



Water Quality Characteristic of the National Hydraulic Research Institute of Malaysia (NAHRIM) Lake Undergoing Remediation by the Constructed Wetlands: A Baseline Study

Aliyu Danjuma Aliyu^{1,3}, Rusea Go^{1*}, Hishamuddin Omar¹, Syazrin Syima Sharifuddin², Azroie Muhammad² and Bashirah Fazli²

¹Department of Biology, Faculty of Science, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

²Water Quality Laboratory, National Hydraulic Research Institute of Malaysia (NAHRIM), Jalan Putra Permai, 43400 Seri Kembangan, Selangor, Malaysia

³Department of Biological Sciences, Faculty of Natural Sciences, Ibrahim Badamasi Babangida University, Lapai, Niger State, Nigeria

ABSTRACT

This study was conducted to determine the baseline water quality characteristics of a contaminated NAHRIM lake undergoing remediation by the constructed wetlands, based on the physico-chemical and biological parameters. The sampling was conducted for six months (May-October) in 2016 from 5 stations of the lake and analysed using APHA standard methods for water and wastewater analysis, while Malaysian water quality index (WQI) was used to calculate quality of the lake. The results showed that, the Conductivity, Dissolved Oxygen, NO₃-N, NO₂-N, PO₄, Temperature, Turbidity, TDS, TSS, and Zn were under class I, while pH, B and COD were categorized under class II. NH₃-N, BOD, Fe,

Escherichia coli, Total coliform and Mn were categorized as class III. Moreover, Al was not given any classification under NWQS but their concentration did not exceed EPA guidelines. Furthermore, as compared to the water samples from the constructed wetlands that reported a class III WQI, the lake was observed to show an overall class II WQI. This is suggestive of the retaining and remedial role of the constructed wetlands being the first point

ARTICLE INFO

Article history:

Received: 15 August 2018

Accepted: 7 February 2019

Published: 25 April 2019

E-mail addresses:

aliyudanjumaaliyu@yahoo.com (Aliyu Danjuma Aliyu)

rusea@upm.edu.my (Rusea Go)

hishamom@upm.edu.my (Hishamuddin Omar)

Syazrin@hotmail.com (Syazrin Syima Sharifuddin)

azroiekl@gmail.com (Azroie Muhammad)

Bashirah.fazli@gmail.com (Bashirah Fazli)

* Corresponding author

of contact for the contaminants going to the lake. Thus the lake is suitable for recreational activities.

Keywords: Biological and physicochemical parameters, constructed wetlands, lake, water quality

INTRODUCTION

Water is one of the important natural resources that have consistently given support to man in different ways. The application of water is found in diverse human activities that cut across the industrial, agricultural and other activities. In the past decades, the persistent use of water resources for various activities by man contributes to the pressure on their availability (UN Water, 2017; Ramakrishnaiah et al., 2009) and degradation in the water quality (Juhair et al., 2011; Jackson et al., 2012). The quality of a water sources is usually identified in relation to their physical, chemical, and biological contents (Loukas, 2010). The degradation in water quality has been a disturbing issues in the developing tropical countries, where the treatment of effluents before being discharged into the water bodies is of low priorities (Konnerup et al., 2011).

Lakes are important type of water sources that are designated as places of recreation, reflection and as storm water retention pond; these activities subjects them to an increasing pressure and stress by contaminants resulting in most of them being degraded (EPA, 2009). Various authors have conducted studies into Malaysian lake with the aim of determining their water quality characteristics. Ismail et al. (2012), in their study of Tasik Chini for its hydrological water quality characteristic found the lake to be under NWQS class II which was suitable for recreational activities. Another study was conducted at Ampang Hilir lake, in Selangor, Peninsular Malaysia. The results classified the water quality as class II which allowed for the body contact for recreation as well as for fishing activities. The concentrations of the metals were lower than the stipulated values (Said et al., 2012a)

Said et al. (2012b) reported a similar study on the water quality parameters in Titiwangsa Lake, Selangor Peninsular Malaysia. Selected parameters were analysed *in-situ* using Hydrolab data sonde 4 and surveyor 4, a water quality multi probe (USA), while the metals were determined using Inductively Coupled Plasma Mass Spectrometer (ICP-MS). The findings identified the water quality to be appropriate only for recreational activities (class II); the metal concentrations found in the lake were reported to be lower than the standard stipulated in international indexes and as such presenting non-toxic effects to the aquatic organisms in the lake. Akinbile et al. (2013) evaluated Bukit Merah lake water for the level of pollution detection which would lead to suggestions of the possible treatment required before the usage of the water. Standard laboratory procedures were employed to assess the concentration of water quality parameters and trace metals. Their findings

showed Bukit Merah Lake to be slightly contaminated with WQI value of 75.63 which placed the status of the lake in class III.

Although, considerable efforts have been expended on understanding the condition of Malaysian lakes water quality, the focus has always been on the natural lakes with bigger sizes while fewer studies have been conducted on the other man-made lakes with respect to discussing the remediation efforts that may enhance their quality.

Constructed wetlands have been shown to have the capability to trap and remove toxic materials through sedimentation, filtration, microbial interactions and uptake or transformation by helophytes to cause an improvement in the water quality (Kadlec and Wallace, 2008; Martins et al., 2013). Moreover, very little information has been reported on the deployment of CWs as contaminant treatment media in the developing countries despite its relative acceptance in the other part of the world (Bojcevska & Tonderski, 2007).

The National Hydraulic Research Institute of Malaysia (NAHRIM) have an artificial lake that serve as the storm water retention ponds and also designed to serve the recreational needs of the staffs. The water quality in this pond was affected by the pollution from point sources and non-point sources (sewerage treatment plant, sullage water from the administrative office, hydraulic laboratory and runoff from the impervious area) surrounding the lake which is making the water unfit for human contact.

The constructed wetlands serving as the remediation media were built with sole purpose of serving as the first point of contact for the discharges and runoff coming from the sewerage treatment plant, drainage system and impervious areas to the Lake. The constructed wetlands were designed as a surface flow type based on the type of the contaminants they were set up to treat. Nine aquatic plants species (*Cyperus papyrus*, *Echinodorus cordifolius*, *Nymphaea capensis*, *Nymphaea nouchali*, *Nymphaea lotus*, *Sagittaria lancifolia*, *Thalia* sp., *Nelumbo nucifera*, *Typha angustifolia* and *Victoria amazonica*) were planted in the CWs, only four become firmly rooted in the wetland; and *Cyperus papyrus* being the most dominant plant species. Based on the preliminary study of the wastes that is being discharged into the lake prior to the construction of the wetlands, the discharge rate of the contaminants of the NAHRIM lake is 163.82m³/ day and the estimated pollution load contribution from the STP and other effluents sources ranges between 2.785kg/ day to 3.457kg/day for the parameters studied (NAHRIM, 2012).

This was supported by the class III water quality status reported for the water sampled from the wetland cells. However, the assessments of the NAHRIM lake water quality improvement have not been carried out since the construction of the wetlands. Thus, the objective of this study is to evaluate the water quality characteristic of the NAHRIM Lake through the analysis of water physicochemical, biological and elemental parameters in order to understand the remedial effects of the constructed wetlands on the lake.

MATERIALS AND METHODS

Study Area and Sampling Stations

The National Hydraulic Research Institute of Malaysia (NAHRIM) is located along Jalan Putra Permai (Lat.3°00'03.88"N and Long.101°41'05.11"E) in Seri Kembangan, Selangor State, Malaysia. The location of the study area is characterised by climate of substantially high but uniform average daily temperatures of 21°C to 32°C. The average daily humidity levels of the area is above 80% with the mean annual rainfall of around 2,500 mm (Abdullah et al., 2012). The Institute has in its compound a drainage system that comprises of three retention ponds named Pond A, Pond B and the lake. The surface area of the lake is approximately 3600m² and with a depth of 3-4 meters at the deepest site. NAHRIM lake covers the entire watershed which is made up of the Institute head office, the Staff quarters, Water quality and Environmental research center, Pond A, Pond B, Hydraulic laboratory, Sewerage treatment plants and the impervious area surrounding the lake are shown in Figure 1.



Figure 1. The Study Zone (NAHRIM Catchment Area).
CW, Constructed wetlands cells; NL, NAHRIM Lake sampling points

In this study, five sampling stations were selected along the Lake, from the upstream to downstream (NL1-NL5), and identified by the GARMIN handheld GPS (GARMIN Handheld GPS, GARMIN, Olathe, Kansas, USA). This is to enable the gauging of the overall water quality of the lake. The sampling points selected were described in Table 1.

