

# Assessment of Water Quality in Kemajuan Lake: A Comparative Study with National Lake Water Quality Criteria and Standards (NLWQS)

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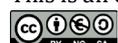
## Abstract

Water is vital for life and supports the agriculture, industry, and recreation sectors. Lentic systems, including lakes, are integral to global hydrological cycles but are sensitive to changes in land use and human activities. The National Lake Water Quality Criteria and Standards (NLWQS) provide a framework for assessing and managing lake water quality to address pollution and maintain Malaysia's ecological balance. This study evaluated the water quality of Kemajuan Lake, UTHM, a Category A lake used for recreation and flood mitigation, based on the NLWQS. The water quality assessment of Kemajuan Lake was carried out weekly over a 10-month period (40 weeks). In-situ measurements recorded the pH, dissolved oxygen (DO), DO saturation, and temperature, while water transparency was assessed using a Secchi disc. Laboratory analysis included biochemical oxygen demand (BOD<sub>5</sub>), chemical oxygen demand (COD), total suspended solids (TSS), ammoniacal nitrogen (AN), nitrate (NO<sub>3</sub><sup>-</sup>), total phosphorus (TP), chlorophyll-a (Chl-a), and heavy metals (As, Cd, Pb, Ni, and Hg). Analysis based on the NLWQS (Category A) revealed that parameters such as pH (6.80±0.83), temperature (27.94±2.03°C), turbidity (20.70±3.19 NTU), TSS (15.45±4.43 mg/L), water transparency (1.28±0.12 m), nitrate (0.36±0.15 mg/L), and selected heavy metals which were As (0.003±0.001 mg/L), Cd (0.00003±0.00001 mg/L), Pb (0.0005±0.0004 mg/L), Ni (0.0001±0.000 mg/L), and Hg (0.0001±0.0001 mg/L) complied with safety standards for body contact. However, DO (4.12±0.54 mg/L), DO % saturation (57.23±5.51%), COD (19.88±5.72 mg/L), BOD<sub>5</sub> (9.43±2.67 mg/L), Chl-a (26.30±12.31 µg/L), TP (0.55±0.36 mg/L), and AN (0.55±0.15 mg/L) exceeded permissible limit, rendering Kemajuan Lake unsuitable for recreational activities due to non-compliance with water quality parameters.

## 1. Introduction

Water is vital for sustaining life and is indispensable for fulfilling various human needs. Its significance permeates various sectors, including agriculture, horticulture, livestock management, fisheries, domestic use, industrial applications, energy generation, and recreational activities [1]. Lentic systems, such as lakes, reservoirs, wetlands,

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and ponds, are essential to global hydrological and biogeochemical cycles [2]. These systems are liable to changes in land use and anthropogenic activities, making them important indicators of environmental change on a global scale [3]. The significance of safeguarding these resources is broadly acknowledged and highlighted by the United Nations in the framework of Sustainable Development Goals (SDGs), highlighting the need for their preservation and sustainable management [4]. The growing population, rapid urbanisation, and industrialisation have significantly increased pollutant discharge into aquatic ecosystems, disrupting ecological balance and posing serious risks to human health [5].

