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ASSESSING LAKES USING SPECIFIC LAKE WATER QUALITY CRITERIA AND STANDARDS FOR MALAYSIA

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Abstract

The quality of inland water resources in Malaysia, including lakes, has been monitored and assessed using the national water quality standards and water quality index developed for the river. However, a specific water quality standard for the lake that has been approved for application in Malaysia since 2017 introduced a few physicochemical and biological criteria suitable for slow-moving water bodies. This study attempted to investigate the water quality status of different types of lentic water bodies in the country using the National Lake Water Quality Criteria and Standards (NLWCQS). The studied lakes include natural lakes, ponds, and reservoirs. Based on the assessment of about 20 environmental variables prescribed by the standards, our results showed different water bodies exhibit different water quality and trophic statuses. Puteri Lake and Dayang Bunting Lake were oligotrophic, Chini Lake, Bukit Merah, and Chenderoh reservoirs were mesotrophic to eutrophic, while Sembrong reservoir and Intan Baiduri pond were hypereutrophic. Hypereutrophic lakes contain high cyanobacterial density and faecal bacteria concentration. Despite showing oligotrophic characteristics, the water in Puteri Lake was acidic and not suitable for recreational purposes. Significant differences in water quality variables between lakes supported the unique characteristics of the water bodies that require monitoring. Assessing the water quality based on NLWQCS provides a better understanding of the overall characteristics of lakes concerning their uses for recreational purposes. This will enable sustainable management and protection of water bodies towards water security for Malaysia.

INTRODUCTION

Monitoring water quality is crucial to support the preservation of the lake ecosystem's functioning, and services. A standardized tool that provides effective monitoring of ambient water quality could support the identification of the best monitoring program and management measures for the improvement of lake water quality. In Malaysia, there are two notable national standards of water quality: the National Water Quality Standards (NWQS) and the National Drinking Water Quality Standards (NDWQS), developed for river and drinking water monitoring [1]. The quality of inland water resources such as lakes and reservoirs has been monitored and assessed using the river water quality standards and/or water quality index (WQI) [2, 3, 4, 5]. The majority of the lakes in Malaysia were categorised as Class II (clean) based on WQI [5, 6] yet these lakes showed characteristics of poor water quality due to algal blooms and macrophyte infestation challenges [6]. As water quality in lakes is known to differ temporally and spatially, both horizontally and vertically depending on lake depth and shape and their retention time [2, 7, 8], monitoring using the general standard may pose erroneousness information due to its different characteristics and purpose

[1]. Studies in the deep lake such as Kenyir Lake, for example, showed that surface water quality was in Class I (Clean) while bottom water quality were mostly in Class III (Slightly polluted) [2]. Other vertical studies showed that bottom water quality for deep lakes contains high nutrients such as ammonia and total phosphorus [8].

Many biological parameters especially for recreational potential have not been included in the current standards (NWQS). Some studies in Indonesia, Africa, and Europe reported that biological parameters such as plankton and pathogenic bacteria can also pose as excellent bioindicators of water quality and pollution [9, 10, 11]. Another study showed chlorophyll-a as a great indicator of algal bloom and water quality conditions such as in lakes in America [12]. Various studies indicated that lake quality in Malaysia is deteriorating [13, 14], a recent publication by NAHRIM indicated about 65% out of the 94 lakes monitored were categorized as eutrophic [14]. Few studies that have adopted the lake standard showed that higher nutrient levels and cyanobacteria in Slim River lake and pathogenic bacteria in urban lakes posed potential health risks [15, 16]. The limited use of the correct, existing water quality standards for lakes represents a serious threat to ecosystem health and its users including humans and wildlife [1, 14].

A specific lake water quality criteria and standards introduced in 2015 and adopted in Malaysia in 2017 emphasized the protection of lake water quality for human and ecosystem health [17]. These criteria were based on beneficial uses of the lake for primary and body contact recreation and the knowledge of aquatic toxicity to different organisms, specifically the targeted protective species [1, 17]. Monitoring parameters introduced in the lake standard that differ from river standards include transparency, Chlorophyll-*a*, total phosphorus, other microbiological parameters such as *Escherichia coli,* enterococci, and Cyanobacteria [1]. This study aimed to investigate and characterized the water quality of different types of lentic water bodies in the country using the correct, existing standard namely National Lake Water Quality Criteria and Standards (NLWCQS). The work focused on seven lakes that were increasingly used or identified for recreational development or purposes.