Sampling Methods and Analytical Procedures

The water samples collection from the NAHRIM Lake was conducted according procedures in the standard method for water and wastewater treatment (APHA, 2005). Duplicates water samples were collected from five sampling sites (NL1-NL5) of the NAHRIM Lake accessed with the aid of a hand paddled boat. Water samples were collected for the

Table 1

The description of the sampling points of the NAHRIM Lake

NAHRIM Lake sampling points	Locations	Description
NL1	N 3°0'0.36", 101°41'6.65"E	Located besides the wetland A (downstream of STP discharge)
NL2	N 3°0'0.38", 101°41'5.95"E	Middle of the NAHRIM Lake
NL3	N2°59'59.50", 101°41'4.92"E	Close to Overflow point
NL4	N 3°0'0.56", 101°41'4.70"E	Downstream of the wetland B (Canteen discharge area)
NL5	N2°59'58.84", 101°41'5.40"E	Located besides the fence downward of NL3.

duration of six months (May-October, 2016). Prior to the sampling, Polyethene sampling bottles which were pre-condition with 5% nitric acid and rinsed thoroughly with distilled de-ionized water were used for the collection of the water samples. Water samples were collected using Van Dorn automatic sampler. About 1 L of the water samples was taken at each of the sampling site. Water samples collected from the lake were placed in an ice box and transported to the laboratory. The water samples with colloidal particles were filtrated using 0.45µm membrane filter (Whatman Milipores, Clifton NJ). This was done to avoid clogging which may interfere with the spectrometry during analysis (APHA, 2005). The water samples that were used for heavy metals were preserved with concentrated HNO₃ to pH<2 to prevent precipitation of metal oxides and hydroxides as well as to stop any biological activities (Radojevic & Bashkin, 2007). The samples were then kept at -10 °C until further analysis.

In-situ water quality parameters such as temperature, turbidity, DO, conductivity, pH and TDS of the water were measured at each sampling point using multiparameters water quality sonde YSI6600 V2 sonde (YSI incorporated, Yellow Spring OH, USA). *Ex-situ* water parameters such as the anions and heavy metals were determined in accordance with the APHA standard method for water and wastewater analysis (APHA, 2005). Biochemical oxygen demand₅ was determined using a modified 5-Day BOD test procedure (method 5210B) (APHA, 2005), Chemical oxygen demand was determined using colorimetric method 5220D of APHA (APHA, 2005). Total suspended solids was determined by using a modified direct HACH Method No. 8006, The determination of NH₃-N concentration was conducted using the APHA standard method 4500-B&C, while Nitrites (NO₂-N) concentration in the water samples was determined by USEPA Diazotization methods (HACH method 8507). Cadmium reduction method 8192 was used to determine the

concentration of Nitrates ($\text{NO}_3\text{-N}$) in the water samples, and the concentration of Total phosphorus (PO_4) in the water samples was achieved using the modified APHA method 4500-P E.

The determination of the *Escherichia coli* and Total coliform in the water samples was carried out using the USEPA method 9223B (Colilert-18/ Quanti-Tray 2000). The analysis of Heavy metals were carried out by Inductively Coupled Plasma-Optical Electron Spectroscopy. The samples were digested according to APHA standard methods for the examination of water and wastewater (APHA, 2005) and analysed.

The Water Quality Index (WQI) of NAHRIM Lake was calculated using the method of Department of Environment Malaysia (DOE, 2008; Rosli et al., 2010). This index has been in use for quite some time now. The WQI is a product of opinion-poll formulated by the experts on the choice of water quality parameters to choose, and the weightage to be assigned to each of the parameters. Thus the parameters chosen were Dissolved oxygen (DO), Biological oxygen demand (BOD), Chemical oxygen demand (COD), Suspended solid (SS), pH value, and Ammonical nitrogen (Khuan et al., 2002). The resultant equation as approved by the DOE was calculated based on the above six parameters with the weighing factors of 0.22, 0.19, 0.16, 0.16, 0.15 and 0.12 assigned to DO, BOD, COD, SS, AN and pH respectively. The overall WQI equation was then turned into sub-indices calculated according to the best-fit relations as illustrated in equation 1 below.

$$\text{WQI} = 0.22\text{SIDO} + 0.19\text{SIBOD} + 0.16\text{SICOD} + 0.16\text{SISS} + 0.15\text{SIAN} + 0.12\text{SIpH} \quad (\text{Eqn 1})$$

Where, WQI = Water quality index; SIDO = Sub-index of DO; SIBOD = Sub-index of BOD; SICOD = Sub-index of COD; SIAN = Sub-index of AN; SISS = Sub-index of TSS; SIpH = Sub-index of pH.

Statistical Analysis

Data generated were subjected to statistical analyses using IBM SPSS (Version 22.0, IBM Corp., Chicago, IL, USA). Basic descriptive statistic reported as mean \pm Standard deviation was performed. One way ANOVA and a post-hoc Tukey pair wise comparison were used to test for significant difference of the each of the studied parameters among the sites for each of the months. Statistical significant difference was set at confidence level of 95% ($\alpha = 0.05$). Pearson correlation was use to combine correlated variables in the data set.

RESULTS

Physical (*In-situ*) Water Quality Parameters of the NAHRIM Lake

Figure 2 (a-f) illustrated the concentration of the analysed *in-situ* parameters of the NAHRIM lake. The parameters were reported as mean \pm SD. The average temperature value recorded was 29.10°C and ranged from $28.33 \pm 0.06^\circ\text{C}$ to $29.90 \pm 0.0^\circ\text{C}$. The highest

