy metals entered	Statistic	df1	df2	df3	Statistic	df1	df2	Sig.
1	Na	0.448	1	1	148	182.573	1	148	0.000
2	Cu	0.472	2	1	148	165.314	1	148	0.000
3	K	0.592	4	1	148	102.075	1	148	0.000
4	Ba	0.720	5	1	148	57.587	1	148	0.000
5	Cd	0.796	6	1	148	37.854	1	148	0.000
6	Ni	0.798	7	1	148	37.524	1	148	0.000
7	Al	0.845	8	1	148	27.223	1	148	0.000
Standardized Canonical Discriminant Function Coefficients (SCDFC)									
		Function 1	Impact ranking		Structure matrix (within group correlation)				
Na		1.423	1		0.490 or 24.0%				
Cu		0.674	2		0.466 or 22.7%				
K		–1.033	3		0.366 or 13.4%				
Ba		0.318	4		0.275 or 7.5%				
Cd		0.442	5		0.223 or 5.0%				
Ni		–0.272	6		0.222 or 5.0%				
Al		–0.189	7		0.189 or 3.6%				
Functions at group centroids									
Dry season		–2.757							
Rainy season		1.838							
Model validation statistics									
Canonical correlation (CCr)		0.915							
CCr^2		0.84							
Eigenvalue		5.136							
Wilks' Lambda		0.163							
Sig.		0.000							
Chi-square (df = 10)		259.428							
Classification accuracy (hit ratio)		98%							

the heavy metals concentrations could be classified into varying more in the rainy or dry seasons. The table showed that at the group centroids, heavy metals concentration in the rainy season had a Z-value of 1.838, while the concentration in the dry season had a Z-value of –2.757. This suggests that a heavy metal concentration having a Z-value in the direction of 1.838 is grouped into the rainy season, while a heavy concentration having a Z-value in the direction of –2.757 is grouped into the dry season. Using the Standardized Canonical Discriminant Function Coefficients (SCDFC), deriving the final discriminant score (Z score) for classification of the groups will take the following form:

$$Z = 1.423\text{Na} + 1.033\text{Cu} + 1.033\text{K} + 0.318\text{Ba} + 0.442\text{Cd} + 0.272\text{Ni} + 0.189\text{Al} \quad (2)$$

Considering that discriminant functions have a zero mean cut-off value, discriminant coefficients in the model that fell above the zero mean cut-offs (i.e., they had positive values) fell under the classification of greater wet season variability. Meanwhile, discriminant coefficients below the zero mean cut-offs (i.e., they had negative values) fell under the classification of greater dry season variability. Thus, with positive wet season group centroids of 1.838, it is clearly followed that the seven heavy metals (Na, Cu, K, Ba, Cd, Ni, and Al) with positive discriminant coefficients were therefore classified under the posterior probability of greater wet season variability, ceteris paribus. Put differently, Na, Cu, K, Ba, Cd, Ni, and Al were classified and predicted in future to have a greater probability of wet season variability.

The results further revealed a classification accuracy or hit ratio of 98%, implying that the discriminant function effectively distinguished the seasonal variability and classified the metals correctly posterior greater wet seasonal variability memberships. The result (Table 4) 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 0.915 implies that the model has explained 84% (CCr^2) of 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 (λ = 0.163; $\chi^2_{(\text{df} = 10)}$ = 259.43 at P < 0.001). As a result, we accept the alternative hypothesis (H1) and conclude that there is a significant discriminating function that differentiates heavy metal concentration in the rainy and dry seasons with respect to Na, Cu, K, Ba, Cd, Ni, and Al.