MATERIALS AND METHODS

Materials

Physico-chemical parameter measurements such as pH, temperature, dissolved oxygen, turbidity, conductivity, salinity were recorded using a multi-parameter probe (YSI Incorporated, Yellow Spring, USA). The chemical, biological and microbiological parameters such as Chlorophyll-*a*, *E. coli*, biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen, nitrate, total suspended solids, total phosphorus, and heavy metals such as arsenic, cadmium, lead, mercury, and nickel were analysed in the laboratories using the APHA standard methods [18]. Chlorophyll-*a* was analysed using spectrophotometer while heavy metals were analysed using Inductively Coupled Plasma Mass Spectroscopy (ICP-MS). Water samples collected at the field using van Dorn sampler were preserved at 4°C and transported to the laboratories in a cooler box within 24-hours. All sample bottles were properly prepared; stabilizing preservatives such as sulphuric acids were added before sampling activities for certain parameters i.e. bottle samples for analysis of total phosphorus and heavy metals.

Additional 1-liter of water samples were collected in separate bottles and preserved using Lugol's solution at the site and enumerated and counted for cyanobacterial density in the laboratory. Transparency was determined based on the depth (in meter) of the Secchi disk (black-and-white disk, 20 cm in diameter) lowered in the water until the disc was no longer visible.

Methods

Assessment of water quality was performed at three types of water bodies namely natural lake, ex-mining pond, and reservoir. Seven water bodies located in different parts of Peninsular Malaysia were chosen in this study namely Chini Lake and Dayang Bunting Lake (natural lake), Intan Baiduri Pond, and Puteri Lake (ex-mining pond), Sembrong Lake, Bukit Merah Lake, and Chenderoh Lake (reservoir). Chini Lake, Dayang Bunting, Bukit Merah and Chenderoh were popular as tourist or eco-tourism destinations. The locations of the water bodies are as shown in Figure 1. Measurements were carried out in the limnetic areas of each lake, at two to three locations, during dry and wet periods. With exception of Intan Baiduri Lake, sampling locations at all lakes were located at the centre of each lake to represent the ambient conditions. For Intan Baiduri Lake, due to the limitation of logistic conditions, the sampling location was taken at the jetty (~2 m) and near the outlet (littoral areas). Trophic state index (TSI) was derived based on Chlorophyll-a values using the Carlson Index calculation [19]. Results were analyzed based on compliance with standard limits sets for secondary body contact recreation (Category B) due to potential human uses in all lakes. Descriptive analysis was performed on the data. All water quality data were checked for normality before testing. Except for the temperature, dissolved oxygen and pH, all other water quality data were log-transformed $x = \log_{10}(x)$ to improve normality and reduce outliers. Further testing of differences between lakes was made using the one-way Analysis of Variance method (ANOVA). Temporal analysis of water quality variables was also tested for each lake using independent samples T-tests. All statistical analyses were carried out using SPSS version 22.