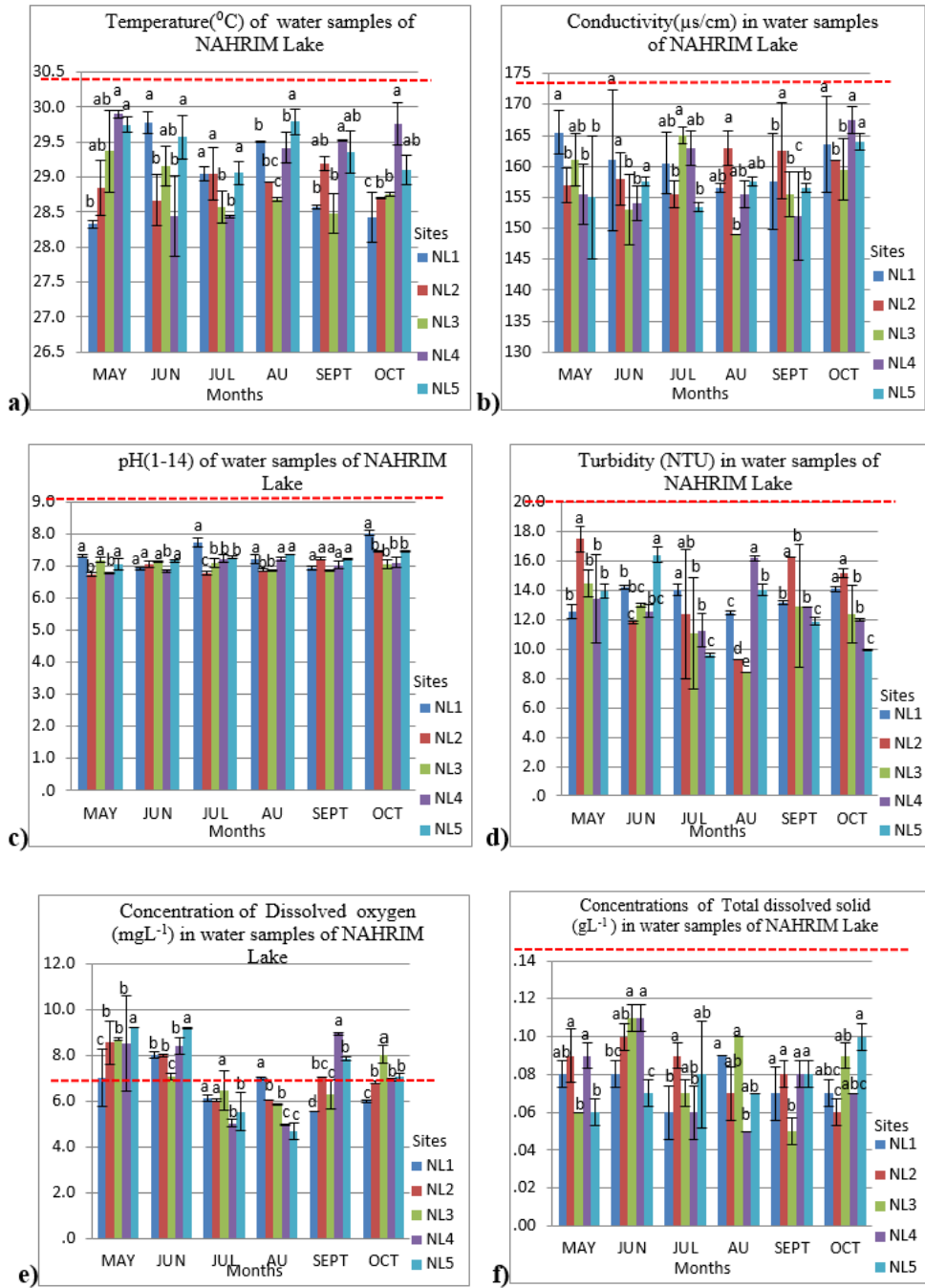


Figure 2. (a) Temperature (b) Conductivity (c) pH (d)Turbidity (e) Dissolved Oxygen and (f) Total Dissolved Solids distribution in water samples of NAHRIM lake in the sites for the months. Bars are expressed as mean \pm standard deviation. Bars with the same superscript letters are not significantly different in their concentration at $p < 0.05$ across the sites in each of the months. The dotted line in red is the National Water Quality Standard for water bodies stipulated for recreational contact.

and the lowest temperature values were observed at sites NL4 and NL1 in the months of May respectively. Significant differences ($p < 0.05$) in temperature values for sites were recorded in all of the studied months (Figure 2a).

The illustration of conductivity was depicted in Figure 2b. The average conductivity values recorded for the lake water samples was $159.10 \mu\text{s}/\text{cm}$ and this ranged from 152 ± 7.07 to $169.5 \pm 5 \mu\text{s}/\text{cm}$. The highest value was recorded in October at site NL4, while the lowest value was recorded in August at site NL3. The significant differences ($p < 0.05$) in conductivity values was observed across the sites in each of the months.

The pH (Figure 2c) average value recorded for the NAHRIM Lake was 7.20; the range concentration is from 6.72 ± 0.04 to 7.82 ± 0.21 . The highest and lowest concentrations were observed at sites NL1 and NL2 in October and May respectively. There is a significant difference ($p < 0.05$) in the concentration among the studied sites for months except for the months of September.

The mean turbidity concentration was illustrated in Figure 2d, with the overall mean of 112.80 NTU which ranged from 8.40 ± 0.00 to 17.5 ± 0.85 NTU. The highest turbidity was recorded at site NL2 in May and the lowest at site NL3 in August. The sites were not significantly different ($p < 0.05$) in concentration of turbidity across the months.

The average dissolved oxygen concentration recorded for the studied water samples of the NAHRIM Lake was 6.77mgL^{-1} . The highest was in May and June ($9.2 \pm 0.014 \text{mgL}^{-1}$) while the lowest and ($4.67 \pm 0.35 \text{mgL}^{-1}$) concentration were recorded at site NL5 in August respectively (Figure 2e). The concentration in the studied sites differ significantly ($p < 0.05$) across the months.

The mean concentration of total dissolved solids in the water samples of NAHRIM Lake was 0.079gL^{-1} and this ranged from 0.05 ± 0.00 to $0.11 \pm 0.01 \text{gL}^{-1}$. The highest concentration was recorded at sites NL3 and NL4 in the month of June, while the lowest was recorded at sites NL5 and NL3 in the months of August and September respectively. The studied sites exhibited a significant difference ($p < 0.05$) in the concentration in each of the months (Figure 2f).

Laboratory (*Ex-situ*) Water Quality Parameters of the NAHRIM lake

The overall descriptive statistics of the laboratory water quality parameters was illustrated in Figures 3(a-e). The illustration of chemical oxygen demand was presented in Figure 3a. The mean chemical oxygen demand recorded for the water samples was 10.13mgL^{-1} , ranging from 8.61 ± 0.04 to $13.00 \pm 1.41 \text{mgL}^{-1}$. The highest ($13.00 \pm 1.41 \text{mgL}^{-1}$) COD concentration was recorded at site NL3 in June and the lowest ($8.61 \pm 0.04 \text{mgL}^{-1}$) was observed at site NL4 in May. The concentration of COD differed significantly ($p < 0.05$) in studied sites across the six months.

The biochemical oxygen demand (BOD) (Figure 3b) concentration of the water samples of NAHRIM lake ranged from 2.97 ± 0.05 to $5.86 \pm 0.09 \text{ mgL}^{-1}$. The average BOD concentration was 4.41 mgL^{-1} and the highest and lowest BOD concentrations were recorded at sites NL5 and NL3 in October. The concentrations in sites for the month of May show no differences ($p > 0.05$), while other months present a significant differences ($p < 0.05$) across the sites.

The concentration of ammoniacal nitrogen ($\text{NH}_3\text{-N}$) in the water samples of NAHRIM lake was illustrated in Figure 3c. The mean concentration is 0.31 mgL^{-1} , with the range of 0.17 ± 0.014 to $0.4 \pm 0.021 \text{ mgL}^{-1}$. The highest and lowest concentrations were recorded at sites NL1 and NL4 respectively in June. All the sites show a significant difference ($p < 0.05$) in their ammoniacal nitrogen concentrations across the months.

The nitrites ($\text{NO}_2\text{-N}$) concentration in the water samples was depicted in Figure 3d, and ranged from 0.000 to $0.009 \pm 0.002 \text{ mgL}^{-1}$. The average concentration was 0.0054 mgL^{-1} . The highest ($0.008 \pm 0.002 \text{ mgL}^{-1}$) and lowest (0.000 mgL^{-1}) concentrations recorded were at sites NL2 and NL1 in October and August respectively. The concentrations in the sites differ significantly ($p < 0.05$) from each other across the months.

Figure 3e elucidated the concentration of nitrates ($\text{NO}_3\text{-N}$) in the water samples of NAHRIM lake. The mean concentration of nitrates ($\text{NO}_3\text{-N}$) was 0.035 mgL^{-1} ranging from 0.015 ± 0.007 to $0.06 \pm 0.014 \text{ mg L}^{-1}$. The highest ($0.06 \pm 0.014 \text{ mgL}^{-1}$) and lowest

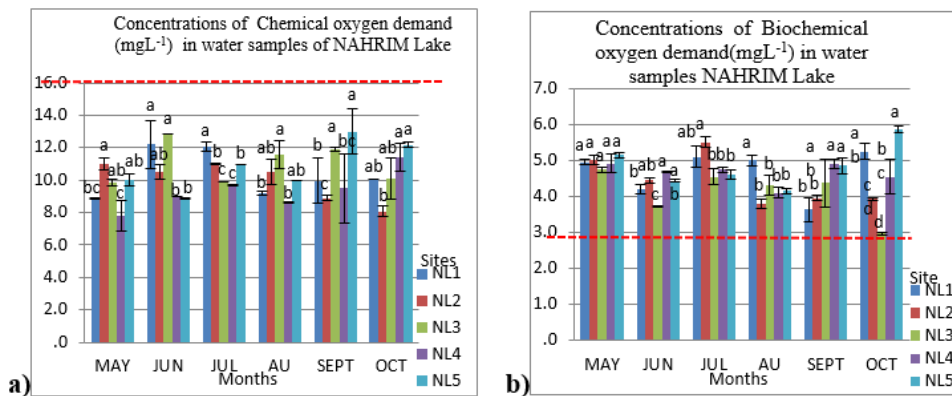


Figure 3. (a) Chemical Oxygen Demand (b) Biochemical Oxygen Demand in water samples of NAHRIM lake in the sites for the months. Bars are expressed as mean \pm standard deviation. Bars with the same superscript letters are not significantly different in their concentration at $p < 0.05$ across the sites in each of the months. The dotted line in red is the National Water Quality Standard limit for water bodies stipulated for recreational contact for the analysed parameter.