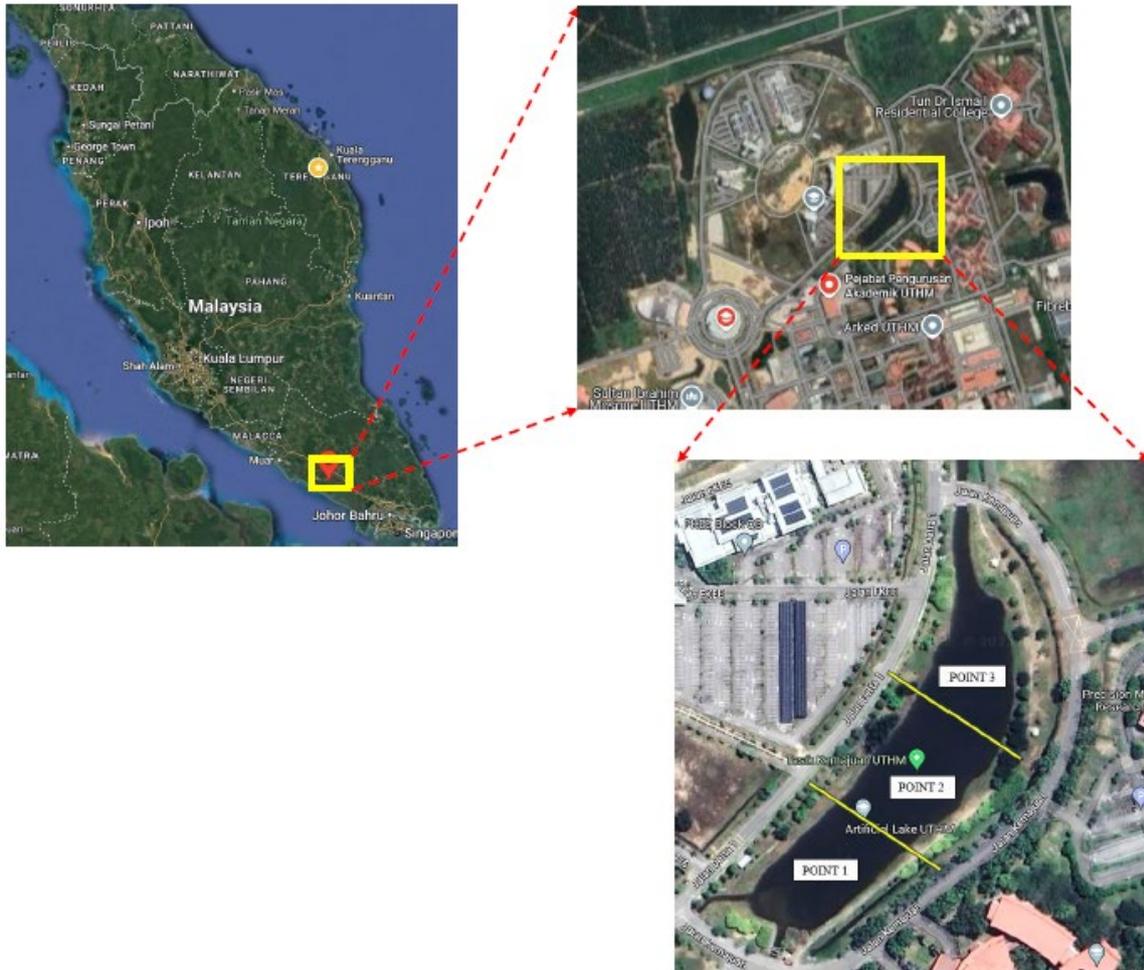
The National Lake Water Quality Criteria and Standards (NLWQS) provide a comprehensive framework consisting of established criteria and guidelines for evaluating and managing the water quality of lakes in Malaysia [6]. This framework has gained broad acceptance because of its systematic approach to assessing lake water's physical, chemical, and biological characteristics [7]. This standard is crucial for addressing water pollution and maintaining the ecological balance of water bodies, particularly lakes in Malaysia [7]. As Malaysia continues its industrialisation efforts, there is an increasing trend of water bodies being used as disposal sites for chemicals, sewage, and other pollutants. In this context, the NLWQS provides a critical framework for monitoring and regulating pollutant that can adversely affect the aquatic ecosystems [7]. The NLWQS specifies water quality standards designed for specific uses and serves as a guideline for protecting Malaysian lakes from various water uses. These standards support informed decision-making regarding fitting lake water for recreational purposes, aimed at safeguarding human health and preserving ecosystem integrity, with particular emphasis on conserving aquatic biodiversity [8].

Kemajuan Lake, located at Universiti Tun Hussein Onn Malaysia (UTHM), is an important freshwater lake for detention ponds and recreational purposes. However, the lake has faced severe water quality problems recently. These issues are mainly caused by nutrient pollution from point sources (such as sewage and wastewater) and non-point sources (like surface runoff). One visible sign of the decline in water quality is the overgrowth of aquatic plants and algae. These excessive plant and algae blooms directly result from the high nutrient levels in the water, particularly nitrogen and phosphorus. As these algae grow, they can lead to oxygen depletion, affecting aquatic life and worsening water quality. This study aimed to determine the water quality of Kemajuan Lake at UTHM, with reference to the NLWQS, specifically for lake in Category A.

## 2. Methodology

### 2.1 Study Area

Kemajuan Lake is located at Universiti Tun Hussein Onn Malaysia's, Batu Pahat, Johor. This lake is characterised by overgrowth aquatic plants, making it a suitable location for study. This lake was selected for the study due to its dual functionality as a flood mitigation pond and a recreational facility. The area of Kemajuan Lake spans approximately 14780m<sup>2</sup>. Fig. 1 provides a top view of the lake and highlights the three designated sampling points. Water samples were collected from these points over 10 months (40 weeks). The specific sampling locations were identified using a GPS coordinate application, corresponding to 01°51'34.6" N, 103°05'08.4" E (Point A), 01°51'36.9" N, 103°05'10.9" E (Point B), and 01°51'39.9" N, 103°05'12.1" E (Point C).



**Fig. 1** Location of Kemajuan Lake and sampling area

## 2.2 Water Sampling, Insitu and Analysis Method

The water quality assessment of Kemajuan Lake was carried out over a 10-month period (40 weeks), with weekly sampling conducted on Sundays between 14 May 2023 and 11 February 2024. Sampling was conducted between 9:00 a.m. and 11:00 a.m. every Sunday to ensure consistency and minimise the effects of daily variation. This time was chosen to avoid changes in water temperature and DO that can occur later in the day due to sunlight and algae activity. Most sampling days were dry and sunny, but occasional rainfall occurred. Weather and sunlight conditions may have influenced some parameters, especially DO and Chl-a, due to the effects of photosynthesis.

In situ measurements were performed using the HI98194 Multiparameter Meter to record parameters like pH, dissolved oxygen (DO), DO saturation percentage, and water temperature. Water transparency was evaluated using a Secchi disc during the field measurements. Water samples were collected by conducting composite sampling for further laboratory analysis, focusing on parameters including biochemical oxygen demand ( $BOD_5$ ), chemical oxygen demand (COD), total suspended solids (TSS), ammoniacal nitrogen (AN), nitrate ( $NO_3^-$ ), total phosphorus (TP), chlorophyll-a (Chl-a), and heavy metals like As, Cd, Pb, Ni, and Hg. Composite water sampling involved collecting grab samples from multiple predetermined locations within the study area. The individual grab samples were combined into a single container to form a composite sample, providing a more comprehensive and representative evaluation of the overall quality of the lake water. The parameters, methods, and sampling frequencies are detailed in Table 1.

