Chapter 13

Formulating Specific Water Quality Criteria for Lakes: A Malaysian Perspective

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Additional information is available at the end of the chapter

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Abstract

Monitoring water quality of inland water bodies such as lakes, reservoirs and ponds throughout Malaysia is important to ensure that these water bodies can be managed sustainably for their ecosystem functioning and services. Determining the quality of these water bodies for different uses is limited due to the unavailability of specific criteria or standards for such water bodies in the country. The aim of this study is to develop national water quality criteria and guidance values for lakes to enhance the water quality of the water bodies in Malaysia. The work is based on a literature review and a consensus among experts from the various stakeholders' consultative sessions. The criteria were divided into four specific uses which aim at protecting the health of human and aquatic life. The criteria and standards are targeted for non-regulatory purposes to promote lake quality monitoring by various stakeholders. More than 20 parameters were identified in the lake criteria to determine the classification. The identification of parameters and limits for the standards, however, was limited by data availability and appropriate understanding of the water body characteristics. The role of the criteria and their limitation was also discussed.

Keywords: lakes and reservoirs, recreational, stakeholder consultations, standards, water quality criteria

1. Introduction

Eutrophication of inland water is a prevalent issue in Malaysia, one which threatens the functioning of lake and reservoir ecosystems throughout the country. A preliminary study of the status of lake eutrophication reported that more than 60% of the 90 lakes being studied were nutrient rich [1] with a few of them especially the urban lakes experiencing algal blooms, which affect human uses of the water, such as recreation and aesthetic values, while other lakes faced macrophyte infestation problems [2]. To address these widespread challenges, developing specific standards for lakes is necessary before introducing a monitoring programme and identifying management measures for improving lake water quality. At present, there are only two national standards of water quality in Malaysia, namely the National Water Quality Standards (NWQS) and the National Drinking Water Quality Standards (NDWQS), which were developed for the purpose of river and drinking water protection. Currently, lake monitoring efforts have focused on using the NWQS due to the unavailability of specific water quality criteria for lakes. In an earlier work, it has been shown that the majority of the lakes studied were categorized as suitable for recreational purposes, although, they did experience eutrophication [2].

Numerous ambient water quality criteria and standards have been introduced and published in various countries throughout the world [3] and compiled based on different uses [4]. Many of these criteria were developed for different protection objectives, mostly for drinking and/or recreation, and derived using different methodologies. Some countries propose unified regulatory standards that classify all water bodies based on beneficial uses [5]. Other countries use general standards which are applied to the water bodies for multiple purposes, with different numerical limits set for different types of water bodies, such as rivers, canals, lakes and coastal waters [6]. In some countries, such as Japan, a specific law to preserve lake water quality, better known as the Clean Lake Law, has been established to protect and improve water quality in the water bodies. Individualized measures have had to be developed in Japan due to differing water quality conditions, sources and causes of pollution amongst lakes [7]. In many states in the United States, site-specific criteria incorporating lake basin features and maximum load have been proposed, such as in the cases of Lake Erie and Lake Tahoe [8, 9]. As national standards for river and marine waters are available, specific criteria and standards for lakes are also needed so that Malaysia can ensure the sustainable management and protection of this lentic water due to its inherent characteristics.

This work describes the efforts in developing a National Lake Water Quality Criteria and Standards (NLWQCS) for Malaysia. The paper will be presented in three ways: (i) a review of the lake water quality criteria and standards in existing literature; (ii) classification and criteria, based on multi-stakeholder consultations and published data and (iii) discussion of the role of this standard for lake management. The main objective in developing these criteria is to provide a standardized reference for the monitoring and management of lakes, based on a consensus of local experts and stakeholders, namely the lake managers and lake owners such the state authority, state water authority and government agencies.

2. Methodology

Various definitions of criteria and standards have been reviewed by Ward [10]. In this paper, the term ‘water quality criteria’ is defined as the level of constituents or state of the physical, chemical, radiological, biological and aesthetic properties of water that determine its suitability for specific uses. The term standard follows the definition by Streeter [11] which is 'an operational goal or objective', such as to enable concerted efforts towards sustainable management of lakes, rather than an established regulatory criterion with legal ramification. The methodology adopted in establishing water quality standards usually involves: (i) identifying the designated or beneficial water uses and (ii) selecting the water quality parameters and determining the necessary limiting criteria to protect the most vulnerable of the beneficial uses.

Reviews of available standards in existing literature were carried out, covering various water quality standards both in Malaysia and worldwide. The local literature evaluated includes the NWQS [12], Putrajaya Lake Water Quality Standards (PLWQS) [13] and the NDWQS [14], as well as the draft document of guidelines for recreational water [15]. Reference was also made to a compendium on water quality regulatory frameworks and selected international standards and guidelines in different continents such as the United States, European Union, Japan, Brazil and Australia as listed in **Table 1**. The reviews were conducted in order to determine the designated water use, and water quality parameters and values. In terms of threshold limits, emphasis for selecting the threshold limit was given to local criteria and lake data from literature. This is followed with criteria or threshold limits from other countries or states with similar tropical conditions such as Brazil, the Philippines, Florida State in the United States and northern Australia. Threshold values of some of the criteria involving human health are based on well-adopted criteria in the developed countries.

Additionally, three stakeholder consultations were organized in 2015 to obtain consensus from stakeholders and expert judgements on the criteria. In the first stakeholder consultation, identified stakeholders were presented with a preliminary idea of the classification and criteria followed by sharing of experience with other international lake standards namely the Japanese lake criteria. Stakeholders were identified randomly comprising selected water quality experts, government agencies and water supply companies. In addition to minutes of discussion, questionnaires were also distributed to stakeholders to identify the need and parameters most important for such standard and to record their input. Second stakeholder consultation was held during the national lake research committee forum to refine the classification of the proposed NLWQCS and the parameter threshold limits.

The national lake research committee consists of experts in various disciplines concerning lakes, and key representatives from federal government agencies and ministries in charge of lake management. In this forum, the role of the standards was also discussed and deliberated. The third stakeholder consultative session involved reviewing the proposed standard by various stakeholders in 45 federal and state jurisdictions, namely the lake owners, with regard to the development of the criteria. A separate engagement with selected experts was carried out to review the improvements made to the criteria resulting from the stakeholder consultations. The final NLWQCS was presented and disseminated in a seminar involving stakeholders. **Figure 1** shows the development process of the NLWQCS.