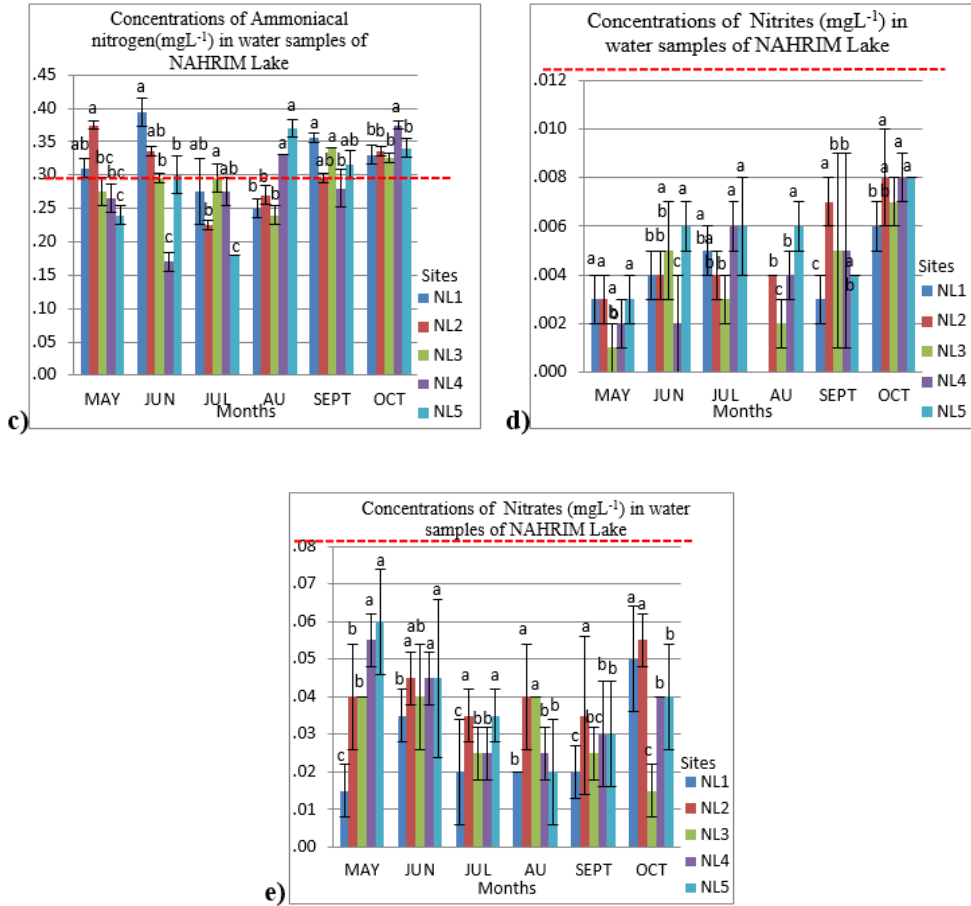


Figure 3. (c) Ammoniacal Nitrogen (d) Nitrites and (e) Nitrates distribution in water samples of NAHRIM lake in the sites for the months. Bars are expressed as mean ± standard deviation. Bars with the same superscript letters are not significantly different in their concentration at $p < 0.05$ across the sites in each of the months. The dotted line in red is the National Water Quality Standard limit for water bodies stipulated for recreational contact for the analysed parameter.

($0.015 \pm 0.007 \text{mgL}^{-1}$) concentrations were recorded in May at sites NL1 and NL5 respectively. The sites in each of the months differs significantly ($p < 0.05$) in the concentration of nitrates.

The total phosphorus (PO_4) recorded mean was 0.056mgL^{-1} and this ranged from 0.046 ± 0.0042 to $0.065 \pm 0.0042 \text{mgL}^{-1}$. The highest ($0.065 \pm 0.0042 \text{mgL}^{-1}$) and the lowest ($0.046 \pm 0.0042 \text{mgL}^{-1}$) concentrations were recorded in May at sites NL5 and NL2 respectively. The analysed concentration indicated a significant differences ($p < 0.05$) in the sites across the months (Figure 4a).

The total suspended solid concentration in the water samples of NAHRIM Lake was presented in Figure 4b. The mean concentration was 12.89mg L^{-1} . The range was from

5.84±0.23 to 27.06±0.08 mg L⁻¹. Site NL4 in the month of September recorded the highest concentration (27.06±0.08 mg L⁻¹) while site NL5 in August had the lowest (5.84±0.23 mg L⁻¹) concentration. The concentration in the sites for October statistically differs significantly ($p < 0.05$) from each other for the studied months.

The analysed data for *Escherichia coli* and Total coliform are presented as a logarithmical transformation of the original data (Figure 4c and 4d). The mean log₁₀ *E. coli* CFU/100mL was 2.91. The range was from 2.47±0.21 to 3.52±0.12. The highest (3.52±0.12) was recorded at September in site NL2 and the lowest (2.47±0.21) in July at site NL1. The significant difference ($p < 0.05$) in the colony forming units of the *E. coli* in the studied sites was exhibited in July and September, while other months presented a non-significant difference ($p > 0.05$) in the *E. coli* counts for the studied sites. The total

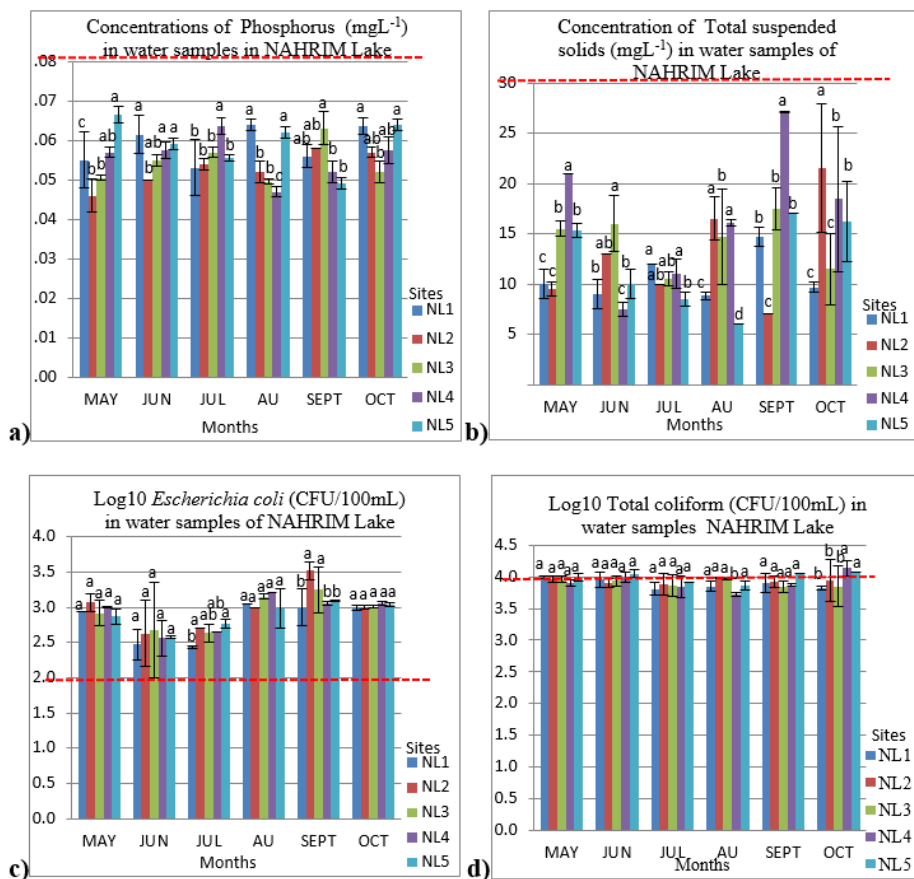


Figure 4. (a) Phosphorus (b) Total Suspended Solids (c) *Escherichia coli* and (d) Total coliform distribution in water samples of NAHRIM lake in the sites for the months. Bars are expressed as mean ± standard deviation. Bars with the same superscript letters are not significantly different in their concentration at $p < 0.05$ across the sites in each of the months. The dotted line in red is the National Water Quality Standard limit for water bodies stipulated for recreational contact for the analysed parameter.

coliform mean log₁₀ CFU/100ml in the water samples of NAHRIM Lake was 3.93 and ranged from 3.72±0.04 to 4.14±0.12. The highest (4.14±0.12) and lowest (3.72±0.04) total coliform were recorded at site NL4 in October and August respectively. The month of August and October also show a significant difference in the counts of total coliform in the studied sites, while other months did not indicate any significant difference in the total coliform counts among the studied sites.