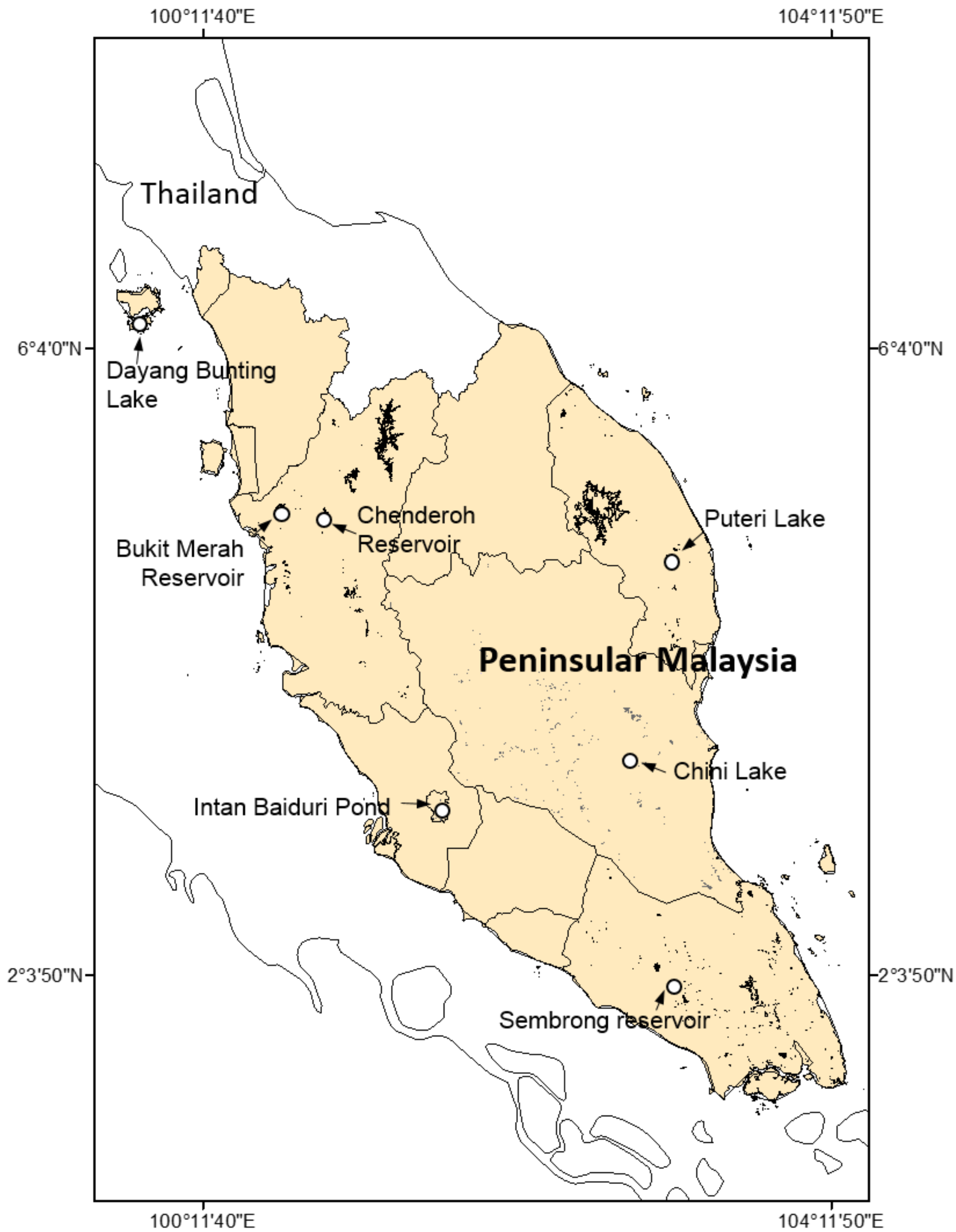
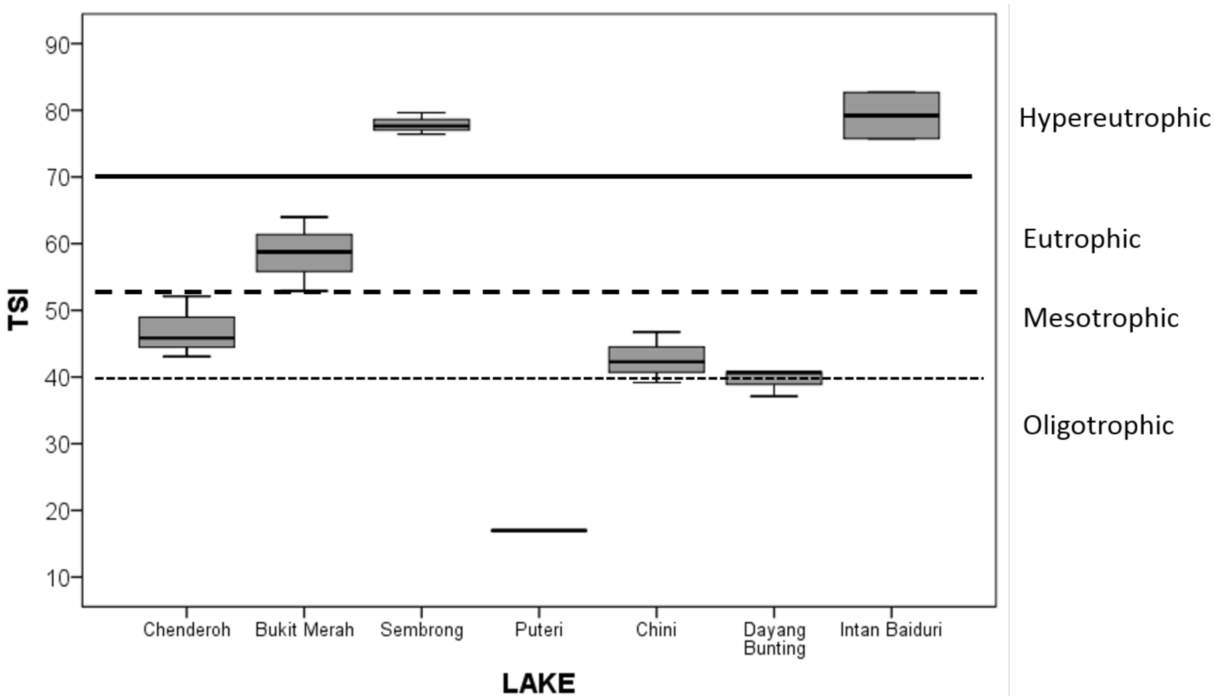