Country/region	Standards and/or guidelines	Purposes or classification
Australia & New Zealand	Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000	Recreation; aquatic ecosystems
Brazil	CONAMA Resolution 274, 2000	Beneficial uses
Canada	Guidelines for Canadian Recreational Water Quality 2012	Recreation
EU	EU Bathing Water Directive 2006	Bathing
	EU Water Framework Directive 2000	
Japan	Basic environmental law 1967; environmental quality standards regarding water pollution 1986	Beneficial uses (protection of natural environment, fishery, drinking, irrigation, industrial water, environmental conservation)
	Law concerning special measures for the preservation of lake water quality 1984	Lake
Malaysia	National Water Quality Standards	Beneficial uses
	National Drinking Water Quality Standards; Raw water quality guidelines	Drinking
	Putrajaya Lake Water Quality Standards	Recreational
South Africa	South African Water Quality Guidelines: recreational uses	Recreation
	South African Water Quality Guidelines: aquatic ecosystem	Aquatic ecosystems
	South African Water Quality Guidelines: domestic uses	Domestic uses
	South African Water Quality Guidelines: domestic uses	Irrigation
	South African Water Quality Guidelines: industrial uses	Industrial uses
	South African Water Quality Guidelines: agricultural uses	Aquaculture; livestock dewatering
UK & Ireland	UK The bathing water regulations 2013	Bathing
	Ireland Water Quality (Dangerous substances) Regulations, 2001	Dangerous substances
	Quality of Bathing Waters Regulations, 1992	Bathing
United States	2012 Recreational Water Quality criteria	Recreation
	State of Ohio Water Quality Standards	
	Lake Tahoe Basin Water Quality Plan	
	State of Michigan Water Quality Standards	
	Florida's surface water quality standards	
Various	WHO Recreational Water Quality Guidelines	Recreation

Table 1. List of selected water quality standards reviewed and compared.

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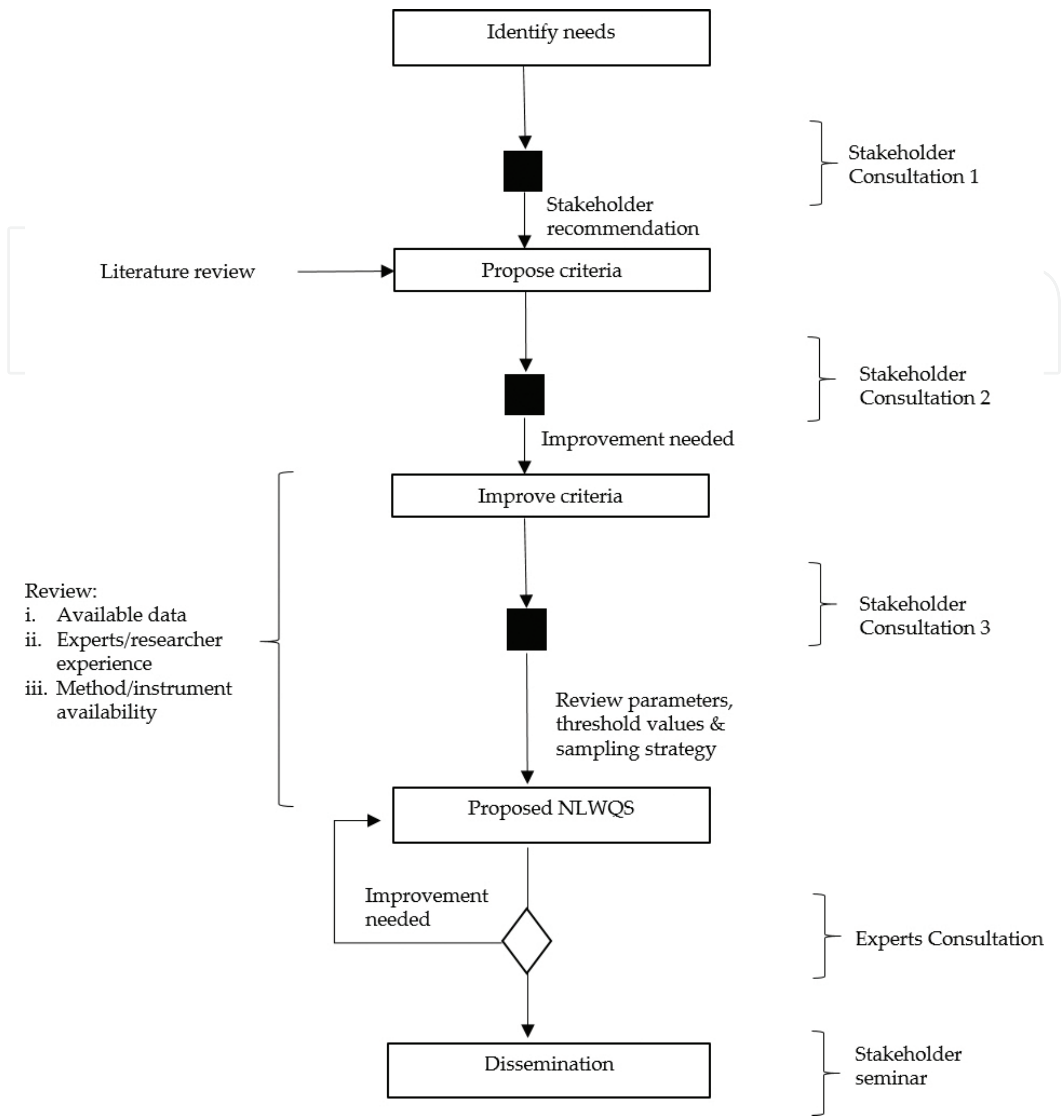

Figure 1. The development process of the NLWQCS.

3. Results and discussion

3.1. Comparison of different water quality criteria and standards

In general, most of the standards were developed to protect the use of water for human health purposes, such as drinking, bathing, and other resource efficiency such as industry, livestock dewatering and aquaculture [4]. The protection of aquatic health has been emphasized in the United States, Brazil, Australia and Japan. The criteria and number of parameters differ between the guidelines and standards. As drinking water standards are already established in Malaysia, emphasis in this work is placed on other human health applications, namely recreational, as well as aquatic life health. The commonly used criterion proposed by USEPA to measure human health is based on carcinogenicity and toxicity [10]. All recreational water quality criteria focus on microbiological parameters affecting human health. Microbial hazards are considered to be the primary concern by the WHO as they have the largest impact on health in terms of waterborne disease, especially when compared to chemical hazards which are usually associated with long-term exposure [16]. The Canadian recreational guidelines emphasize *Escherichia coli*, enterococci and cyanobacteria as indicators for microbial parameters [17]. In contrast, the South African guidelines identify nine microbiological parameters of concern related to recreational waters, namely algae measured by chlorophyll-*a* and blue-green algae counts, faecal coliforms, enterococci, *E. coli*, enteric viruses, coliphage and schistosoma/bilharzia [18]. Enterococci and *E. coli* are the only parameters monitored in the European Union bathing water directive, while microbiological parameters differ among states in the United States, with *E. coli* and faecal coliform mostly prescribed for monitoring. *E. coli* is the preferred indicator of faecal pollution for fresh recreational waters due to its strong correlation with the risk of gastrointestinal illness and the availability of a standardized method of detecting the organism within 24–48 h [17, 19]. *E. coli* is also a good indicator of human faeces, contributing 97% of the coliform organisms and recent faecal contamination due to its short survival rate [17]. Biochemical oxygen demand and chemical oxygen demand were not listed in many standards except for those in Japan and Malaysia. The impact on health from cyanobacteria is related to irritative dermal exposure to cyanobacteria genera such as Anabaena, Aphanizomenon, Nodularia and Oscillatoria, or the ingestion of cyanotoxin [16].

Within many standards and guidelines for recreational water, pH, clarity and colour are the most frequently prescribed physical and aesthetic parameters monitored (**Table 2**). Additionally, temperature and turbidity are important physicochemical and aesthetic parameters in Canadian Guidelines, while odour and floating objects are of concern within Australian and South African recreational guidelines, respectively. Turbidity is frequently used as a substitute for total suspended solids (TSS) and clarity, with numerical values specified in some standards or guidelines, such as in Australia and Malaysia.