Heavy Metals in the Water Samples of the NAHRIM Lake

The descriptive statistic of the concentration of the five detected heavy metals in NAHRIM Lake is given in Figures 5(a-e). The average Aluminium (Al) concentration was 0.19 mgL⁻¹. The range concentration was from 0.07±0.01 to 0.37±0.02mg L⁻¹. The highest Aluminium (Al) concentration (0.37±0.02mgL⁻¹) was detected at site NL4 in August and the lowest

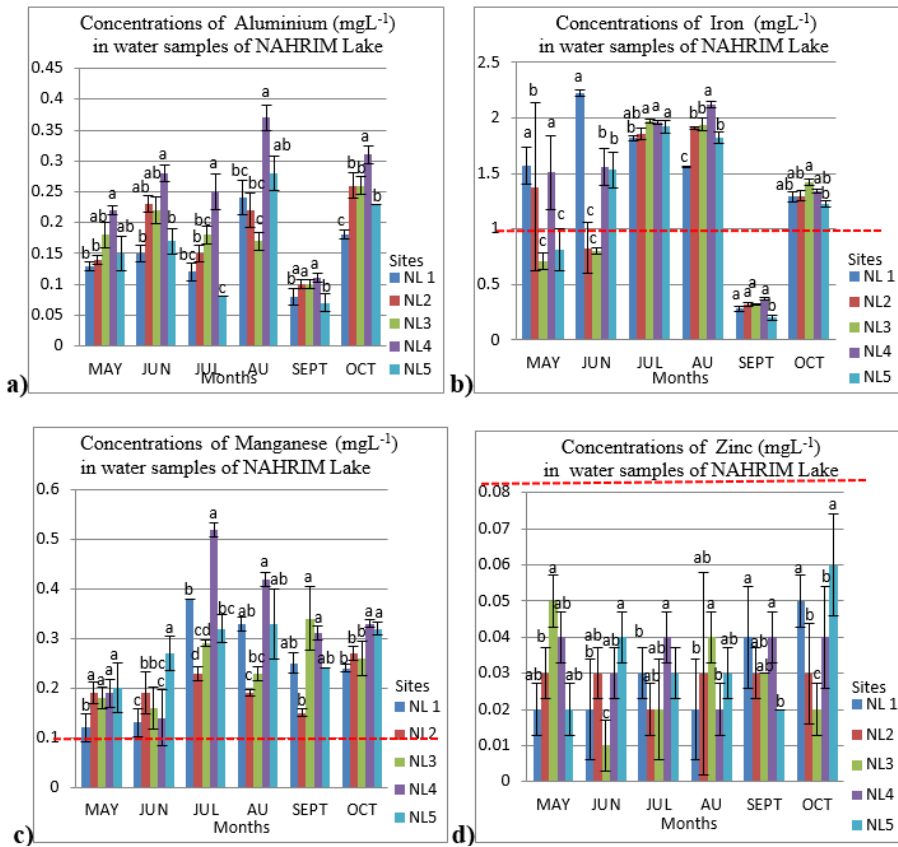


Figure 5. (a) Aluminium (b) Iron (c) Manganese (d) Zinc distribution in water samples of NAHRIM lake in the sites for the month. Bars are expressed as mean ± standard deviation. Bars with the same superscript letters are not significantly different in their concentration at $p < 0.05$ across the sites in each of the months. The dotted line in red is the National Water Quality Standard limit for water bodies stipulated for recreational contact for the analysed parameter.

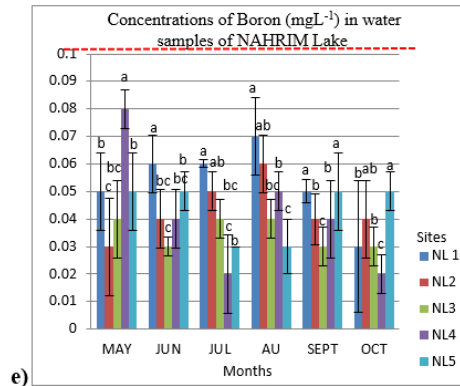


Figure 5. (e) Boron distribution in water samples of NAHRIM lake in the sites for the month. Bars are expressed as mean \pm standard deviation. Bars with the same superscript letters are not significantly different in their concentration at $p < 0.05$ across the sites in each of the months. The dotted line in red is the National Water Quality Standard limit for water bodies stipulated for recreational contact for the analysed parameter.

($0.07 \pm 0.01 \text{ mgL}^{-1}$) at site NL5 in September. All the sites across the months show significant difference ($p < 0.05$) in their aluminium concentration (Figure 5a).

Figure 5b shows the distribution trend of the iron in the water samples of NAHRIM Lake. The mean iron (Fe) concentration in the water samples of NAHRIM Lake was 1.33 mgL^{-1} , ranging from 0.20 ± 0.03 to $2.22 \pm 0.03 \text{ mgL}^{-1}$. The detected highest iron concentration ($2.22 \pm 0.03 \text{ mg L}^{-1}$) was at site NL1 in June, while the lowest concentration ($0.20 \pm 0.03 \text{ mg L}^{-1}$) was recorded at site NL5 in September. Each of the studied sites across the months indicates a significant difference ($p < 0.05$) from the other.

The variation in the manganese (Mn) concentration of the water samples of NAHRIM Lake (Figure 5c) was from 0.12 ± 0.03 to $0.52 \pm 0.01 \text{ mgL}^{-1}$ and presented in Fig. 4.7c. The mean concentration was 0.26 mgL^{-1} . The highest manganese concentration was $0.52 \pm 0.01 \text{ mgL}^{-1}$ recorded at site NL4 in July and lowest concentration of $0.12 \pm 0.03 \text{ mg L}^{-1}$ was recorded at site NL1 in May. The significant differences ($p < 0.05$) in the concentration level of manganese in sites was observed in each of the reported months. The zinc (Zn) concentration detected in the water samples was highest ($0.05 \pm 0.007 \text{ mgL}^{-1}$) at site NL5 in October and lowest ($0.01 \pm 0.00 \text{ mgL}^{-1}$) at site NL3 in June. The overall zinc contents varied from 0.01 ± 0.00 to $0.05 \pm 0.007 \text{ mgL}^{-1}$. The sites in the months exhibited a significant difference ($p < 0.05$) in the level of zinc present in (Figure 5d).

The average boron (B) concentration trend (Figure 5e) observed for the water samples of NAHRIM Lake was 0.046 mgL^{-1} , and this ranged from 0.02 ± 0.014 to $0.08 \pm 0.007 \text{ mgL}^{-1}$. The highest ($0.08 \pm 0.007 \text{ mgL}^{-1}$) and lowest ($0.02 \pm 0.014 \text{ mgL}^{-1}$) concentration were recorded at sites NL4 and NL2 in May and October respectively. The sites show any significant differences ($p < 0.05$) in the boron concentration across the months.

Correlation Analysis of the Studied Water Quality Parameters of the NAHRIM Lake

The statistical analysis of the Pearson correlation of the studied water quality parameters of the NAHRIM Lake is presented in Table 2. The correlation analysis was employed to show how the concentrations of the water quality parameters impacted on each other. This usually helps in explaining the role such parameters plays in the maintaining the status of such water quality and how they impacted the general ecosystem. The observed correlation varies from moderate negatively to strong positively correlations. There was however one very strong positive relationship ($r = 0.930^*$) between turbidity and electrical conductivity; a strong positive correlation between ammoniacal nitrogen and COD ($r = 0.746^*$) and a moderate positive relationship between turbidity and total coliform ($r = 0.570$), ammoniacal nitrogen and conductivity ($r = -0.542^*$), Fe and B ($r = 0.408^*$), manganese and calcium ($r = 0.546^{**}$) as well as a moderate negative relationship between DO and turbidity ($r = -0.538^*$), DO and Manganese ($r = -0.484^*$) and between total coliform and iron ($r = -0.420^{**}$).