Figure 1. Location of study water bodies.

RESULTS AND DISCUSSION

Trophic Classification

The boxplot of the trophic classification of the water bodies based on primary productivity is shown in Figure 2. Two lakes namely Puteri lake and Dayang Bunting Lake were oligotrophic or had low nutrient concentrations and biological productivity, while Chini Lake, Bukit Merah, and Chenderoh reservoirs were meso-eutrophic or had medium to high nutrient levels and moderate biological productivity. TSI values recorded in the Chenderoh reservoir and Bukit Merah reservoir were consistent findings from other studies that ranged between 38.6 – 48.0 [20] and 47.0 – 51.0 [21]. TSI value for Puteri Lake was very low (<30) and distinct from other water bodies. Two water bodies namely Sembrong and Intan Baiduri were also significantly different than the other lakes due to high biological productivity and nutrient-rich or hyper-eutrophic conditions ($p < 0.001$).



Spatial Variation of Water Quality Variables

The mean values of the monitored environmental variables at different lakes are given in Table 1. ANOVA results showed significant differences between lakes for all parameters including pH, conductivity, transparency, BOD and ammoniacal nitrogen ($p < 0.001$). The pH level in Tasik Puteri was too acidic to enable phytoplankton growth as such the water was crystal clear with transparency reach to the lake bottom. Being an ex-mining iron-ore mine in Terengganu, the low pH values indicated that Puteri Lake is an example of an acid-mine drainage system that has very low productivity. These low pH, and high conductivity, can leach heavy metals into the water. Elevated levels of acidity, conductivity, and salinity in Puteri Lake were likely due to geological factors [22]. High salinity recorded in Dayang Bunting Lake was reported to be likely due to the intrusion of saline water into the lake [23]. DO and pH in the Chini lake was quite low.

Ammoniacal nitrogen and COD levels recorded in Chini Lake were lower than in the literature [24, 25, 26]. The water in Intan Baiduri pond detected high BOD, COD and ammoniacal nitrogen concentrations. High levels of these parameters have always been associated with sewage consistent with high *E. coli* levels [16]. This is consistent with results reported in other urban lakes [4, 5].

The transparency level in Chini lake is slightly lower for recreational potential (< 0.6 m) but within the category suitable for ecosystem health (> 0.3 m). The transparency level in the Intan Baiduri lake was lowest (< 0.3 m) among all lakes, not meeting the standard level for recreational purposes. Higher turbidity in Intan Baiduri lake water could be induced by suspended matter such as silt, and organic matter as well as plankton and other microscopic organisms [16]. In Sembrong Reservoir, the low transparency and elevated turbidity levels could be originated to detritus and plankton cells since total suspended solids values were low.

In terms of Chlorophyll-*a* values, Chini Lake has moderate biological productivity while Chenderoh and Bukit Merah reservoirs were having moderate to high biological productivity. Higher Chlorophyll-*a* value in Bukit Merah is consistent with other findings that recorded Chlorophyll-*a* between the range of 14.8 µg/L to 68.16 µg/L [27]. The elevated Chlorophyll-*a* concentrations (>90 µg/L) in both Sembrong and Intan Baiduri lakes indicate serious eutrophication problems that require intervention. High Chlorophyll-*a* in Sembrong has been reported in a few studies [28, 29, 30, 31, 32]. In contrast, Chlorophyll-*a* values were lowest in Puteri Lake, below the detection limit, distinguishing this lake from other water bodies.

Table 1. Mean values of water quality parameters in different lakes.