An attempt was made to examine concentration heavy metals concentrations within the seasons. The results Fig. 1 showed that in the rainy season, the month of December had the highest metal concentrations, and

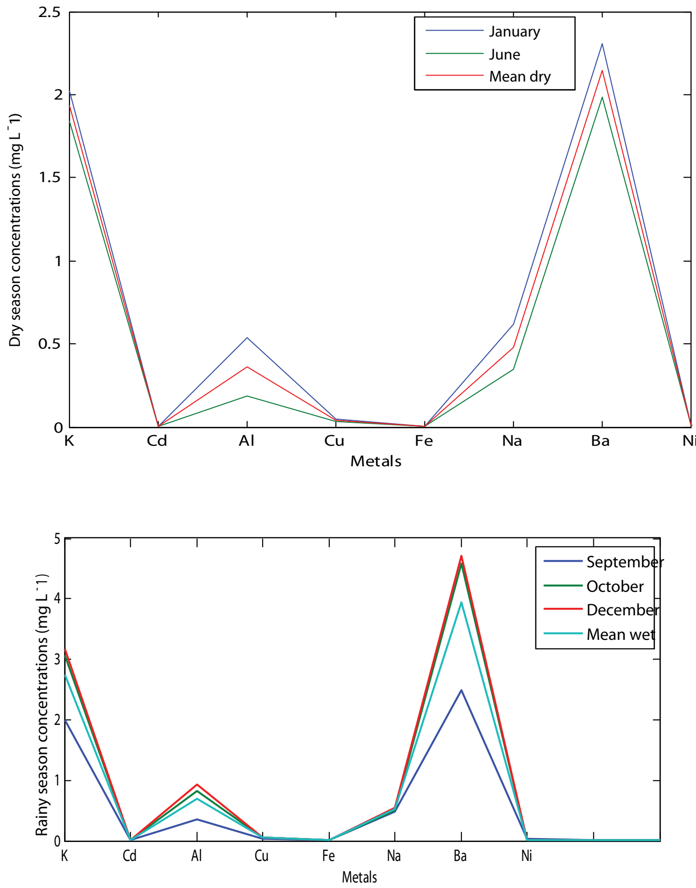

Fig. 1. Comparing metal concentrations within seasons.

then followed by October, while September had the lowest, but in the dry season, the month of January had the highest metal concentration, while June had the lowest, with Na having the greatest concentrations in all the months.

3.3. Comparing metal concentrations within depth data

Vertical variation in heavy metal concentrations is represented in (Table 5). The results showed a pattern for five metal concentration with respect to depth, where greater concentrations were recorded with the 1.5 m depth for Cd (0.00072 μg L^{-1}), Fe (0.55 μg L^{-1}), Na (3.25 μg L^{-1}), Ba (0.02 μg L^{-1}) and Ni (0.00096 μg L^{-1}), then followed by the 1 m depth; Cd (0.00064 μg L^{-1}), Fe (0.497 μg L^{-1}), Na (3.23 μg L^{-1}), Ba (0.017 μg L^{-1}) and Ni (0.00066 μg L^{-1}) and the 0.5 m depth had the lowest Cd (0.00056 μg L^{-1}), Fe (0.458 μg L^{-1}), Na (3.17 μg L^{-1}), Ba (0.012 μg L^{-1}) and Ni (0.0006 μg L^{-1}). However, K, Al, and Cu did not show any consistent pattern with depth. The results in Fig. 2 also show that the 1.5 m depth has a greater metal concentration compared to those of 1 m and 0.5 m, respectively.

The analysis of variance results under the test of equality of group means was used to identify heavy metal concentrations that differed significantly according to depth. However, from the results (Table 4), it can be seen that the three group mean depths concentrations for all the eight heavy metals investigated, (K, λ = 1.0, F = 0.005) (Cd, λ = 0.992, F = 0.561) (Al, λ = 0.997, F = 0.252) (Cu, λ = 0.994, F = 0.421) (Fe, λ = 0.98, F = 1.495) (Na, λ = 0.999, F = 0.056) (Ba, λ = 0.968, F = 2.43) (Ni, λ = 0.988, F = 0.86) were not significant at 0.05 significant level (P > 0.05). We can therefore accept the null hypotheses that there is no difference between the concentrations of heavy metals in the Varsity Lake with depth and reject the alternative hypotheses that the concentrations of heavy metals in the Varsity Lake is greater at the 1.5 m depth compared to those of 1 and 0.5 m, respectively.