Of common concern in terms of the chemical parameters for recreational water were total nitrogen (TN) and total phosphorus (TP), due to their ability to cause nuisance algal growth. Japan's regulations specified TN and TP of 0.2 mg/l and 0.01 mg/l, respectively for bathing purposes, while Lake Tahoe specifies TN and TP of 0.15 mg/l and 0.008 mg/l, respectively [8]. In Malaysia, the PLWQS and NWQS only list TP. In the United States, ammonia is also monitored in the various states' standards such as Ohio, Michigan and New York. In these US states, the narrative standard states that the water should be free of ammonia, or should contain amounts that cannot cause nuisance growths of aquatic weeds and algae. However, national recommendations on nutrient criteria were developed by USEPA and consider the region and waterbody approach by dividing the country into 14 nutrient ecoregions and four water body types, including lakes, reservoirs and wetlands [20]. Ranges of reference values were adopted in Australia to provide guidelines for managers to characterize ambient conditions [21]. In many regulations and guidelines, specific site studies are recommended to determine the appropriate concentrations for preserving the individual lakes [6, 9].

The number of chemicals criteria (specifically toxicants and pesticides) has increased greatly over the years [3]. More than 100 pesticide parameters have been specified in Australian guidelines [6]. The most typical pesticides mentioned due to health-related concerns are Aldrin, DDT, chlordane, lindane, endosulfan, malathion, paraquat and parathion.

	Units	**Australia[1a]**	**Australia[1b]**	**Brazil[2]**	**Canada[3]**	**EU[4]**	**Japan[5]**	**Malaysia**			**South Africa**			**United States**				**UK**
								6	7	8	9	10	11	12	13	14	15	16
Temperature	°C	15–35			NR			±2		±2						NR		
Transparency	m	>1.6		NR	>1.2					0.6	>1					16		
Odour	–	NR		NR				NOO		NOO		1 ton			NR	NR	NR	
Taste	–			NR						NOT						NR		
floatables	–			NR						Nil	NR				NR	NR		NR
pH	–	5–9	6–8	6–9	5–9		6.5–8.5	6–9	6.5–9	6.5–9		6–9				6.5–8.5	6–8.5	
Colour	TCU	NR		<75	NR			150	15	150		NR			NR	NR		
Turbidity	NTU		2–200	<100	50			50	5	50		1				NR	≤29	
Hardness		500						250	500	250								
Oil & grease	mg/L	NR		NR												NR	≤5	
TSS	mg/L						≤5	50		50			<100		NR	NR		
DO	mg/L	>6.5		>6, >5			≥7.5	5–7		5–7								
TP	mg/L		0.01	0.025			≤0.01	0.2		0.05						0.01		
TN	mg/L		0.35	10			≤0.2						NR		NR	0.114		
BOD	mg/L			3–5				3		3			NR		NR			
COD	mg/L						≤3	25		25							NR	
Chlorophyll-a	µg/l			3						0.7	<15					0.9		
E. coli	Counts/100ml	35 (230)			≤70				0		≤130			*126 (410)*	126 (235)			900
Enterococci					≤400									*35 (130)*				330
Faecal coliform	Counts/100 ml	150 (1000)		1000				400	0	100	≤130				5000	200 (800)		
Total coliform	Counts/100 ml			5000			1000	5000	0	5000								
Enteric virus										0								
Cyanobacteria		>15,000			≤100,000													NR
Microcystin					≤20													
BGA											>6							
Clostridium perfringens									0	0								
Cadmium	mg/L	0.005		0.001		≤0.45	≤0.01	0.01	0.003	0.002			0.					

	Units	Australia[1a]	Australia[1b]	Brazil[2]	Canada[3]	EU[4]	Japan[5]	Malaysia			South Africa			United States				UK
								6	7	8	9	10	11	12	13	14	15	16
Lead	mg/L	0.05					≤0.01	0.05	0.01	0.05								
Arsenic	mg/L	0.05		0.05			≤0.01	0.05	0.01	0.05			0.01		0.01	≤0.05	0.05	
Mercury	mg/L	0.001		0.0002		≤0.07	≤0.0005	0.001	0.001	0.0001					#	#	0.012	
Chromium (IV)	mg/L	0.05		0.02			≤0.05	0.05	0.05	0.05					#	#		
Copper	mg/l	1						0.02	1	0.02					#	#		

Note: NR, narrative criteria or standard; #, a function of hardness; NOO, no obvious odour; NOT, no obvious taste.
[1] Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000, (a) recreation, (b) aquatic ecosystems.
[2] CONAMA Resolution 274, 2000.
[3] Canada, Recreation water quality 2012.
[4] EU Bathing Water Directive 2006.
[5] Basic environmental law; environmental quality standards regarding water pollution.
[6] National Water Quality Standards.
[7] National Drinking Water Quality Standards.
[8] Putrajaya Lake Water Quality Standards.
[9] South African Water Quality Guidelines: recreational uses.
[10] South African Water Quality Guidelines: domestic uses.
[11] South African Water Quality Guidelines: aquatic ecosystem.
[12] Quality criteria for water 1986/2012.
[13] State of Ohio Water Quality Standards.
[14] State of New York Nutrient standard plan.
[15] Florida's surface water quality standards.
[16] The bathing water regulations 2013.

Table 2. Comparison of selected parameters in different water quality standards and guidelines.

Water quality criteria for aquatic health are mostly chemical criteria that require knowledge of aquatic toxicity and environmental fate data. Most of aquatic ecosystems criteria are derived from toxicity data from multiple receptors in order to determine the ranges of tolerance for different organisms, including targeted protective species in relation to pollutants [3]. The commonly used criterion proposed by USEPA to measure the aquatic ecosystem health is usually the chronic effect value and the acute effect value. The minimum amount of data required for deriving water quality criteria for protecting freshwater aquatic environments varies between countries, as critically reviewed by Sha et al. [3]. In the United States and Europe, concentration approach is used with numeric criteria developed for cold water and warm water fish. In Australia, ecological health criterion is used compared to the contaminant limits approach adopted in the United States and Europe. Four biological criteria or indicators, namely species richness, species composition, primary production and ecosystem function, were recommended for assessing the ecosystem health [21]. When compared to developed countries where water quality criteria are well established for biota such as fish, specific information regarding the effects of pollutants that affect biota are very limited in tropical countries such as Malaysia. A recent work by Shuhaimi et al. has identified the acute test value for four heavy metals, namely iron, lead, nickel and zinc, on local biota [22].

Dissolved oxygen (DO), pH and turbidity levels are also important for aquatic life. Fish and other aquatic organisms could not survive if DO levels were less than 4 mg/l, and pH levels lower than 4 or above 11. For protecting specific wildlife such as salmonids, turbidity is specified in many standards in the United States and Alaska [23]. Various effects of turbidity and suspended solid concentrations include reduced growth, abundance, survival and feeding, fatality, altered behaviour and displacement [23]. The recommended criteria for turbidity vary as follows: <50 NTU for Canada and Malaysia, <100 NTU for Brazil and 2–200 NTU for tropical Australia. In the United States, numerical turbidity standards for protecting fish and aquatic habitats lie within 5–25 units above natural levels [23].