PARAMETER	UNIT	Chenderoh	Bukit Merah	Sembrong	Chini	Puteri	Dayang Bunting	Intan Baiduri	National Lake Water Quality Standard (Category B)
Temperature	°C	30.6	31.3	30.0	24.5	30.5	29.9	30.4	28 ± 3
Transparency	m	1.2	**0.58**	**0.34**	**0.5**	8.1	2.0	**0.2**	0.6
Turbidity	NTU	5.3	10.6	58	28.5	0	17	55	40 - 170
Conductivity	µS/cm	54	28	19	28	795	**>1000**	309	1000
Salinity	ppt	0.01	0.01	0.14	0.01	0.34	0.60	0.13	-
Dissolved Oxygen	mg/L	10.0	6.4	8.0	**4.2**	6.4	6.5	9.0	5.5 – 8.7
pH	-	6.6	6.8	8.0	6.5	**3.0**	6.8	8.2	6.5 – 8.5
Biochemical oxygen demand	mg/L	4	3	**10**	3	0.9	6	**17**	6
Chemical oxygen demand	mg/L	17	13	**69**	9	1.4	17	**90**	25
E. coli	CFU/100 ml	nd	34	10	175	-	-	**9700**	600
Total coliform	CFU/100 ml	1500	**5633**	42	441	-	-	**162500**	5000
Total suspended solids	mg/L	4	11	4	5	0.3	1	53	100 - 200
Ammonia-N	mg/L	0.01	nd	nd	0.01	0.01	0.03	**6.2**	0.3
Nitrate-N	mg/L	0.35	nd	0.13	0.02	nd	-	0.7	7
Total phosphorus	mg/L	**0.08**	**0.06**	**0.09**	0.02	0.035	<0.01	**0.9**	0.035
Cyanobacteria	Cells/ml	2.9	41.9	**56387**	8.4	-	120.3	**3550045**	15000

Note: nd – not detected, bold values – exceeded the standard limit

Table 2. Range of heavy metals concentrations detected in the selected lakes.

PARAMETER	Arsenic	Lead	Cadmium	Nickel
UNIT	mg/L	mg/L	mg/L	mg/L
Chenderoh	0.005 – 0.025	nd	nd	nd
Bukit Merah	0.002 – 0.004	nd	nd	0.009 – **0.029**
Chini	nd	nd	nd	0.001
Puteri	nd – 0.024	0.004 – 0.01	nd – 0.013	nd
Intan Baiduri	nd – 0.03	nd – 0.04	nd – 0.002	nd
NLWQCS limits (Category B)	0.1	0.05	0.002	0.02

Note: nd- not detected, bold values – exceeded standard limit, NLWQCS - National Lake water Quality Criteria and Standard

Few heavy metals including arsenic, cadmium, and lead were detected in Puteri Lake (Table 2). In this study, the only heavy metal detected in Chini Lake was nickel. Heavy metals of concern detected in Chenderoh and Bukit Merah reservoirs were arsenic and nickel, respectively. The elevated concentrations of heavy metals in Bukit Merah Lake were consistent with findings in 2010 [33]. In this study, the maximum nickel detected in Bukit Merah Lake exceeded the NLWQCS. Among the health risk associated with exposure, orally or dermatologically, to the high concentration of nickel includes gastrointestinal, hematological, neurological and immune systems [34]. Elevated levels of heavy metals, namely arsenic, lead, and cadmium, were also detected in Intan Baiduri lake possibly due to geological factors or contribution from effluent discharges from factories located in the nearby areas.

Both total coliform and *E. coli* in Chini Lake were detected in low concentrations complying with the standard limits consistent with prior findings [24]. Total coliform levels in this lake exceeded the standard limit. High faecal bacteria in Intan Baiduri pond and Sembrong Reservoir supported other findings that reported it to have been linked to the influence of sewage [16] and poultry and livestock [28, 29], respectively. Urban lakes in other tropical countries such as Indonesia also frequently experience threats of water pollution including pathogenic bacteria and toxic pollutants contamination that affects human health due to untreated sewage inflow and storm water runoff [35].

In this study, high cyanobacterial density was observed in both hypereutrophic water bodies that exceeded the limit of 15,000 cells/ml suggested in the standards. A previous study identified the range of Cyanobacterial density in Sembrong reservoir between 20000 to 65000 cells/ml [28] which falls in the range of relatively low probability to medium probability of adverse health effects of the WHO Guidelines for safe recreational water use [35]. This study recorded a higher range between 40000 to 80000 cells/ml. The cyanobacterial density in Intan Baiduri pond exceeded the range of 100,000 cells/ml of the WHO Guidelines or in the category of a high probability of adverse health effects such as acute poisoning.