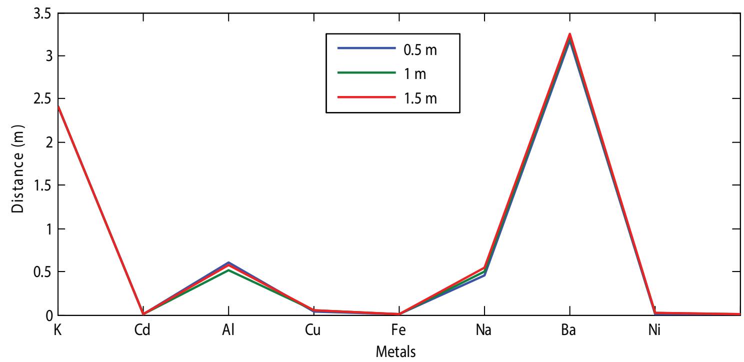

Fig. 2. Comparing metal variations with depth.

Table 5
Group mean differences and test of equality of group means for depths

Variables	Total (mean) concentration for dry and wet season (mg kg^{-1})	Group means			Tests of equality of group means		
		0.5 m	1 m	1.5 m	Wilks' Lambda	F^a	Sig.
K	2.42 (0.603)	2.42 (0.57)	2.42 (0.624)	2.41 (0.63)	1.000	0.005	0.995
Cd	0.000641 (0.00075)	0.00056 (0.00058)	0.00064 (0.00096)	0.000720 (0.00067)	0.992	0.561	0.572
Al	0.568 (0.57)	0.602 (0.70)	0.523 (0.49)	0.58 (0.51)	0.997	0.252	0.778
Cu	0.005 (0.0041)	0.0046 (0.0042)	0.0045 (0.0038)	0.0052 (0.0043)	0.994	0.421	0.657
Fe	0.502 (0.269)	0.458 (0.27)	0.497 (0.27)	0.55 (0.27)	0.98	1.495	0.228
Na	3.22 (1.23)	3.17 (1.20)	3.23 (1.24)	3.25 (1.27)	0.999	0.056	0.945
Ba	0.016 (0.015)	0.012 (0.0032)	0.017 (0.02)	0.02 (0.02)	0.968	2.43	0.092
Ni	0.00074 (0.0015)	0.000600 (0.0011)	0.0006) (0.002)	0.0009 (0.0011)	0.988	0.86	0.427

3.4. Comparing metal concentration within locations

Overall, the summative metal concentration is highest in the inlet section of the lake, followed by the outlet sections. Concentration was least in the middle section. As can be seen from Table 6, the concentration of metals within locations for both seasons showed that location 4 had the highest concentration (0.83 mg L^{-1}), followed by locations 2 (0.82 mg L^{-1}) and 3 (0.81 mg L^{-1}) respectively. This remained elevated at 0.78, 0.74 and 0.73 mg L^{-1} at locations 8, 9 and 5 respectively and then decreased to 0.72, 0.71, 0.69 and 0.68 mg L^{-1} at locations 1, 10, 6 and 7 respectively. When the concentration of individual metals was compared within locations, it was observed that Na had the highest concentration at the locations (L3, 4, 1, 2) in the inlet port of the lake. Al concentration was higher in the inlet and bay sections of the lake (L2, L4, L7). *K* concentration was higher in the inlet and middle sections (L4, L5, L6), while Fe concentration is higher in the inlet and outlet sections (L2, L8, L3). The salts of Na and K are the dominant metals entering the lake.

3.5. Discussion

In the present study, the total mean concentration of Cd, AL and Fe exceeded the CCME guideline values but was below the USEPA and INWQS guideline values, respectively. In comparison, the total mean concentration of Cu was within the range of values for the CCME and below the range of values for both USEPA and INWQS guidelines, respectively. Conversely, the total mean concentrations of Ba and Ni were below the INWQS and all the guideline values, respectively. Similar results were obtained by a researcher, where Cd concentrations of 0.421 μg L^{-1}, also exceeded the CCME guideline values but were below the USEPA and INWQS guideline values, respectively [14]. In the same study, Al and Fe concentrations (194.53 and 794.84 μg L^{-1}, respectively) both exceeded the CCME guideline values but were below the USEPA and INWQS, respectively. Also, the concentration of Ba (22.07 μg L^{-1}) was below the INWQS in the same study. The authors described the range of metal concentrations obtained in their study, which are also within the ranges obtained in the present study as low.