There are numerous criteria or limits for heavy metals due to their impact on both human and aquatic health. Almost all standards require criteria for lead, arsenic, mercury, cadmium and chromium. In the United States, criteria for most metals such as lead, cadmium, chromium and copper are based on natural logarithms of total hardness [24, 25] and are targeted for protecting human health. In Australia, numeric guideline values for maximum concentration are prescribed for about 17 parameters relating to heavy metals, while in South Africa a total of 12 parameters are listed [6, 26]. References on the lake conditions were made based on published literature [27–30].

3.2. Multi-stakeholder consultation on criteria and standards

A total of 32 local and four international experts were involved in the first stakeholder consultation. The findings from the first consultative process identified the need for the standards to be based on real data. They also stressed the need to consider the timing of data collection, the weather and the lake characteristics. Water quality parameter will differ with depth, and if sample is taken during daytime or night-time and during dry and wet weather conditions. The findings in the second consultative process further refined the classification of the proposed NLWQCS and the threshold limits of parameters that may affect water quality. The need to engage with various stakeholders in the state jurisdiction was also highlighted. The state authority and/or state water authority can decide whether water standard is to be used throughout the state for managing or controlling activities within lakes within the state. The application of water quality criteria in Malaysia can be regulatory, depending on regulation and law, or voluntarily such as to support in maintaining water quality for respective uses.

The findings of the third consultative process include further refinement of the threshold values based on various monitoring experiences by the respective stakeholders. In the consultation process, stakeholders were divided into four groups to discuss the individual classification. Discussions were focused on the parameters that need to be identified as criteria determining the class. Other toxicants criteria were also reviewed by the groups. The main parameters of concern in determining of threshold limits includes chlorophyll-*a*, turbidity, suspended solids, transparency, salinity, conductivity, total nitrogen, total phosphorus, coliform and *E. coli*. A separate group was formed to discuss the minimum sampling strategy to support the criteria and standard. This includes the minimum number of samples required and the compliance level of the criteria. The final engagement with experts on the criteria suggested to change the classification into category as the four classifications were not based on ranking of parameters. Refinement was also made in setting the parameters, such as BOD, which is defined as BOD_5 or BOD 5-day test consistent with other standards in Malaysia.

3.3. Proposed lake water quality criteria and standards

3.3.1. Classification and monitoring parameters

The development of the NLWQCS aims at providing a tool stakeholders and lake owners can use manage a lake or reservoir. NLWQCS applies to all lakes, reservoirs, ponds and wetlands. The proposed standard is divided into four categories, which were suggested as targets for the respective lakes to achieve [31] based on designated uses proposed by the respective authorities. Categories A and B were criteria to be applied for lakes used for recreational environment: Category A for primary body contact such as bathing, diving, skiing and wind-surfing activities, and Category B for secondary body contact such as boating, cruising and angling. Category A is the more stringent of the two and included criteria for parameters related to waterborne disease. The contaminant limits for certain parameters in Category A is more stringent than the raw water for drinking standard. Categories C and D were criteria to be applied for lakes that are productive and meant for fisheries and other economic activities: Category C for protection of aquatic health, and Category D for other limited uses. Category D is allowed to be more turbid, have higher concentrations of TSS and nutrients, and have lower transparency.

The main parameters identified for the different classes are categorized as (i) physical parameters; (ii) nutrients; (iii) biochemical and microbial constituents and (iv) other toxicants. Only approximately 23 physical-chemical parameters were identified to determine the categories. Factors considered in parameter selection include simplicity of measurement, availability of measuring devices and the reasonable cost of sampling and analysis [31]. Aesthetic parameters such as colour, odour, taste, floating objects, transparency, turbidity and suspended solids are emphasized in all categories for lake management. These parameters reflect aesthetic values of the lake and most can be measured easily. Normal temperature was set at 28 ± 3°C [31]. Nutrient parameters relate to ammonia nitrogen, nitrate-nitrogen and TP. Hardness, which influences heavy metals, is deliberated to be around 50 mg/l.

The proposed criteria for lake water quality are given in **Table 3**. The criteria in this work are based on established criterion found in the literature assuming similar health and aquatic life effects will be experienced when levels of water quality parameters exceeding the criteria. In terms of aesthetic parameters, floating objects, colour and odour are rarely reported on in the literature. Suitability for swimming has been associated with the clarity or the depth of light penetration into water. The clarity of Malaysian lakes mentioned in the literature range between 0.3 m and 5.7 m [2, 27]. This parameter is associated with the colour of the water, levels of turbidity, algae and suspended solids. Guidelines for water clarity or Secchi depth were set at 1.2 m and 1 m in Canada and South Africa, respectively as being the minimum visibility level for water to be suitable for swimming [17, 18]. In Australia and New Zealand,

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the visual clarity level based on Secchi depth required to ensure swimmer safety in wadeable areas was recommended as 1.6 m [6]. A survey of perception for bathing in New Zealand found a Secchi depth of 1.5 m as the aesthetic consideration [32]. Currently, no survey has been carried out to measure perception for bathing in Malaysia. In the NLWQS, a lower threshold limit of 0.6 m was set following experience in Putrajaya. TSS in most lakes were generally found to be less than 20 mg/l, except in Sembrong and Aman Lakes which are known to experience algal bloom that can reach about 50 mg/l. DO concentrations in Malaysian lakes are highly variable and depend on the timing of the sampling. DO <5 mg/l is common for lakes located in peat swamp areas. In terms of nutrient parameters, TP was set to below <0.01 mg/l for primary contact and <0.05 mg/l for the other classes [31]. Nutrient values (specifically TP) were very high in many lakes and needed to be controlled to decrease eutrophication problems. Monitoring is necessary to ensure informed decision making regarding effective management measures to control nutrient inputs. These values are consistent with the limits set in Japanese regulations and at Lake Tahoe for bathing purposes, and are much more stringent than the PLWQS which specified higher TP value (0.05 mg/l) for its ambient recreational standard.

Parameter	Unit	Category A	Category B	Category C	Category D
Physico-chemical					
Temperature	°C	Normal ±3	Normal ±3	Normal ±3	Normal ±3
pH	**-**	**6.5–8.5**	**6.5–8.5**	**6.0–9.0[a]**	**5.5–9.0[k]**
Dissolved oxygen saturation	**%**	**80–100**	**70–110**	**55–130**	**40–130**
Dissolved oxygen	**mg/L**	**6.3–7.8**	**5.5 – 8.7**	**4.5 – 10.3**	**3.3 – 10.3**
Conductivity	**µS/cm**	**1000[ai]**	**1000[ai]**	**2000**	**5000**
Floatables	**-**	**NV[i]**	**NV[i]**	**NV[i]**	**NV[i]**
Odour	**-***	**NOO[i]**	**NOO[i]**	**NOO[i]**	**NOO[i]**
Taste	**-****	**NOT[i]**	**NOT**	**NOT**	**NOT**
Colour	**TCU**	**100–200**	**150–300**	**300**	**300**
Total suspended solid	**mg/L**	**100**	**100–500**	**200**	**500**
Turbidity	**NTU**	**40**	**40–170**	**70**	**250**
Transparency (Secchi depth)	**m**	**0.6[i]**	**0.6[i]**	**0.3**	**0.3**
Oil & Grease	**mg/L**	**1.5[i]**	**1.5[i]**	**1.5[i]**	**1.5[i]**
Salinity	**psu**	**nvd**	**nvd**	**<1[a]**	**>1**
Hydrogen carbonate	mg/L	<200	<200	**[a]	**[a]
Total dissolved solids	mg/L	1,000[>k]	1,000[>k]	1,000[>k]	1,000[>k]
Nutrient					
Ammoniacal Nitrogen	**mg/L**	**0.1[a]**	**0.3[i]**	**1**	**2.7[a]**
Nitrite-N	mg/L	0.04[i]	0.4[a]	0.4[a]	0.4[a]
Nitrate-N	**mg/L**	**7[a]**	**7[a]**	**10**	**10**
Total nitrogen (TN)	mg/L	0.35[f]	0.35[f]	0.35	0.35
Total phosphorus (TP)	**mg/L**	**0.01[b]**	**0.035[b]**	**0.035[b]**	**0.05[b]**
Biochemical and microbiological/water-borne disease					
Biochemical Oxygen Demand (BOD)	**mg/L**	**3**	6[a]	6	8