**Table 1** Water quality parameters, methods, and sampling frequency

Parameter	Method	Frequency
pH, Dissolved oxygen, Temperature	Hanna Instrument 98194 Multiparameter meter	
Biochemical oxygen demand	5210B (APHA, 2023)	
Chemical oxygen demand	DR6000 (HACH Method 8000)	
Total suspended solids	DR6000 (HACH Method 8006)	
Turbidity	TB400 Turbidity Meter	
Chlorophyll-a	Based on the methanol extraction method of Pearson <i>et al.</i> , (1987) [9]	Every week for 40 weeks
Total phosphorus	DR6000 (HACH Method 8190)	
Ammoniacal nitrogen	DR6000 (HACH Method 8038)	
Nitrate	Ion Chromatography	
Heavy metals (Arsenic, Cadmium, Lead & Nickel)	Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	
Mercury	Mercury Analyser	

### 2.3 National Lake Water Quality Criteria and Standard (NLWQS)

The NLWQS applies to all impounded water bodies, like lakes, reservoirs, dams, and ponds, regardless of their intended use. These standards serve as a critical resource for water body owners, providing essential guidance for assessing water suitability and supporting broader water quality management efforts. The NLWQS aligns with internationally recognised lake water quality standards while specifically adapting to Malaysian environmental conditions. The proposed model provides users with practical insights for evaluating lake water suitability and offers benchmarks for achieving optimal water quality across various applications [8].

The NLWQS categorises lakes based on their primary functions, as outlined in Table 2 [8]. Kemajuan Lake is classified under Category A, reflecting its dual role as a recreational lake, supporting activities such as kayaking and a detention pond for flood mitigation. Table 3 lists the water parameters and criteria for category A based on the NLWQS. The water quality data for Kemajuan Lake were compared to the standard limits set by the NLWQS.

**Table 2** Categories of water bodies and description [8]

Categories	Description
Category A	<ul style="list-style-type: none"> <li>Lakes that are managed in which the water to be used for recreational purposes- primary body contact such as swimming, diving and kayaking.</li> </ul>
Category B	<ul style="list-style-type: none"> <li>Lakes used for recreational purposes – secondary body contact such as boating and cruising.</li> <li>Swimming is not allowed in this category of lakes.</li> </ul>
Category C	<ul style="list-style-type: none"> <li>The lakes are meant for the preservation of aquatic life and biodiversity.</li> </ul>
Category D	<ul style="list-style-type: none"> <li>Lakes managed for the minimum preservation of good aquatic life in the lakes.</li> <li>It applies good management practices of lakes.</li> </ul>

**Table 3** Parameters and criteria for category A [9]

Parameter	Unit	Standard Limit
Pyhsicals		
Dissolved oxygen	mg/L	6.3-7.8
DO percentage saturation	%	80-100
pH	-	6.5-8.5
Temperature	°C	28±3°
Total suspended solids	mg/L	<100
Turbidity	NTU	40
Transparency (Secchi)	m	0.6
Nutrients		
Ammoniacal Nitrogen	mg/L	0.1
Nitrate	mg/L	7
Total Phosphorus	mg/L	0.01
Heavy metals		
Arsenic	mg/L	0.05
Cadmium	mg/L	0.002
Lead	mg/L	0.05
Mercury	mg/L	<0.001
Nickel	mg/L	0.02
Biological		
Chlorophyll-a	µg/L	10
Biochemical oxygen demand	mg/L	3
Chemical oxygen demand	mg/L	10

### 3. Results and Discussion

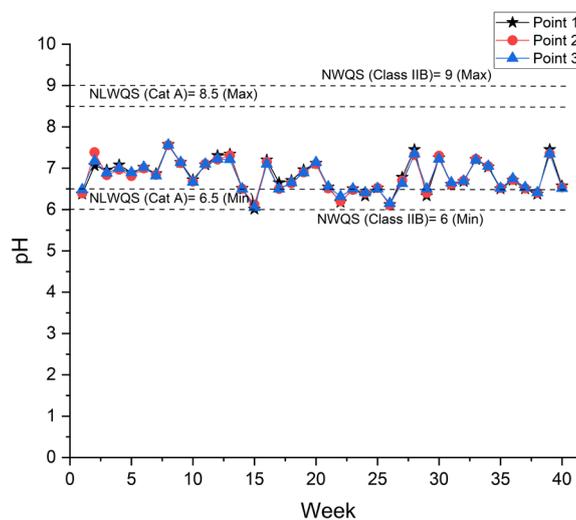
#### 3.1 Water Quality of Kemajuan Lake

The findings from the 10-month water quality monitoring of Kemajuan Lake are summarised in Table 4, which offers critical insights into the lake's ecological condition. These data serve as a foundation for informing future management strategies that align with the NLWQS.