Temporal Variation of Water Quality Variables

Seasonal differences in water quality variables were not significant between all lakes in this study. The seasonal or temporal variation in water quality variables, however, were observed in the individual lake and differed between environmental variables. For example, DO differed temporally in Chenderoh and Bukit Merah lakes (<0.05) while conductivity varied temporally in Chenderoh, Sembrong, and Intan Baiduri lakes (<0.05). Higher DO concentrations were recorded during the dry season in Chenderoh Lake (mean = 10.0 mg/L) while higher DO were observed during the wet season in Bukit Merah lake (mean = 9.17 mg/L) respectively. Lower DO in Chenderoh lake during the wet season is likely due to the influence of lake mixing with the incoming water released from cascading dams upstream namely Kenering, Bersia and Temenggor reservoirs containing low DO. These dams were very deep and anoxic conditions of the hypolimnion (bottom water column) have been reported due to stratifications [8]. Whilst higher DO during the wet season in Bukit Merah Lake is probably due to incoming water from Kurau River that improved circulation in this very shallow and large reservoir.

High BOD was apparent in Puteri Lake during the wet season (<0.05) while high COD was recorded in Intan Baiduri Lake during the wet season (<0.001) indicating flows of organic pollutants from surrounding areas. Secchi depth transparency varied significantly between seasons in Chini Lake and Sembrong reservoir probably due to incoming turbid water from the main river such as Pahang river for the case of Chini Lake. Only pH differed between wet and dry seasons in Dayang Bunting Lake with higher pH occurring during the dry season possibly induced by ecosystem processes rather than by external influences. This study does not report seasonal changes in Chlorophyll-a values. Much longer monitoring of Chlorophyll-a values such as in Lake Baringo, Kenya (> 10 years) illustrated the fluctuation of lake trophic status between mesotrophic to hypereutrophic that affects the water supply [7].

Suitability as Recreation

Despite having oligotrophic characteristics and high transparency, the water in Puteri Lake was not suitable for recreational purposes. These low pH, and high conductivity, and heavy metals in the water are dangerous for body contact and human health [9]. In contrast, Tasik Dayang Bunting has good pH, and DO concentrations. The water has a high transparency level (>0.6 m) that is suitable for both primary and secondary body contact recreation. Most of the environmental variables were also within the standard limit. Chini Lake, Pahang is a lake known as a dystrophic system having high organic matter. In this study, the lake is characterised by low DO and pH, and moderate biological productivity.

Overall, most lakes studied here are generally able to meet the standard limit sets in the NLWQCS. Lakes that have the highest percentage of compliance were Dayang Bunting Lake followed by Chenderoh reservoir and Chini Lake. Among all parameters specified, the only parameter that most lakes have difficulty meeting the standard limit is the total phosphorus. Such high values of total phosphorus exceeding 0.035 mg/L will promote excessive growth of phytoplankton or macrophytes [17]. This is consistent with qualitative observation where all four water bodies namely Chenderoh, Bukit Merah, Sembrong, and Intan Baiduri are facing the deterioration of ecosystem health with the occurrence of excessive macrophytes (i.e., water hyacinth) or algal bloom. As lake catchments in the rural areas are increasingly been developed for agriculture development, monitoring nutrient levels such as total phosphorus in lake water is crucial to better understand eutrophication status. Monitoring microbiological parameters are also important especially for urban water bodies to detect any faecal pollution and other pathogenic bacteria [34]. Continuous monitoring of water quality parameters and pollutants in lakes is necessary so that prevention and mitigation measures can be undertaken to control or improve the lake water quality for their intended purposes.

CONCLUSION

In conclusion, this study applied the National Lake Water Quality Criteria and Standards which introduced parameters needed for monitoring water quality for the protection of human and ecosystem health, besides detecting the potential of eutrophication and sedimentation in seven lakes. Eutrophication, based on trophic status, varied between lakes ranging from oligotrophic to hypereutrophic while parameters of concern to detect possible sedimentation were low. Monitoring status on three types of water bodies using the standardized tool showed that the NLWQCS provides a better understanding of the lake water quality characteristics to aid in the management and protection of water bodies.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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