Parameter	Unit	Category A	Category B	Category C	Category D
Chemical Oxygen Demand (COD)	**mg/L**	**10[a]**	25[a]	25	50
Chlorophyll-a	**µg/L**	**10**	**3 – 15**	**15**	**25**
Cyanobacteria	**Cells/ml**	**15000[cf]**	15000[cf]	15000[cf]	15000[cf]
Faecal Coliform	MPN/ 100ml	150[fg]	<1000[g]	5000 (20000)[*a]	5000 (20000)[*a]
Total Coliform	**Counts/ 100ml**	**5000[a]**	5000[a]	50000[a]	50000[a]
E.coli	**cfu/100ml**	**100[d]**	1200[g]	3000[h]	3000[h]
Enterococci	**MPN/ 100ml**	**33[d]**	230[c]	nvd	nvd
***Clostridium perfringens* (including spores)**	**-**	**nd[i]**	nd[i]	nvd	nvd
***Cryptosporodium* sp.**	**-**	**nd[i]**	nd[i]	nvd	nvd
***Giardia* sp.**	**-**	**nd[i]**	nd[i]	nvd	nvd
***Leptospira* sp.**	**-**	**nd[e]**	Nd[e]	nvd	nvd
Enteroviruses	PFU/L	nvd	nvd	nvd	nvd
Microcystin–LR	µg/L	0	0	0	0
Heavy metals					
Arsenic	**mg/L**	**0.05[ai]**	**0.1[a]**	**0.15[d]**	**0.4[a]**
Aluminium	mg/L	0.1[ji]	0.1[ji]	0.05[i]	0.05[i]
Antimony	mg/L	0.03[i]	0.03[i]	0.03[i]	0.03[i]
Argentum	mg/L	0.05[k]	0.05[>k]	0.05[>k]	0.05[>k]
Barium	mg/L	0.1[g]	0.1	1[ai]	1[ai]
Beryllium	mg/L	0.004[i]	0.004[i]	0.004[i]	0.004[i]
Boron	mg/L	1[ai]	1[ai]	1[ai]	1[ai]
Calcium ion	mg/L	200	200	**[a]	**[a]
Cadmium	**mg/L**	**0.002[i]**	**0.01[a]**	**0.25[d]**	**0.25[d]**
Chloride	mg/L	250[j]	250	250	250
Chromium	mg/L	0.05[ac]	0.025[ac]	0.05[ac]	0.05[ac]
Cobalt	mg/L	0.05[c]	0.05[c]	0.05[c]	0.05[c]
Combined Chlorine	mg/L	>1.0	>1.0	>1.0	>1.0
Copper	mg/L	0.02[ai]	0.02[>ai]	0.02[>ai]	0.02[>ai]
Fluoride	mg/L	1	1	1.5[f]	1.5[f]
Iron	mg/L	1[ai]	1	1	1
Lead	**mg/L**	**0.05[a]**	**0.05[a]**	**0.0025[d]**	**0.05[a]**
Magnesium	mg/L	150[k]	150	150	150
Manganese	mg/L	0.1[ai]	0.1	0.1	0.1
Mercury	**mg/L**	**0.001[a]**	**0.002[a]**	**0.00077[d]**	**0.002[a]**
Nickel	**mg/L**	**0.05[a]**	**0.05[a]**	**0.052[d]**	**0.05[a]**
Potassium ion	mg/L	200	200	200	200
Silver	mg/L	0.05[ai]	0.05	0.05	0.05
Sodium	mg/L	200[k]	200[k]	200[k]	200[k]
Sulphur	mg/L	0.05[ai]	0.05	0.05	0.05
Zinc	mg/L	3[k]	3[k]	5[ai]	5[ai]
Organics or pesticides					
1,2-dichloroethane	µg/L	30[k]	30[k]	30	30
2,4-D	µg/L	30[k]	30[k]	70[ai]	70[ai]

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Parameter	Unit	Category A	Category B	Category C	Category D
2,4-DB	μg/L	90[k]	90[k]	90	90
2,4-dichlorophenol	μg/L	90[k]	90[k]	90	90
2,4,5-T	μg/L	9[k]	9[k]	10[ai]	10[ai]
2,4,5-TP	μg/L	4[ai]	4[ai]	4[ai]	4[ai]
2,4,6-trichlorophenol	μg/L	200[k]	200	200	200
Acrylamide	μg/L	0.1[g]	0.1[>g]	0.1[>g]	0.1[>g]
Alachlor	μg/L	20[k]	20[>k]	20[>k]	20[>k]
Aldicarb	μg/L	10[k]	10[>k]	10[>k]	10[>k]
Aldrin / Dieldrin	μg/L	0.02[i]	0.02[>i]	0.02[i]	0.02[i]
Anionic Detergent MBAS	μg/L	1000[k]	1000[>k]	1000[>k]	1000[>k]
Atrazine	μg/L	nvd	nvd	nvd	nvd
BHC	μg/L	2[ai]	2[ai]	2[ai]	2[ai]
Benzene	μg/L	10[f]	10[f]	10[f]	10[f]
Benzo(a)pyrene	μg/L	0.01[c]	0.01[c]	0.01[c]	0.01[c]
Bromate	μg/L	10[>g]	10[>g]	10[>g]	10[>g]
Bromodichloro methane	μg/L	60[>k]	60[>k]	60[>k]	60[>k]
Bromoform	μg/L	100[>k]	100[>k]	100[>k]	100[>k]
Carbofuran	μg/L	7[>k]	7[>k]	7[>k]	7[>k]
Carbon Chloroform Extract	μg/l	500[ai]	500[ai]	500[ai]	500[ai]
Chlordane	μg/L	0.08[ai]	0.08[ai]	0.08[ai]	0.08[ai]
Chloroform	mg/L	0.2[>k]	0.2	0.2	0.2
Cyanide	mg/L	0.05[g]	0.05[g]	0.05[g]	0.05[g]
DDT	μg/L	2[>k]	2	2	2
Dibromoaceto nitrile	μg/L	100[>k]	100[>k]	100[>k]	100[>k]
Dibromochloro methane	μg/L	100[>k]	100[>k]	100[>k]	100[>k]
Dichloroacetic acid	μg/L	50[>k]	50[>k]	50[>k]	50[>k]
Dichloroaceto nitrile	μg/L	90[>k]	90[>k]	90[>k]	90[>k]
Endosulfan	μg/L	10[ai]	10[ai]	10[ai]	10[ai]
Epichlorohydrin	μg/L	4[f]	4[f]	4[f]	4[f]
Free Residual Chlorine	mg/L	1.5[i]	1.5[i]	1.5[i]	1.5[i]
Glyphosate	μg/L	200[k]	200[k]	200[k]	200[k]
Heptachlor	μg/L	0.05[ai]	0.05[ai]	0.05[ai]	0.05[ai]
Hexachloro benzene	μg/L	1[>k]	1[>k]	1[>k]	1[>k]
Lindane	μg/L	2[ij]	2[ij]	2[ij]	2[ij]
MBAS/BAS (Methylene Blue)	μg/L	200[f]	200[f]	200[f]	200[f]
MCPA	μg/L	2[>k]	2[>k]	2[>k]	2[>k]
Methoxychlor	μg/L	20[>k]	20[>k]	20[>k]	20[>k]
Mineral Oil	μg/L	300[>k]	300[>k]	300[>k]	300[>k]
Oil & Grease (Emulsified Edible)	mg/L	7:N[i]	7:N[i]	7:N[i]	7:N[i]
Oil & Grease (Mineral)	mg/L	0.04:N[i]	0.04:N[i]	0.04:N[i]	0.04:N[i]
Paraquat	μg/L	10[ai]	10[ai]	10[ai]	10[ai]
Parathion	μg/L	30[k]	30[k]	30[k]	30[k]
PCB	μg/L	0.1[ai]	0.1[ai]	0.0001	0.0001