**Table 4** Water quality monitoring data for Kemajuan Lake

Parameter	Water Quality Data (Average value)	Standard Limit (NLWQS CAT A) [8]
pH	6.80±0.83	6.5-7.8
Dissolved Oxygen	4.12±0.54 mg/L	6.3-7.8 mg/L
DO % Saturation	57.23±5.51%	80-100%
Temperature	27.94±2.03°C	28 ± 3°C
Turbidity	20.70±3.19 NTU	40 NTU
Total Suspended Solids	15.45±4.43 mg/L	<100 mg/L
Water Transparency	1.28±0.12 m	0.6 m
Chemical Oxygen Demand	19.88±5.72 mg/L	10 mg/L
Biochemical Oxygen Demand	9.43±2.67 mg/L	3 mg/L
Chlorophyll-a	26.30±12.31 µg/L	10 µg/L
Total Phosphorus	0.55±0.36 mg/L	0.01 mg/L
Ammoniacal Nitrogen	0.55±0.15 mg/L	0.1 mg/L
Nitrate	0.36±0.15 mg/L	7 mg/L
Arsenic	0.003±0.001 mg/L	0.05 mg/L
Cadmium	0.00003±0.00001 mg/L	0.002 mg/L
Lead	0.0005±0.0004 mg/L	0.05 mg/L
Nickel	0.0001±0.000 mg/L	<0.001 mg/L
Mercury	0.0001±0.0001 mg/L	0.02 mg/L

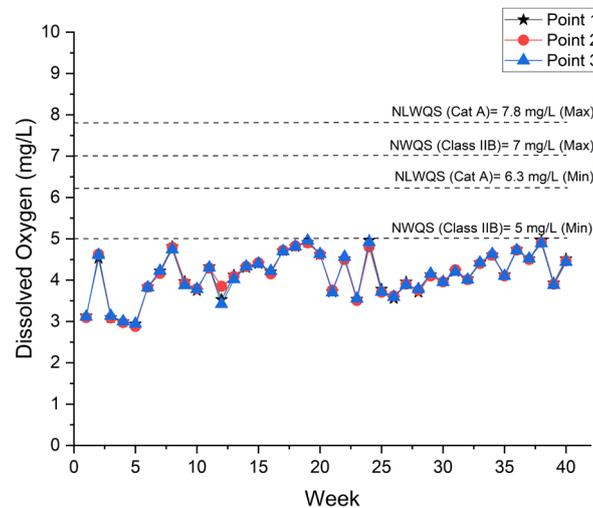
Fig. 2 shows Kemajuan Lake's pH profile over 40 weeks. The average pH values at Points 1, 2 and 3 were 6.80±.39, 6.79±.38 and 6.79±.36 respectively. Point 2 had the highest average pH value according to the comparative analysis and significantly differed from the other points. The ranges of pH values from both measured samples are acceptable for sustaining freshwater ecosystems, as the recommended level is between 6.0 and 8.5 [10]. Pollution frequently disrupts the pH levels of aquatic environments, presenting a considerable risk to organisms that inhabit these ecosystems. Aquatic plants and animal species generally evolved to survive within the pH range. Even minor changes in pH levels can harm these organisms, potentially disrupting their physiological processes and overall ecosystem balance [11].



**Fig. 2** pH of Kemajuan Lake

According to the NLWQS, the pH values for Category A water bodies for recreation (swimming, diving, and kayaking) are 6.5 - 8.5. The pH values dropped below the minimum acceptable threshold of 6.5 in weeks 1, 15, 22, 23, 24, 26, 29, and 38, indicating empirical evidence that the lake water could present a potential risk to users during those times. Nonetheless, the mean pH of 6.80±0.83 was within the regulated limits. Minor fluctuations in pH levels are unlikely affect aquatic organisms' survival significantly. Nevertheless, variations in pH can influence water acidity, which, in turn, impacts various biochemical processes in surface waters [12].

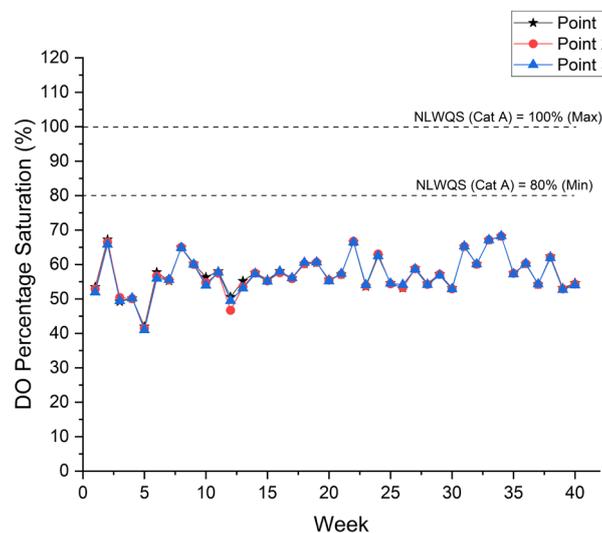
The DO is widely recognised as one of the water quality indicators, representing the equilibrium between oxygen production and consumption. Thus, it constitutes a critical parameter in water quality management. Variations in DO concentration are influenced by multiple factors, with primary sources including photosynthetic activity, aeration through structures, and atmospheric re-aeration [13]. Fig. 3 presents the DO profile of Kemajuan Lake over 40 weeks. The average DO concentrations in this lake were  $4.13 \pm 0.55$  mg/L,  $4.12 \pm 0.54$  mg/L, and  $4.12 \pm 0.54$  mg/L at Points 1, 2, and 3, respectively.