Table 2

Pearson correlation analysis of studied water quality parameter of the NAHRIM Lake

Parameters	r- value	Parameters	r- value	Parameters	r- value
Temp x B	0.326*	DO x Turb	-0.538*	TDS x EC	0.243*
EC x Ph	0.311*	DOxNO ₂	0.348**	TDS x Mn	0.383*
ECxNH ₃	0.542*	DO x Fe	-0.349**	COD x NH ₃	0.746*
ECxNO ₂	0.255*	DO x TCO	0.335*	NO ₂ x NH ₃	0.330**
pH x DO	-0.284*	DO x Mn	-0.484**	NO ₂ x Mn	0.296*
pH x TDS	-0.259*	DO x Ca	0.278*	NO ₂ x TCO	0.319*
pH x NO ₂	0.383**	DO x Mg	-0.271*	NO ₃ x TCO	0.32*
pH x Mn	0.289*	Turb xNH ₃	-0.314*	NO ₃ x Mn	-0.279*
pH x B	-0.279*	Turb x EC	0.930*	NH ₃ x Fe	-0.283*
pH x Mg	0.273*	Turb x TCO	0.570*	TCO x Fe	-0.420**
pH x K	-0.267*	Turb x COD	-0.306*	Al x Mn	0.261*
NO ₂ x B	-0.294*	Fe x B	0.408*		

Temp., Temperature; EC, Electrical Conductivity; B, Boron; NO₂, Nitrites; NO₃, Nitrates; NH₃, Ammoniacal Nitrogen; PO₄, Phosphorus; Mn, Manganese; TDS, Total dissolved solids; DO, Dissolved oxygen; Turb., Turbidity; Fe, Iron; COD, Chemical oxygen demand; BOD, Biochemical oxygen demand; ECO, *Escherichia coli*; TCO, Total coliform; Al, Aluminum.

*Correlation is significant at the 0.01 level (2- tailed)

**Correlation is significant at the 0.05 level (2- tailed)

Water Quality Index (WQI) of the water samples from the NAHRIM Lake and Constructed wetlands

The mean calculated water quality index for the NAHRIM lake sampling sites varies from 84.27 to 87.19; with the highest and the lowest water quality index recorded at site NL4 and site NL2 respectively. The highest WQI of the water samples from the wetlands was recorded at the sites CW3 (66.32) and the lowest at the CW2 (61.99) (Table 3).

Table 3

The mean Water Quality Index (WQI) for the sampling sites of NAHRIM lake and the constructed wetlands

Study sites	Sampling points	DOE-WQI	Class	Status
NAHRIM Lake	NL1	86.93	II	Clean
	NL2	87.19	II	Clean
	NL3	86.44	II	Clean
	NL4	84.27	II	Clean
	NL5	84.79	II	Clean
Constructed wetlands	CW1	63.41	III	Polluted
	CW2	61.99	III	Polluted
	CW3	66.32	III	Polluted
	CW4	63.80	III	Polluted
	CW5	63.74	III	Polluted
	CW6	65.23	III	Polluted

DISCUSSION

In-situ Water Quality Parameters

The temperature value reported in this study varies among the sites in the studied months. The mean temperature value of 29.10°C is lower than the NWQS threshold for class IIB (normal ± 2) but slightly higher than the temperature (29.02°C) reported by Said et al. (2012b) for Titiwangsa lake with related recreational activities. The slight differences in the temperature may be due to the stagnant nature of the lake that allows for the retention of the heat during low precipitation periods. In an event of an increase in temperature, which is not the case with the NAHRIM Lake, there will be a shoot up in metabolic activities of the living components which in turn will lead to a reduction in dissolved oxygen content of the lake and may impact negatively on fish and other organisms.

The conductivity of the water samples exhibited slight spatial and temporal differences. However, the total mean conductivity value of 159.10 $\mu\text{s}/\text{cm}$ was far below the stipulated level for class IIB of NWQS and can be categorised under class I. The conductivity was higher than those reported by Gasim et al. (2015) and those reported by Al-Badaii

et al. (2013) for Cempaka Lake and Semenyih river respectively. The highest detected conductivity was at NL4 which was located at the downstream of the constructed wetland B support the facts that conductivity is affected by wide range of organic chemicals and a failed sewerage system. And a very strong significant positive correlation of conductivity with Turbidity ($r = 0.93^*$) lends credence to the impact of particles that contributes to the turbid water which is a contributing factor to higher conductivity (Bhateria & Jain, 2016).

The overall mean pH value was 7.20 which is within the class IIB (pH= 9). However, the slight variation in pH concentration from weak acidic to basic is an indication of decomposition of some organic matter in a complex photosynthetic process by plants and algae that utilised carbondioxide released in the water (Gandaseca et al., 2011). The pH contaminant sources are from the discharges of canteen and laboratory activities. This is clearly supported by the low to moderate positive significant relationship of pH with $\text{NO}_2\text{-N}$ ($r = 0.383^{**}$), Mg ($r = 0.273^*$) and Mn ($r = 0.289^*$) that may be the content of the discharges stated above and responsible for the pH. The pH recorded in this study is similar to those reported by Ismail et al. (2012) in their study of hydrological and water quality characteristics of Chini Lake but contrasted the findings of Said et al. (2012b) that reported a higher pH value for Lake Titiwangsa.

There is spatial distribution in dissolved oxygen concentration for the NAHRIM water samples. Dissolved oxygen is one of the critical parameter in water quality assessment that present an insight into the biological and physical processes occurring in the water (Dirican, 2015). The dissolution of oxygen in water occurs from the atmospheric diffusion and aquatic vegetations photosynthetic processes. The total mean concentration of dissolved oxygen of 6.77mg L^{-1} was below the NWQS class IIB threshold of 7 mg L^{-1} but on the monthly basis, the majority of sites present DO concentration level higher than the class IIB threshold and fell under class I, which is similar to the one reported for water quality studies of Temmengor lake, Perak by Khalik & Abdullahi, (2012) and Gasim et al. (2015) for Cempaka lake in Selangor. The reported DO in this study can effectively support the physiological activities of various organism especially the planktons since the deleterious effect of DO can only manifest at a DO level of below 5 mgL^{-1} and critical for fishes at 2mgL^{-1} (Said et al., 2012b).

The mean turbidity concentration (8.40 NTU) is less than NWQS class 1 threshold of 1000 NTU, and appropriate for NAHRIM lake recreational activities since the NWQS does not have a defined level for turbidity. Turbidity occurred from atmospheric deposition that leads to erosion taking place at the NAHRIM lake watershed, with most of the effluents coming off the wash down of the materials from the impervious areas. However, the turbidity value recorded in this study did not agree with the turbidity findings of Ismail et al. (2012) reported for Chini Lake. High turbid water may have injurious effect to the fishes and other organisms and this may lead to the movement of the fishes away from a very turbid water (Said et al., 2012b).

The total dissolved solids concentration among the sites in the studied months did not highlight any spatio-temporal variation. The average TDS value of 0.079gL^{-1} categorised

the lake on water quality basis of class 1. Although there is no stipulated level of TDS for the freshwaters meant for recreational activities, its high presence in water can lead to clarity issues which may have a devastating effect on the photosynthetic organism. In addition to the runoff from the roads and impervious areas during weathering processes, organic substances from the waste treatment and agricultural chemicals like fertilizers contribute to the level of total dissolved solids in the lake (Bhateria & Jain, 2016). The high increment in TDS especially those with salt content disrupts aquatic life in the water since the salt enhances the dehydration of the skin of most of the animals. The minimal TDS recorded in this study may be due to less land use for anthropogenic activities at NAHRIM Lake but more of runoff with large suspended particles from the impervious area. In comparison, the TDS value reported in this study is slightly higher than the one reported for by Ismail et al. (2012) for Chini Lake; Rostom et al. (2017) for Mariut Lake but slightly lower than that reported for Siling reservoir by Naveedullah et al. (2016).

***Ex-situ* Water Quality Parameters**

The chemical oxygen demand (COD) concentration pattern across the sites in the months exhibited a slight spatial and temporal variation. However, the mean COD (10.15 mg L^{-1}) recorded for the study lies between the NWQS class 1 and II which is suitable for recreational body contact. This identifies the organic pollution of the lake water to be at a minimal level. COD examination is usually used to determine the oxygen required for the decomposition of organic matter and oxidation of inorganic chemicals to occur. This implies that theoretically, a high COD concentration is an indication of a polluted water (Amneera et al., 2013). The COD concentration reported in this study is in agreement with those reported for Temenggong lake and Tasik Chini (Ismail et al., 2012; Khalik & Abdullah, 2012) but contrasted the higher findings of Mood et al. (2017) in their study of effectiveness of Lake remediation towards water quality: application in varsity lake as well as that of Sener et al. (2017) for Aksu lake in Turkey.