Regarding variation with respect to seasons, metal concentrations in the rainy season were greater than those in the dry season. Studies by Shuhaimi-Othman et al. [14] also found seasonal variation in metal concentrations, with greater metal concentrations in the rainy season (October–December), which later decreased following the cessation of rains. The authors attributed this to stormwater inflow

Table 6
Metal concentration within locations (mg L^{-1})

		Loc_1	Loc_2	Loc_3	Loc_4	Loc_5	Loc_6	Loc_7	Loc_8	Loc_9	Loc_10
K	TM	2.33	2.39	2.48	2.52	2.50	2.36	2.32	2.50	2.43	2.37
	DM	1.82	1.84	1.90	1.92	1.94	1.87	1.89	2.02	2.03	2.09
	WM	2.68	2.76	2.86	2.92	2.83	2.68	2.60	2.82	2.69	2.55
Cd	TM	0.0004	0.0005	0.0005	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	DM	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001
	WM	0.0002	0.0004	0.0002	0.0004	0.001	0.001	0.0003	0.0001	0.001	0.0003
Al	TM	0.37	0.99	0.64	0.80	0.37	0.27	0.26	0.72	0.65	0.60
	DM	0.13	0.18	0.28	0.25	0.19	0.17	0.23	0.78	0.63	0.80
	WM	0.54	1.53	0.88	1.17	0.49	0.34	0.28	0.67	0.67	0.47
Cu	TM	0.004	0.0057	0.005	0.004	0.003	0.003	0.004	0.01	0.01	0.01
	DM	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.003	0.004	0.003
	WM	0.01	0.01	0.01	0.01	0.004	0.005	0.01	0.01	0.01	0.01
Fe	TM	0.51	0.71	0.61	0.54	0.42	0.37	0.33	0.62	0.47	0.46
	DM	0.61	0.44	0.47	0.39	0.31	0.29	0.33	0.87	0.51	0.57
	WM	0.44	0.89	0.69	0.63	0.49	0.41	0.33	0.46	0.44	0.38
Na	TM	3.23	3.23	3.53	3.52	3.27	3.17	3.13	3.12	3.07	2.92
	DM	2.11	2.10	2.16	2.18	2.12	2.13	2.16	2.29	2.07	2.13
	WM	4.00	3.98	4.45	4.42	4.04	3.86	3.78	3.67	3.74	3.44
Ba	TM	0.03	0.016	0.014	0.014	0.012	0.011	0.01	0.02	0.02	0.02
	DM	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
	WM	0.04	0.02	0.015	0.02	0.01	0.014	0.01	0.01	0.02	0.02
Ni	TM	0.001	0.0001	0.001	0.001	0.005	0.001	0.001	0.001	0.001	0.001
	DM	0.001	–0.001	0.001	0.001	0.001	0.001	0.001	0	0.001	0.001
	WM	0.001	0.001	0.001	0.002	0.0002	0.001	0.0003	0.001	0.001	0.001
	GTM	0.72	0.82	0.81	0.83	0.73	0.69	0.68	0.78	0.74	0.71