Parameter	Unit	Category A	Category B	Category C	Category D
Pendimethalin	µg/L	20[>k]	20[>k]	20[>k]	20[>k]
Pentachlorophenol	µg/L	9[>k]	9[>k]	9[>k]	9[>k]
Permethrin	µg/L	20[>k]	20[>k]	20[>k]	20[>k]
Pesticides	µg/L	nvd	nvd	nvd	nvd
Phenol	µg/L	5[g]	5[g]	5[g]	5[g]
Polycyclic Aromatic Hydrocarbons	µg/L	nvd	nvd	nvd	nvd
Propanil	µg/L	20[>k]	20	20	20
Selenium	mg/L	0.01[fj]	0.01[f]	0.01[f]	0.01[f]
Simazine	µg/L	20[k]	20[k]	20[k]	20[k]
Sulphate	mg/L	250[j]	250[>j]	250[>j]	250[>j]
t-DDT	µg/L	0.1[ai]	0.1[ai]	0.1[ai]	0.1[ai]
Tetrachloroethene and Trichloroethene	µg/L	10[gj]	10[gj]	10[gj]	10[gj]
Total indicative dose	µg/L	nvd	nvd	nvd	nvd
Total organic carbon (TOC)	µg/L	nvd	nvd	nvd	nvd
Toxicants (heavy metal, organics)	µg/L	#	#	#	#
Trichloroacetic acid	µg/L	100[>k]	100[>k]	100[>k]	100[>k]
Trichloroaceto nitrile	µg/L	1[>k]	1[>k]	1[>k]	1[>k]
Trihalomethanes–Total	µg/L	1000[>k]	1000[>k]	1000[>k]	1000[>k]
Tritium	µg/L	nvd	nvd	nvd	nvd
Vinyl chloride	µg/L	5[>k]	5[>k]	5[>k]	5[>k]
Radiological parameters					
Gross-alpha	Bq/L	0.1[ai]	0.1[ai]	0.1[ai]	0.1[ai]
Gross-Beta	Bq/L	1[ai]	1[ai]	1[ai]	1[ai]
Radium-226	Bq/L	<0.1[ai]	<0.1[ai]	<0.1[ai]	<0.1[ai]
Strontium-90	Bq/L	<1[ai]	<1[ai]	<1[ai]	<1[ai]

Notes: Item in light grey—should be measured for categorization.
NV, not visible; NOO, no obvious odour; NOT, no obvious taste; nd, not detected; nvd, no value determined.
[a]DOE [12].
[b]Health Canada [17].
[c]ANZECC [6].
[d] USEPA [24, 25].
[e] WHO [16].
[f] Ministry of Health, unpublished report.
[g] EPA Ireland [40].
[h] Conversion using USEPA ratio (126 *E. coli* = 200 faecal).
[i] Perbadanan Putrajaya [13].
[j] CONAMA [5].
[k] NDWQS.
[*] maximum not to be exceeded.
[#] parameter not fully established.

Table 3. National Lake Water Quality Criteria and [C2]Standards 2015 [30].

Biochemical and microbiological parameters suggested in the standard include BOD, COD, total and faecal coliforms, *E. coli*, enterococci, cyanobacteria and three pathogens, namely *Cryptosporidium* sp., *Leptospira* and *Giardia* sp. [31]. Few researchers have debated the suitability of faecal indicator bacteria such as faecal coliform, enterococci and *E. coli* in tropical freshwater bodies [33, 34]. These studies show that the indicator bacteria can multiply to establish itself in the soil of tropical countries, and are thus inadequate to suggest an indicator of pollution from human and animal faeces [32, 33]. In another study, *Clostridium perfringens* has been suggested as a better indicator for recreational water quality standards in tropical countries due to its inability to multiply in the soil [35]. Despite this variability, enterococci and *E. coli* remain widely used as indicators of faecal coliforms [36]. In order to apply these standards to Malaysian lakes, *E. coli*, enterococci and *Clostridium perfringens* were identified as indicators. Additionally, pathogens such as *Cryptosporidium* sp., *Leptospira* and *Giardia* sp. were included as they can lead to potentially severe disease outbreaks in Malaysia, such as diarrhoea. Waterborne disease associated with *Cryptosporidium parvum* and *Giardia duodenalis* has emerged as an important public health concern in developed and developing countries [37]. The presence of *Giardia* sp., *Cryptosporidium* sp. and *leptospira* sp. have been reported in some of the urban lakes suggesting the use of this water body for recreational purpose is a major health concern [38, 39] and requiring monitoring and enforcement of source of pollutants.

Stakeholders recommended monitoring of five heavy metals in lakes, namely arsenic, cadmium, lead, mercury and nickel, due to their toxicity in human health. Some of these chemicals were frequently detected in many rivers throughout Malaysia [12]. Arsenic was classified as very toxic and widely associated with industrial pollution from the mining industry, dye manufacturers, the glass and ceramics industry, fertilizers and pesticides [40]. High arsenic levels were reported in post-mining lakes such as Blue Lake, due to its use in the gold mining process. This has led to the barring of the lake for any human activities [41, 42]. Both cadmium and lead are potentially hazardous to most forms of life and are considered to be toxic to aquatic organisms. The main environmental sources of cadmium are discharges from mining, metal smelters and agricultural uses of sludge, pesticides and fertilizers. For lead, the main sources are anthropogenic activities such as runoff associated with lead emissions from gasoline-powered motor vehicles, and industrial and municipal wastewater discharges [26, 40]. Mercury is of major concern in the natural aquatic environment due to its extreme toxicity to aquatic organisms, high concentrations of which in water bodies are associated with industrial pollution. Information on many toxicants, in particular pesticides in Malaysian lake water quality were not found in the literature. The threshold limit for many toxicants provided here presents as a starting point for monitoring of the pollutants. Future studies on threshold levels of toxicants in lakes are needed to confirm and validate the criteria.