**Fig. 3** Dissolved oxygen of Kemajuan Lake

The NLWQS specifies that the acceptable DO concentration for Category A water bodies for recreational activities should range between 6.3 mg/L and 7.8 mg/L. Notably, the DO measurements over the 40 weeks did not meet the minimum threshold of 6.3 mg/L. This indicates that Kemajuan Lake requires appropriate management interventions that align with the NLWQS standard and are suitable for Category A activities. DO levels are inversely related to the organic matter concentration and activity of anaerobic bacteria, which consume oxygen in the water body [12]. An increase in these factors reduces DO levels, potentially compromising the health and survival of aquatic species.

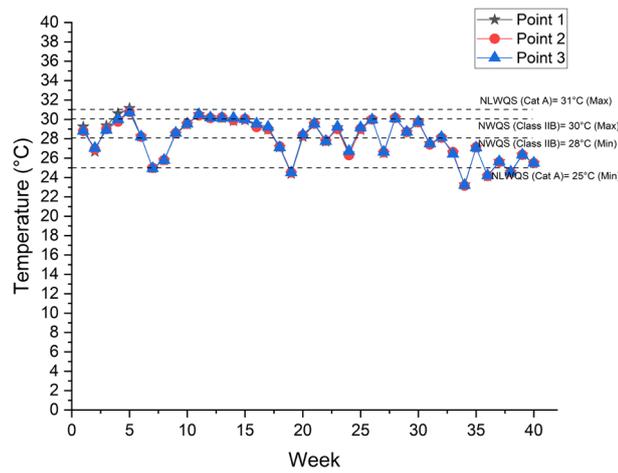
The DO percentage saturation of Kemajuan Lake was analysed over 40 weeks, and the results are presented in Fig. 4. The average DO percentage saturation at Points 1, 2, and 3 was  $57.43 \pm 5.41\%$ ,  $57.16 \pm 5.62\%$ , and  $57.11 \pm 5.55\%$ , respectively. According to the NLWQS, Category A water bodies should maintain a DO percentage saturation level between 80% and 100%. However, the average DO percentage saturation for Kemajuan Lake, recorded as  $57.23 \pm 5.51\%$ , falls below this recommended range, indicating non-compliance with the NLWQS criteria.



**Fig. 4** Percentage dissolved oxygen saturation of Kemajuan Lake

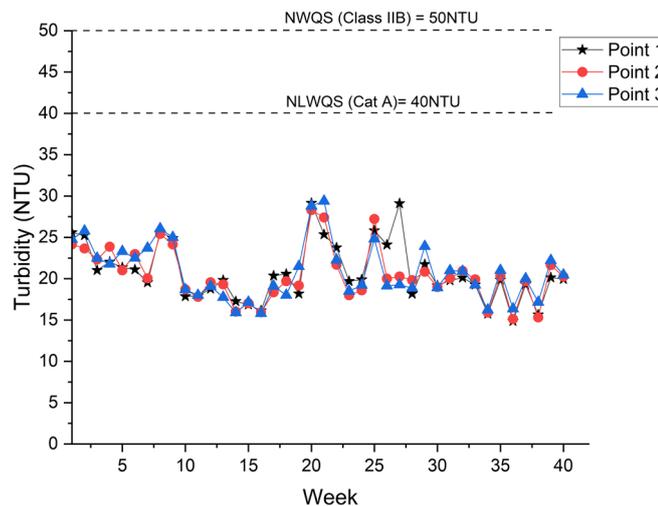
The percentage saturation of DO affects the quality of water [14]. Water bodies with a DO percentage saturation below 60% are categorised as having poor water quality, whereas a range of 60% to 74% is considered fair [14]. Based on the study's findings, with an average percentage DO saturation of  $57.23 \pm 5.51\%$ , Kemajuan Lake's water quality is poor.

Fig. 5 illustrates the water temperature data of Kemajuan Lake over 40 weeks at Points 1, 2, and 3. The average temperatures recorded were  $27.95 \pm 2.07^\circ\text{C}$ ,  $27.92 \pm 2.01^\circ\text{C}$ , and  $27.96 \pm 2.03^\circ\text{C}$ , respectively. The NLWQS set that Category A lakes should uphold a temperature range of  $28 \pm 3^\circ\text{C}$ . While the overall average temperature during the study,  $27.94 \pm 2.03^\circ\text{C}$ , complied with the NLWQS standard, certain weeks, specifically weeks 7, 19, 34, 36, and 38, recorded temperatures below the minimum acceptable threshold of  $25^\circ\text{C}$ . This indicates occasional deviations from the recommended range, although the general temperature profile is consistent with the NLWQS criteria. Temperature influences parameters including palatability, viscosity, solubility, odour, and chemical reaction rates. Temperature is a key factor in various processes like sedimentation and chlorination, and in the measurement of BOD, all of which are temperature dependent [11].