The biochemical oxygen demand (BOD) together with COD are the two important water quality parameters that give an indication of the organic pollutant content in the water bodies. The biochemical oxygen demand (BOD) distribution trend recorded in this study does not show high differences among the study sites, however, the mean BOD of 4.41 mgL^{-1} recorded is above the recommended threshold for the surface water meant for recreational activities (3.0 mgL^{-1}) and fell in NWQS class III. This finding is similar to the findings reported by Sujaul et al. (2012) but deviates from the findings of Sabri et al. (2016) in their study of water quality monitoring of Tasik Cempaka, Bangi, where a lower BOD was reported.

The ammoniacal nitrogen which ranged from 0.17 to 0.38 mgL⁻¹(0.34 mg L⁻¹) is slightly above the class IIB but still suitable for the recreational contact. The ammoniacal nitrogen concentrations in the surface water is associated with the biological decay of organic matter discharged from the watershed of the lakes or released from the bottom sediment of the lake. Farming and domestic sewage discharge were also contributing agent to ammoniacal nitrogen contamination in the water (Naveedullah et al., 2016). This scenario is true for the NAHRIM Lake since discharges occurs from the laboratory and canteen area as well as sewerage treatment plant with a pollution load that ranged between 2.785kg/day to 3.457kg/day (NAHRIM, 2012). The result of this study is partially different from the one reported by Al-Badaai et al. (2013) for Semenyih river and Sujaul et al. (2012) in their study of surface water pollution in peninsular Malaysia. Ammoniacal nitrogen, nitrites, nitrate and phosphorus have a role in the eutrophication of the lake (Orderud & Vogt, 2013).

The nitrites (NO₂-N) and nitrates (NO₃-N) concentrations in the NAHRIM Lake were far below the stipulated level of 0.4 and 7 mg L⁻¹ by the NWQS. They can be categorised as class I. This implies that, the agricultural and canteen sources in the lake watershed that should be responsible for their contamination is having minimal effects on the water quality of the lake. The findings deviated from the one reported by Gasim et al., (2015) for Cempaka lake.

The mean phosphorus concentration (0.056mgL⁻¹) recorded for the NAHRIM Lake were below the recommended level for surface water and hence categorised under class I. Although phosphorus contamination results from the domestic discharges containing detergents, fertilizers and wastes from treatment plants which are present in NAHRIM, the discharges from NAHRIM phosphorus sources are having a minimal effect on the lake water pollution. The concentration of phosphorus above 0.025mg L⁻¹ usually triggers algae and other aquatic plant growth (Yasir et al., 2017). However the concentration recorded here is lower than those reported by Gasim et al. (2015) and Yasir et al. (2017) in their respective studies of water quality of Cempaka lake and Chini lake respectively.

TSS is an important parameter for water quality study because the oxygen will easily dissolve in low suspended solids water. The concentration of the total suspended solids of the NAHRIM Lake falls within the range of class I to II of the NWQS. The average TSS for the lake effectively categorised the lake in Class I. This occurrence is associated with less consistent land use within the lake general area as well the erosive contribution of the rain that washed down the particles from the impervious areas that is less covered by the constructed wetlands. The finding of TSS is higher than those reported by the Gasim et al. (2015) and Ismail et al. (2012) for Cempaka and Chini lakes respectively but consistent with the findings of Sabri et al. (2016) for the same Cempaka lake.

The *Escherichia coli* and total coliform content of the lake were way above the stipulated level of Class II (5000CFU/100mL) and fell in the class III category of NWQS.

This occurrence is attributed to the high amounts of discharge containing substances that will aid the growth of the microbes. This effluents majorly from the sewerage treatment plant of the Institute with a contribution from drainage system that connects the laboratory, canteen and workshop to the lake. This findings is consistent with similar one reported for Cempaka Lake by Gasim et al. (2015) and Al-Badaii et al. (2013) for Semenyih river. Bacterial counts evaluation of the water is usually utilised to determine the pathogenic strains of organisms that may be related to the faecal microbes.

Heavy Metals

Heavy metals are important part of the earth crust that are needed for various developmental activities by the organisms. However, at certain concentrations they induce toxicity. Hence analysing their concentration in the water bodies meant for human contact is important. The detected heavy metal concentrations in the water samples of the NAHRIM lake followed a decreasing order of Fe (1.33 ± 0.62) > B (0.46 ± 0.01) > Mn (0.26 ± 0.09) > Al (0.19 ± 0.08) > Zn (0.026 ± 0.01). The threshold level was not stipulated for aluminium for surface water with recreational purpose but the mean concentration can be categorised under class I. Meanwhile, the lowest concentration of aluminium recorded at sites in September is an indication of less discharge of effluents for that particular month. Iron threshold was set at 1 mg L^{-1} and this implies that, the finding reported here is slightly higher (class III) than the stipulated level. Similar lower iron concentration was also observed for September.

The distribution trend observed for manganese follows the pattern observed for iron. Different trend was observed for zinc that recorded a lower concentration as compared to the class IIB level of 0.2 mg L^{-1} . These findings are similar to those reported by Said et al. (2011) for related heavy metals in Cempaka Lake, and for Lake Titiwangsa and Tasik Chini (Shuhaimi-Othman et al., 2008; Said et al., 2012b). Thus, the elemental concentrations of the lake water can be said to be at the natural level. The lower concentration of the elements detected may be attributed to their higher accumulation first by the components of constructed wetlands such as the sediments and plants.

Water Quality Index (WQI)

The calculated water quality index for the lake varies from a strong class II to a very strong class II for each of the sites in the studied months. This shows that, with respect to NWQS standard, the lake is suitable for the recreational contact and also for the survival of the organisms. The contribution of each of the parameters in the index varies. Similar findings of class II status have also been reported for other Malaysian lakes such as Tasik Chini, Ampang Hilir lake and Titiwangsa lake (Ismail et al., 2012; Yasir et al., 2017; Said et al., 2012a, Said et al., 2012b) while a class III was reported for Bukit Merah lake by Akinbile et al. (2013).

The analysis of the water samples taken from the constructed wetlands indicated higher concentrations for majority of the parameters as compared to the water sampled from the lake with majority of the parameters being categorised as class III. This may be attributed to the filtration process of the wetland which leads to the reduction in the concentration of the same parameters in the lake. This finding is in agreement with earlier researches (Sim et al., 2008; Zhai et al., 2011; Mburu et al., 2012) that reported the effective role of the wetlands in improving the water quality from the contaminants of different of matrices.

CONCLUSION

The water quality characteristics of NAHRIM Lake was determined. The analysis of the individual water quality parameters shows that most of the water quality parameters fell between the NWQS class I and II. However, the bacterial counts (class III) recorded in the water samples of the lake is above the stipulated threshold. The cumulative National Water Quality Standard of Malaysia water quality index categorised the lake under Class II which makes it suitable for the recreational activities. Generally, the anthropogenic activities observed in the study area is the major factors that deteriorate the water quality of the NAHRIM lake, however the remediation process by the constructed wetlands acting as the first point of contacts limits their impact which is supported by the WQI of class III reported for the water samples from the wetlands. Thus, it is recommended that constructed wetland can be deployed as a medium of the improvement of water quality in other urban lakes with similar contamination problems.

ACKNOWLEDGEMENTS

The authors' gratitude goes to laboratory staffs of National Hydraulic Research Institute of Malaysia (NAHRIM) for their technical support and guidance during the conduct of this study.

REFERENCES

- Abdullah, A. O. O. A. M., Ramli, M. F., & Sood, A. M. (2012). Factors affecting Agricultural land use for vegetables production-a case study of the state of Selangor, Malaysia. *African Journal of Agricultural Research*, 7(44), 5939-5948.
- Al-Badaai, F., Shuhaimi-Othman, M., & Gasim, M. B. (2013). Water quality assessment of the Semenyih River, Selangor, Malaysia. *Journal of Chemistry*, 2013, 1-10.
- Akinbile, C. O., Yusoff, M. S., Talib, S. H. A., Hasan, Z. A., Ismail, W. R., & Sansudin, U. (2013) Qualitative analysis and classification of surface water in Bukit Merah Reservoir in Malaysia. *Water Science and Technology: Water Supply*, 13(4), 1138-1145.