3.3.2. Role of standards and limitation

The proposed standards were based on expert judgement and the best available information found in the literature. Part of the role of the NLWQCS is to provide the directional targets for research and management programmes. The standards can be used to guide rehabilitation measures and conservation efforts as well as to develop management measures to address eutrophication issues. The standards are proposed to be non-binding and to be gradually improved as more information and data are gathered by the stakeholders. As water quality monitoring in lakes in still in infancy, this NLWQCS does not provide a plan for enforcement to enable protection of the uses nor become an established regulatory criterion with legal ramification. However, the criteria can also be used by the respective agencies and stakeholders to assist in monitoring and to classify various lakes under their regulatory or management controls for their fitness for different uses.

In the proposed document, the sampling strategy was not described in detail. Water quality in lakes is known to differ temporally and spatially, both horizontally and vertically depending on lake depth. Seasonal and daily variations associated with irradiance, along with dissimilarity in surface waters' mixing related to weather patterns can induce variations in temperature, DO and the transportation of nutrients or pollutants. Thermal and chemical stratification are common features of deeper lakes which affect the water quality being monitored. Variations in water quality are also dependent on the composition of discharges over both short and extended periods. Discharges from housing, commercial buildings and industry can vary within a day, a week or a season. Domestic discharges depend on the homes' occupancy, which is usually higher during the early morning, at midday and in the early evening, while industrial discharges depend on operation hours. Higher home discharges and lower industrial discharges could happen during weekends and festive seasons. Exceedances of bacterial indicator to health risk were also temporally sporadic and geographically limited with the reduction of pollutant loading not necessarily reducing the health risk [43]. Narrative criteria were proposed in NLWQCS namely to consider the size and shape of the lake when choosing a sampling location, so that the site selection is representative of the whole lake. The choice of site for routine water monitoring sampling can make a significant difference to the classification of microbial water quality [44], owing to the hydrodynamics and proximity of pollutant sources.

With respect to the criteria for protecting aquatic life in the NLWQCS, many limitations exist due to unavailability of extensive data. The criteria in this are mostly based on chronic and acute effect values in temperate countries which have different species. Most of the water quality criteria were also based on a single pollutant model which mostly targeted single species instead of community response [3]. Some of the criteria for aquatic life protection adopted the same value for the human health protection criterion assuming that the effects to all types of aquatic life, all stages of their life cycle and the whole aquatic community are similar. Further research is much needed on deriving the chronic and acute effects of many pollutants on freshwater local species in order to establish more accurate criteria for protecting the Malaysian aquatic environment.

In these criteria, the sampling methodology aims at testing the ambient condition of the lakes via a minimum of three sets of samples, to be monitored at least twice a year, once in the dry and once in the wet season. The proposed depth is surface measurement, in accordance with standard methods [45]. However, adult chest depth at ~1.2–1.5 m is the most common sampling depth recommended in the United States and Canadian recreational guidelines, due to strong evidence in the form of the mathematical relationship between indicator organism density and swimmer illness. Intensifying the number of samples and frequency of monitoring may provide a better representation of the lake's overall water quality and trends. A minimum frequency of once per week during the swimming season was recommended by Canadian guidelines [17] and monthly by the UK and a few US states [9, 46, 47], in order to make more informed decisions regarding lake suitability for recreation. As bathing or swimming activities in lakes is not widely practiced in Malaysia, nor is there a specific swimming season, monitoring measures will depend on the authority's management budgets.

In order to determine the extent of violation or compliance levels, this standard proposes the 90th percentile of sampling results to be considered as acceptable for determining any class. Few guidelines or standards such as in the United States propose the use of dual limits, with the first being a maximum limit for the geometric mean concentration over an interval, and the second being a single-sample maximum or threshold limit set to better evaluate the water quality in both the short- and long-term. The short-term limit is usually set over a 30-day interval and aims at addressing immediate water quality issues, while the long-term limit is set over the duration of the swimming season and aims to address chronic contamination problems. Other standards such as that of the UK advocate the use of percentage compliance levels, mostly of 95% or 90% [46] and some others such as Japan use annual averages [48]. The 90th percentile was taken into account following stakeholder consensus, the values of which consider top end variability in the distribution of water quality and also in order to curb influence of possible small sample sizes. The water quality classification of risk or status was not described in the NLWQCS due to unavailability of reference data.

Financial issues relating to water testing were collectively identified by the stakeholders as major challenges for NLWQCS implementation. Water quality monitoring was usually performed based on the parameters to estimate the water quality and Carlson's trophic state index [49] due to limited funds. Pathogenic parameters such as *Leptospira* and *Giardia* sp. are rarely monitored. Measurements were usually undertaken by the relevant departments when there were reported cases. In this NLWQCS, focus is placed on the main physicochemical, microbial and selected toxicants in order to promote lake monitoring. The main aim is to monitor and control nutrient, microbial and organic pollutants, and improve aesthetic values of existing lakes. The various lists of pesticides and toxicants is encouraged to be monitored if funding is not limited and if testing methods are available at lower detection limits, such as for trace chemicals. The proposed criteria and standard serve as a reference and a starting point in the proper monitoring of lakes and in working towards sustainable management of the water bodies. Future review has been suggested upon the availability of more data from monitoring efforts, and possibly to expand the standard further from water quality-based management to ecologically based management to protect the whole aquatic system [21]. It is hoped that the criteria will evolve and be adopted as a regulatory monitoring program in the future to enable a better connection to standard compliance and violations.

4. Conclusion

The importance of this work is to develop criteria that can be used for sustainable management of lakes and reservoirs in Malaysia. The lake criteria and standards are proposed to be non-regulatory to promote monitoring efforts by various stakeholders. The development of such a criteria and standard, however, may be limited by time constraints, fund allocations and expert knowledge as well as the variability of environmental data. Future work will look into governing the standard with an appropriate methodology and regulatory framework to ensure an effective national standard for application.

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References

[1] NAHRIM. 2009. Study on the Status of Eutrophication of Lakes in Malaysia. NAHRIM, Seri Kembangan.

[2] Sharip Z, Zaki ATA, Shapai MAH, Suratman S, Shaaban AJ. 2014. Lakes of Malaysia: water quality, eutrophication and management. Lakes Reservoirs: Res. Manage., 19: 130–141.

[3] Yan S, Zhou Q, Gao J. 2012. Methodology for derivation of water quality criteria for protecting aquatic environment and future development. Crit. Rev. Env. Sci. Technol., 42: 2471–2503.

[4] UN-Water. 2015. Compendium of Water Quality Regulatory Frameworks: Which Water for Which Use?

[5] CNE (Council National Environment). 2000. CONAMA resolution 274, Brazil.

[6] ANZECC (Australian and New Zealand Environment and Conservation Council). 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1. The Guidelines. ANZECC and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

[7] Kai-Qin X, Ebie Y, Jimbo Y, Inamori Y, Sudo R. 2009. Measures and Policies against the Eutrophication for Lake Water Quality in Japan. Proceeding of 13th World Lake Conference. Wuhan, China.

[8] CRWQB (California Regional Water Quality Control Board). 1995. Water quality control plan for the Lahontan Region. CRWQB, California.