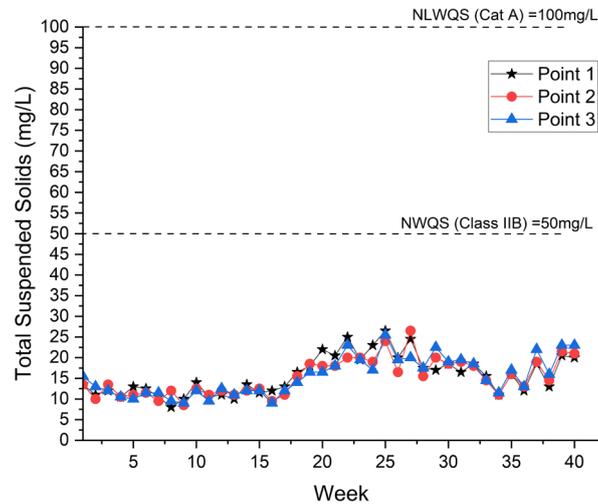
**Fig. 5** Water temperature of Kemajuan Lake

The graph in Fig. 6 illustrates the water turbidity data of Kemajuan Lake over 40 weeks. The average turbidity levels were  $20.77 \pm 3.50$  NTU,  $20.49 \pm 3.21$  NTU, and  $20.85 \pm 3.40$  NTU, respectively. Category A lakes should maintain turbidity below 40 NTU based on the NLWQS. The data collected over 40 weeks showed that turbidity levels at Kemajuan Lake consistently remained below this limit, with an overall average of  $20.70 \pm 3.19$  NTU. These findings indicate that the lake complies with the NLWQS standard, making it suitable for recreational activities under Category A. Elevated turbidity often results from soil erosion, mainly in the deposition of silt and clay. Urban runoff, including pollutants from roads, rooftops, and parking areas, can further increase turbidity. Additionally, organic matter such as decaying plants and animals, microorganisms, and hydrocarbons like petrol, diesel, or oil from urban surfaces contribute to turbidity in water bodies [15].



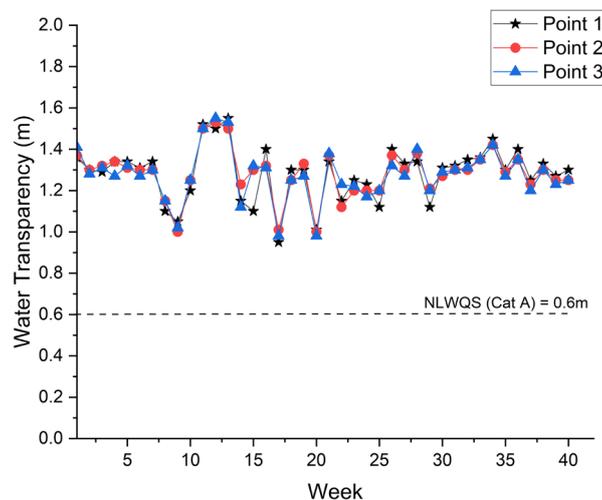
**Fig. 6** Turbidity of Kemajuan Lake

The TSS data for Kemajuan Lake, recorded over 40 weeks, are presented in Fig. 7. The average TSS values at Points 1, 2, and 3 were  $15.66 \pm 4.75$  mg/L,  $15.23 \pm 4.40$  mg/L, and  $15.48 \pm 4.62$  mg/L, respectively. The NLWQS set the Category A lake should maintain TSS levels below 100 mg/L. The data shown in Fig. 7 indicate that the TSS levels in Kemajuan Lake consistently remained below this limit, with an overall average of  $15.45 \pm 4.43$  mg/L. These findings confirm that the lake complies with the NLWQS standard, making it suitable for recreational activities under Category A. Furthermore, all recorded data demonstrate that the TSS levels in the lake are well within the acceptable range.



**Fig. 7** Total suspended solids of Kemajuan Lake

Fig. 8 illustrates the water transparency of Kemajuan Lake over 40 weeks. The average transparency values at Points 1, 2, and 3 were consistently recorded at  $1.28 \pm 0.13$  m,  $1.28 \pm 0.12$  m, and  $1.28 \pm 0.12$  m, respectively. According to the NLWQS, the recommended water transparency for Category A water bodies, as measured using a Secchi Disc, is a minimum of 0.6 m. The data from Kemajuan Lake exceeds this threshold, indicating compliance with the NLWQS standard.

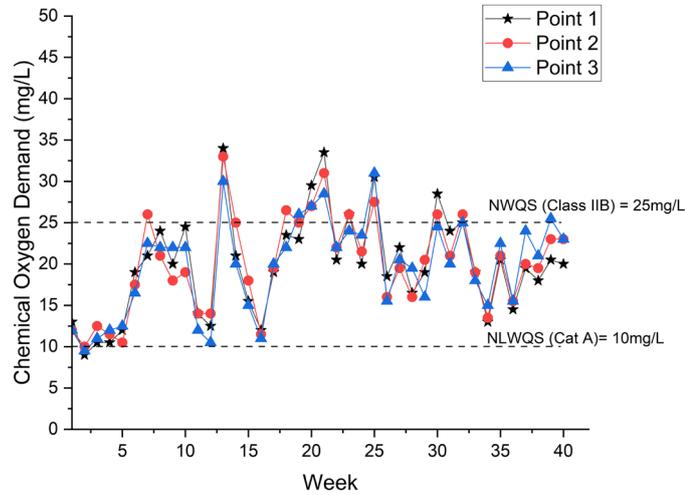


**Fig. 8** Water transparency of Kemajuan Lake

However, water transparency alone cannot comprehensively assess a lake's ecological health. High transparency values suggest reduced suspended particles and algae, indicating more transparent water. Water transparency is not always correlated with cleanliness or ecological stability [16]. Moreover, while Kemajuan Lake's transparency is within acceptable limits, clear water may still contain pollutants, such as nutrients and toxins, which pose risks to aquatic life. Higher water transparency is generally associated with better water quality

[17]. However, a holistic approach that incorporates multiple parameters of the water quality is important to obtain a more accurate evaluation of the lake's ecological condition.