TM = Total mean; DM = Dry season mean; RM = Rainy season mean; GTM = Grand total mean; Loc = Location into the lake during the rainy season, thereby increasing the entry of metals into the lake. Conversely, the same authors reported lower metal concentrations in the dry season, which they attributed to the reduction in Fe and Al transport in the dry season [15]. A researcher also found greater metal concentrations in the rainy season than in the dry season [16]. They found greater concentrations of both total and dissolved Al in the rainy season (153 ± 26 and 93 ± 10 μg L^{-1}, respectively) than in the dry season (118 ± 25 and 42 ± 27 μg L^{-1}, respectively). Although the month of July had greater concentrations of Al (213 ± 7 and 152 ± 3 μg L^{-1}, respectively) compared to the values obtained in both dry and rainy seasons, which the authors attributed to sudden flooding during the month of July, thus carrying anthropogenically derived metals along. Another major explanation for the higher values of Al during the month of July was due to maximum dissolution. The authors reported that higher concentrations of Al are found at acidic or alkaline pH or together with complexes. In their study, a pH of 5.73 was recorded during the month of July, which was the least and most acidic. Other evidence to support the observation mentioned above includes the greater concentrations of other metals (Cd, Cu and Ni) in the rainy season compared to the dry season, irrespective of the flooding that occurred in July. Mean concentrations of all the metals were greater in the wet season than in the dry season. The analysis of variance under the univariate ANOVA (F) test of equality of two seasonal means revealed strong evidence of significant seasonal mean concentration variations. From the results of the F-test for Wilks' Lambda, it was seen that the group means of the nine heavy metals investigated were statistically unequal and therefore substantially different, indicating the presence of significant mean differences in the wet and dry season concentrations. Similarly, the Model Wilks' Lambda (also called multivariate Lambda) provides evidence of the statistical significance of the discriminant function. Consequently, it was substantively concluded that there is a significant discriminant function that depicts wet and wet seasonal variations in heavy metal concentrations and the metals that contribute most to the discriminant function are Na, Cu, K, Ba, Cd, Ni, and Al. The functions at group centroids provide the basis for the classification and prediction of a group membership. Thus, given positive wet season group centroid and all positive discriminant coefficients, the seven heavy metals (Na, Cu, K, Ba, Cd, Ni, and Al) were classified under the posterior probability of more significant wet season variability ceteris paribus. Put differently, Na, Cu, K, Ba, Cd, Ni, and Al were classified and predicted in future to have a greater probability of wet season variability.

From the perspective of vertical variability (with respect to depth), there was no observed significant variation in metals concentrations for all the eight heavy metals monitored. A similar absence of significant vertical variations has also been observed and reported, for example, a researcher said that there was no variation with depth in their studies. However, it is worth noting that in the present study, the 1.5 m depth had higher metal concentrations when compared to 1 and 0.5 m, respectively. One major explanation for the lack of significant differences with depths may likely be due to dilution, but the greater concentrations at the 1.5 m depth, could be attributed to its closeness to the sediments, where heavy metals settle after deposition by transport [17–24]. It is therefore obvious that water closer to the sediments will have higher metal concentrations compared to those further away from the sediments.

4. Conclusion

The objectives of this study are to adopt the discriminant analytical method to determine the seasonal, depth, and lateral variation in heavy metal concentrations in Varsity Lake Malaysia. It attempts to derive and test a discriminant function that clearly provides evidence of significant seasonal variation and also includes only the most important metals that best predict the significant wet-and-dry seasonality. The study also investigated the extent to which the water quality has degenerated base on three water quality guidelines. The results showed that the total mean season concentrations for rainy and dry seasons are in the following decreasing order Na > K > Al > Fe > Ba > Cu > Ni > Cd. The univariate Wilks' Lambda (F) test of equality of two seasonal means shows that the group means of the nine heavy metals studied were substantially different, indicating the presence of significant mean differences in the wet and dry season concentrations. The result of multivariate Wilks' Lambda (model Wilks' Lambda) clearly showed strong evidence of significant discriminant function, leading us to substantively conclude that there is significant seasonality in heavy metal concentration in the Varsity Lake. Based on the SCDFC and structure correlations, the heavy metals that had the strongest discriminant coefficients and highest correlations with the discriminant function were Na, Cu, K, Ba, Cd, Ni, and Al. In other words, these metals contributed the highest in predicting the seasonal variability. Given the functions at group centroids and Z-scores, Na, Cu, K, Ba, Cd, Ni, and Al were predicted with 98% predictive accuracy and classified under the future probability of greater wet season variability. Consequently, all other things being equal, it is predicted that in the Varsity Lake, there is a greater probability for the concentrations of the seven heavy metals to be higher in the wet season than in the dry season. The result indicated no significant vertical (depth) variation in concentration. Nevertheless, overall concentration was higher at 1.5-m depth. In terms of lateral distribution, concentration was in general found to be highest in the inlet locations of the lake, followed by the outlet locations. The total mean concentration for all the metals investigated was below the Malaysian INWQS Class II. This implies that the lake is safe for macro aquatic habitation and recreational purposes. However, caution is advised here as the total mean concentration of Cd, Al and Fe exceeded the CCME guideline.

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