- Amneera, W. A., Najib, N. W. A. Z., Yusof, S. R. M., & Rangunathan, S. (2013). Water quality index of Perlis River, Malaysia. *International Journal on Civil and Environmental Engineering*, 13(2), 1-6.
- APHA. (2005). *Standard methods for the examination of water and wastewater* (21st Ed.). Washington, D.C.: American Public Health Association.
- Bhateria, R., & Jain, D. (2016). Water quality assessment of Lake water: a review. *Sustainable Water Resources Management*, 2(2), 161-173.
- Bojcevska, H., & Tonderski, K. (2007). Impact of loads, season, and plant species on the performance of a tropical constructed wetland polishing effluent from sugar factory stabilization ponds. *Ecological Engineering*, 29(1), 66-76.
- DOE. (2008). *National Water Quality Standards for Malaysia*. Kuala Lumpur, Malaysia: Department of Environment.
- Dirican, S. (2015). Assessment of water quality using physico-chemical parameters of Çamlığıze Dam Lake in Sivas, Turkey. *Ecologia*, 5(1), 1-7.
- EPA. (2009). *Drinking Water Contaminants*. Washington, D.C.: United States Environmental Protection Agency.
- Gandaseca, S., Rosli, N., Ngayop, J., & Arianto, C. I. (2011). Status of water quality based on the physico-chemical assessment on river water at Wildlife Sanctuary Sibuti Mangrove Forest, Miri Sarawak. *American Journal of Environmental Sciences*, 7(3), 269-275.
- Gasim, M. B., Toriman, M. E., Muftah, S., Barggig, A., Aziz, N. A. A., Azaman, F., & Muhamad, H. (2015). Water quality degradation of Cempaka Lake, Bangi, Selangor, Malaysia as an impact of excessive E. coli and nutrient concentrations. *Malaysian Journal of Analytical Sciences*, 19(6), 1391-1404.
- Ismail, B. S., Islam, M. S., Barzani, G. M., Sahibin, A. R., & EKhwan, T. M. (2012). Hydrological assessment and water quality characteristics of Chini Lake, Pahang, Malaysia. *American-Eurasian Journal of Agricultural and Environmental Science*, 12(6), 737-749.
- Jackson, B. P., Taylor, V. F., Punshon, T., & Cottingham, K. L. (2012). Arsenic concentration and speciation in Infant formulas and first foods. *Pure Applied Chemistry*, 84(2), 215-223.
- Juahir, H., Zain, S. M., Yusoff, M. K., Hanidza, T. T., Armi, A. M., Toriman, M. E., & Mokhtar, M. (2011). Spatial water quality assessment of Langat River Basin (Malaysia) using environmetric techniques. *Environmental Monitoring and Assessment*, 173(1-4), 625-641.
- Kadlec, R. H., & Wallace, S. (2008). *Treatment wetlands*. Boca Raton: CRC press.
- Khalik, W. M. A. W. A., & Abdullah, M. P. (2012). Seasonal influence on water quality status of Temenggor Lake, Perak. *Malaysian Journal Analytical Sciences*, 16, 163-171.
- Khuan, Y. L., Hamzah, N., & Jailani, R. (2002, July 17). Prediction of water quality index based on artificial neural network. In *Student Conference on Research and Development* (pp. 157-161). Shah Alam, Malaysia, Malaysia.
- Konnerup, D., Trang, N. T. D., & Brix, H. (2011). Treatment of fish pond water by recirculating horizontal and vertical flow constructed wetlands in the tropics. *Aquaculture*, 313(1-4), 57-64.

- Loukas, A. (2010). Surface water quantity and quality assessment in Pinios River, Thessaly, Greece. *Desalination*, 250(1), 266–273.
- Martín, M., Oliver, N., Hernández-Crespo, C., Gargallo, S., & Regidor, M. C. (2013). The use of free water surface constructed wetland to treat the eutrophicated waters of Lake L'Albufera de Valencia (Spain). *Ecological Engineering*, 50, 52-61.
- Mburu, N., Tebitendwa, S. M., Rousseau, D. P., Van Bruggen, J. J. A., & Lens, P. N. (2012). Performance evaluation of horizontal subsurface flow–constructed wetlands for the treatment of domestic wastewater in the tropics. *Journal of Environmental Engineering*, 139(3), 358-367.
- Mood, N. C., Othman, N. F. M. A., & Adham, M. I. (2017). Effectiveness of Lake Remediation towards water quality: application in varsity lake, University of Malaya, Kuala Lumpur. *Sains Malaysiana*, 46(8), 1221-1229.
- NAHRIM. (2012). Water quality status of Tasik NAHRIM. In M. F. Kasim (Ed.), *Report on Water quality of Tasik NAHRIM*. Unpublished.
- Naveedullah, N., Hashmi, M. Z., Yu, C., Shen, C., Muhammad, N., Shen, H., & Chen, Y. (2016). Water quality characterization of the siling reservoir (Zhejiang, China) using water quality index. *CLEAN–Soil, Air, Water*, 44(5), 553-562.
- Orderud, G. I., & Vogt, R. D. (2013). Trans-disciplinarity required in understanding, predicting and dealing with water eutrophication. *International Journal of Sustainable Development and World Ecology*, 20(5), 404-415.
- Radojevic, M., & Bashkin, V. (2007). *Practical environmental analysis*. Cambridge: Royal society of chemistry.
- Ramakrishnaiah, C. R., Sadashivaiah, C., & Ranganna, G. (2009). Assessment of water quality index for the groundwater in Tumkur taluk, Karnataka state. India. *E-Journal of Chemistry*, 6(2), 523–530.
- Rosli, N., Gandaseca, G., Johan, I., & Mohd, I. J. (2010). Comparative study of water quality at different peat swamp forest of Batang Igan, Sibul Sarawak. *American Journal of Environmental Sciences*, 6(5), 416-421.
- Rostom, N. G., Shalaby, A. A., Issa, Y. M., & Afifi, A. A. (2017). Evaluation of Mariut Lake water quality using hyperspectral remote sensing and laboratory works. *The Egyptian Journal of Remote Sensing and Space Science*, 20, S39-S48.
- Sabri, N. A. S. M., Abdullah, M. P., Mat, S., Elfithri, R., & Khalik, W. M. A. W. M. (2016). Evaluation of hydrochemistry variation in water quality of Cempaka lake, Malaysia using multivariate statistical analysis. *Journal of Materials and Environmental Science*, 7(12), 4403-4410.
- Said, K. S., Shuhaimi, M., & Kutty, A. (2011). The water quality and metal concentrations of Cempaka Lake, Selangor, Malaysia. *WIT Transactions on Ecology and the Environment*, 148, 47-52.
- Said, K. S., Shuhaimi-Othman, M., & Ahmad, A. K. (2012a). Ampang Hilir Lake, Selangor, Peninsular Malaysia. *Pakistan Journal of Biological Sciences*, 15(9), 437-447.
- Said, K. S., Shuhaimi-Othman, M., & Ahmad, A. K. (2012b). The evaluation of water quality and metal concentrations of Titiwangsa Lake, Selangor, Peninsular Malaysia. *Pakistan journal of Biological Science*, 15(10), 459-468.

- Şener, Ş., Şener, E., & Davraz, A. (2017). Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey). *Science of the Total Environment*, 584, 131-144.
- Shuhaimi-Othman, M., Lim, E. C., & Mushrifah, I. (2008). Water quality changes in Chini Lake, Pahang, West Malaysia. *Environmental Monitoring and Assessment*, 131(1-3), 279-292.
- Sim, C. H., Yusoff, M. K., Shutes, B., Ho, S. C., & Mansor, M. (2008). Nutrient removal in a pilot and full scale constructed wetland, Putrajaya city, Malaysia. *Journal of Environmental Management*, 88(2), 307-317.
- Sujaul, M. I., Hossain, M. A., Sobahan, M. A., Zularisam, A. W., & Aziz, E. A. (2012). Spatial variation of water quality parameters in Gebeng industrial area, Pahang, Malaysia. In *Proceedings of International Conference on Environment, Chemistry and Biology IPCBEE* (Vol. 49, pp. 6-11). Singapore: IACSIT Press.
- UN Water. (2017). *Wastewater: Generation and impact on Environment and Human health*. Retrieved October 12, 2017, from <http://www.unwater.org/publications/world-water-development-report-2017>
- Yasir, A. M., Mir, S. I., Zularisam, A. W., & Edriyana, A. A. (2017). Characterization of chini lake water quality with malaysian WQI using multivariate statistical analysis. *Bangladesh Journal of Botany*, 46(2), 691-699.
- Zhai, J., Xiao, H. W., Kujawa-Roeleveld, K., He, Q., & Kerstens, S. M. (2011). Experimental study of a novel hybrid constructed wetland for water reuse and its application in Southern China. *Water Science and Technology*, 64(11), 2177-2184.