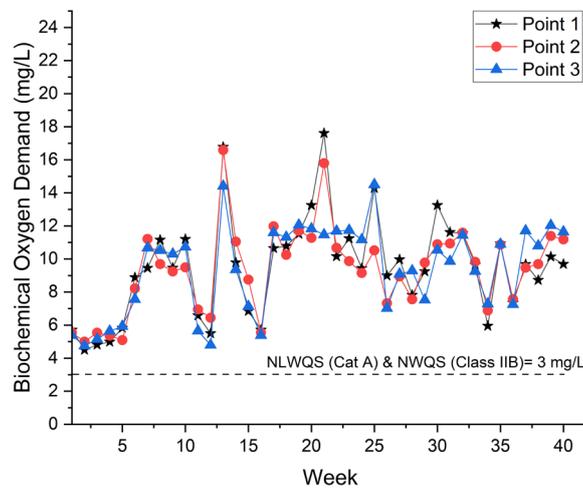
The COD data for Kemajuan Lake, recorded over 40 weeks are shown in Fig. 9. The average COD values at these points were  $19.91 \pm 6.17$  mg/L,  $19.98 \pm 5.77$  mg/L, and  $19.75 \pm 5.71$  mg/L. Based on the NLWQS, Category A water bodies should maintain COD levels below 10 mg/L. However, the recorded COD values for Kemajuan Lake consistently exceeded this limit, with an average of  $19.88 \pm 5.72$  mg/L, except for week 2, which recorded a lower level of  $9.50 \pm 0.5$  mg/L. This consistent exceedance indicates that the COD levels in Kemajuan Lake do not comply with the NLWQS standards, raising concerns regarding water quality.



**Fig. 9** Chemical oxygen demand of Kemajuan Lake

The elevated COD levels may be attributed to various pollution sources, including runoff from the G3 building, Arked, Pejabat Pendaftar, and fertilisers used in landscaping. The COD concentration in water can increase because of the influx of organic substances and inorganic chemicals such as cafeteria food waste and surrounding wastewater [18].

The BOD data for Kemajuan Lake, collected over 40 weeks are presented in Fig. 10. The average BOD values recorded were  $9.52 \pm 3.04$  mg/L,  $9.37 \pm 2.63$  mg/L, and  $9.41 \pm 2.70$  mg/L. Based on the NLWQS, Category A's lakes should maintain a BOD level below 3 mg/L. However, the BOD data for Kemajuan Lake consistently exceeded this limit, with an overall average of  $9.43 \pm 2.67$  mg/L. This persistent exceedance indicates that the lake does not meet the NLWQS standards, raising significant concerns about water quality.

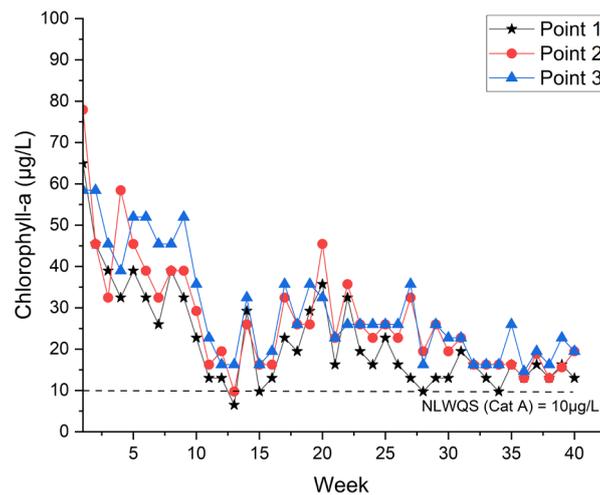


**Fig. 10** Biochemical oxygen demand of Kemajuan Lake

The elevated BOD levels suggest that Kemajuan Lake is unsafe for body contact activities. BOD is frequently employed as an indicator of oxygen uptake by microorganisms during the aerobic breakdown of organic matter in aquatic environments. This parameter is related to the presence of organic matter, with higher BOD values

indicating more significant levels of organic pollutants in water [18]. The elevated BOD levels in Kemajuan Lake are likely due to organic matter entering the lake from various sources, including surface runoff, leaves, grass clippings, garden waste, and cafeteria waste. It is acknowledged that algae present in unfiltered water samples may have contributed to elevated COD and BOD levels. Since filtered samples were not analysed separately, a portion of the measured oxygen demand may be attributed to biological activity rather than external organic pollution [19].