[9] Ohio EPA. 2014. State of Ohio water quality standards. Ohio Environmental Protection Agency.

[10] Ward R. 2001. Development and use of water quality criteria and standards in the United States. Regional Environ. Change 2: 66–72.

[11] Streeter HW. 1949. Standards of stream sanitation. Sewage Work J. 21.

[12] DOE. 2013. Malaysia Environmental Quality Report 2013. Department of Environment Malaysia, Petaling Jaya.

[13] Perbadanan Putrajaya. 2000. Catchment Development and Management Plan for Putrajaya Lake. Perbadanan Putrajaya, Putrajaya.

[14] MOH (Ministry of Health). 2004. National Standard for Drinking Water Quality. Engineering Services Division, Putrajaya.

[15] MOH (Ministry of Health). 2013. National Water Quality Standards and Guidelines for Monitoring Recreational Water Quality Environment (marine and freshwater). Engineering Services Division, Putrajaya, Unpublished report.

[16] WHO. 2003. Guidelines for safe recreational water environment. WHO, Geneva.

[17] Health Canada. 2012. Guidelines for Canadian Recreational Water Quality, Third Edition. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

[18] DWAF (Department of Water Affairs and Forestry). 1996a. South African Water Quality Guidelines (second edition), Volume 2: Recreational Use.

[19] Kinzelman J, Ng C, Jackson E, Gradus S, Bagley R. 2003. Enterococci as indicators of Lake Michigan recreational water quality: comparison of two methodologies and their impacts on public health regulatory events. Appl. Env. Microbiol., 69: 92–96.

[20] USEPA. 2000. Nutrient Criteria Technical Guidance Manual: Lakes and Reservoirs. Office of Water, US EPA, Washington.

[21] Hart B, Campbell I, Angehrn-Bettinazzi C, Jones M. 1993. Australian water quality guidelines: a new approach for protecting ecosystem health. J. Aquat. Ecosys. Health, 2: 151–163.

[22] Shuhaimi-Othman M, Nur-Amalina YNR, Umirah NS. 2012. Deriving freshwater quality criteria for iron, lead, nickel and zinc for protection of aquatic life in Malaysia. Sci. World J. 861576–861576

[23] Lloyd DS. 1987. Turbidity as a water quality standard for salmonid habitats in Alaska. N. Am. J. Fish. Manage., 7: 34–45.

[24] USEPA. 2012b. 2012 Recreational Water Quality Criteria. Office of Water, US EPA, Washington.

[25] USEPA. 2012a. Federal Water Pollution Control Act. Office of Water, US EPA, Washington.

[26] DWAF. 1996b. South African Water Quality Guidelines, Volume 7: Aquatic Ecosystems.

[27] ASM (Akademi Sains Malaysia). 2010. Managing lakes and their basins for sustainable use in Malaysia (Lake Briefs Report Series I), ASM, Kuala Lumpur.

[28] Furtado JI, Mori S. 1982. The Ecology of a Tropical Freshwater Swamp, the Tasek Bera, Malaysia. Dr W. Junk Publishers, The Hague.

[29] NAHRIM. 2012. Managing lakes and their basins for sustainable use in Malaysia. NAHRIM, Seri Kembangan.

[30] NAHRIM. 2013. Proceedings National Seminar on Research and Management of Lakes and their Basins for Sustainable Use: The Current Status of Selected Lakes in Malaysia. Seri Kembangan.

[31] NAHRIM. 2015. The Development of Lake Water Quality Criteria and Standards for Malaysia. NAHRIM, Seri Kembangan.

[32] Smith DG, Croker GF, McFarlane K. 1995. Human perception of water appearance. N. Z. J. Mar. Freshwater Res., 29: 29–43.

[33] Hazen TC. 1988. Fecal coliforms as indicators in tropical waters: a review. Toxicity Assessment 3: 461–477.

[34] Fujioka R, Sian-Denton C, Borja M, Castro J, Morphew K. 1998. Soil: the environmental source of Escherichia coli and Enterococci in Guam's streams. J. Appl. Microbiol. 85: 1365–2672.

[35] Fujioka R, Roll B, Byappanahalli MN. 1997. Appropriate recreational water quality standards for Hawaii and other tropical regions based on concentrations of *Clostridium perfringens*. Proc. Water Environ. Fed., 4: 405–411.

[36] Boehm AB, Sassoubre LM. 2014. Enterococci as indicators of environmental fecal contamination. In: Enterococci: From Commensals to Leading Causes of Drug Resistant

Infection (Gilmore MS, Clewell DB, Yasuyoshi I, Nathan S, eds.), Massachusetts Eye and Ear Infirmary, Boston.

[37] Carmena D. 2010. Waterborne transmission of Cryptosporidium and Giardia: detection, surveillance and implications for public health. In: Current Research, Technology and Education Topics in Applied Microbiology and Microbial Biotechnology (Mendez-Vilas A, ed.), pp. 1–14.

[38] Benacer D, Woh PY, Zain SNM, Amran F, Thong KL. 2013. Pathogenic and saprophytic leptospira species in water and soils from selected urban sites in peninsular Malaysia. Microbes Environ., 28: 135–140.

[39] Onichandran S, Kumar T, Lim YAL, Sawangjaroen N, Andiappan H, Salibay CC, Chye TT, Ithoi I, Dungca JZ, Sulaiman WYW, Ling LY, Nissapatorn V. 2013. Waterborne parasites and physico-chemical assessment of selected lakes in Malaysia. Parasitol Res., 112: 4185–4191.

[40] EPA Ireland. 2001. Parameters of Water Quality: Interpretation and Standards. Ireland Environmental Protection Agency.

[41] Sari SA, Ujang Z, Ahmad UK. 2006. Geospeciation of arsenic using MINTEQA2 for a post-mining lake. Water Sci. Technol., 54: 289–299.

[42] Harith MN, Hassan R. 2008. Preliminary investigation on vertical distribution of phytoplankton biomass and nutrients in Tasik Biru (Blue Lake), Bau, Sarawak. In: Proceedings of the 3rd Regional Symposium on Environment and Natural Resources "Conservation for a Green Future", pp. 446–454

[43] Soller JA, Eisenberg JNS, DeGeorge JF, Cooper RC, Tchobanoglous G, Olivieri AW. 2006. A public health evaluation of recreational water impairment. J. Water Health, 04.1: 1–19.

[44] Quilliam RS, Clements K, Duce C, Cottrill SB, Malham SK, Jones DL. 2011. Spatial variation of waterborne *Escherichia coli* – implications for routine water quality monitoring. J. Water Health, 09.4: 734–737.

[45] APHA (American Public Health Association). 2012. Standard methods for the examination of water and waste water. APHA, Washington.

[46] DEFRA & EA (Department for Environment, Food & Rural Affairs and Environment Agency). 2013. Water resources: The Bathing Water Regulations 2013 No. 1675, UK.

[47] FDEP (Florida Department of Environmental Protection). 2012. Surface Water Quality Standards. FDEC, Florida.

[48] Ministry of Environment. 1985. Law concerning special measures for the preservation of lake water quality. Law 61, Government of Japan, p. 15.

[49] Carlson RE. 1977. A trophic state index for lakes. Limnol. Oceanogr., 22: 361–369.