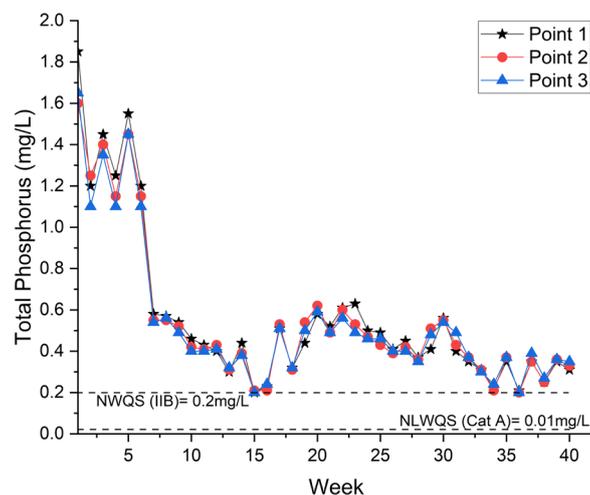
The Chl-a concentration data of Kemajuan Lake, collected over 40 weeks, are presented in Fig. 11. The average Chl-a concentrations recorded at these points were  $22.08 \pm 12.15 \mu\text{g/L}$ ,  $27.32 \pm 13.62 \mu\text{g/L}$ , and  $29.50 \pm 12.88 \mu\text{g/L}$ , respectively. Based on the NLWQS, a lake that is classified as Category A should maintain a Chl-a concentration below  $10 \mu\text{g/L}$ . However, the levels of Chl-a in Kemajuan Lake consistently exceeded this threshold, averaging  $26.30 \pm 12.31 \mu\text{g/L}$ . The concentration fell below the limit during week 13 at Point 1 ( $6.49 \mu\text{g/L}$ ) and Point 2 ( $9.74 \mu\text{g/L}$ ). However, the average Chl-a concentration at week 13,  $10.82 \mu\text{g/L}$ , still exceeded the NLWQS limit. This indicates that the lake does not meet the required standards and is unsafe for body contact activities based on the Chl-a concentration.



**Fig. 11** Chlorophyll-a of Kemajuan Lake

Excessive nutrients, particularly phosphorus and nitrogen, promote phytoplankton growth, increasing Chl-a concentrations in water. Elevated Chl-a levels can also affect the colour and odour of the water, making it less suitable for recreational activities [20].

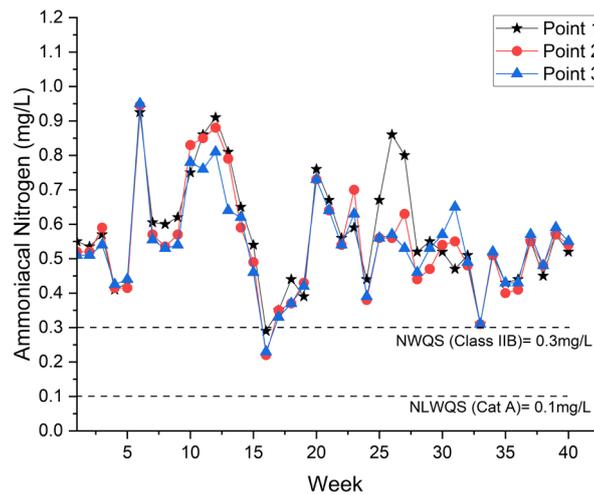
The TP concentration in Kemajuan Lake was collected over 40 weeks and is presented in Fig. 12. The average TP concentrations for the three points were  $0.56 \pm 0.39 \text{ mg/L}$ ,  $0.55 \pm 0.36 \text{ mg/L}$ , and  $0.54 \pm 0.34 \text{ mg/L}$ . According to the NLWQS standard, Category A water bodies should maintain a TP concentration below  $0.01 \text{ mg/L}$ . However, the average TP levels for Kemajuan Lake was  $0.55 \pm 0.36 \text{ mg/L}$ , consistently exceeding the limit value for the entire 40-week period. This indicates that the TP levels in Kemajuan Lake do not comply with the NLWQS standards.



**Fig. 12** Total phosphorus of Kemajuan Lake

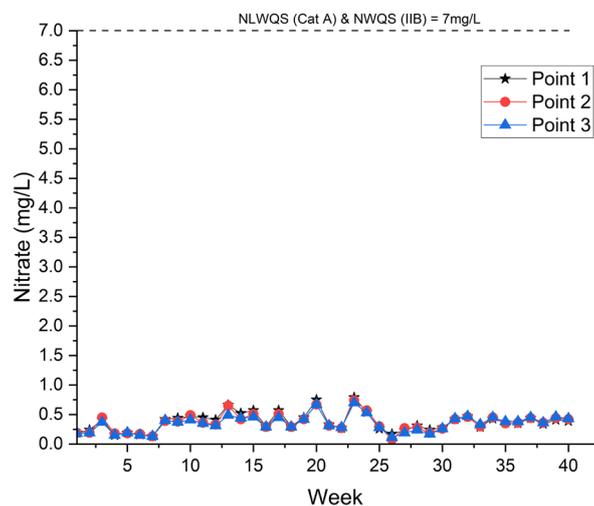
The eutrophic conditions conducive to algae blooms can occur when the TP concentrations higher than 0.02 mg/L (20 µg/L) [21]. Even lower concentrations, such as 0.01 mg/L (10 µg/L), can promote algae growth in nutrient-sensitive lakes [22]. The phosphorus in Kemajuan Lake may originate from surface runoff, which carries fertiliser from the surrounding landscape, and kitchen wastewater from the cafeteria, which may contain detergents, disinfectants, and cooking additives. The presence of accumulated sludge at the lake bottom may act as a significant internal source of phosphorus due to anaerobic decomposition processes. Addressing internal loading through dredging or aeration could mitigate the recurrence of nutrient-driven eutrophication [23].

Data on AN concentration for 3 points in Kemajuan Lake were collected over 40 weeks, as presented in Fig.13. The average AN concentration at these points were  $0.57 \pm 0.16$  mg/L,  $0.55 \pm 0.16$  mg/L, and  $0.54 \pm 0.14$  mg/L, respectively. The NLWQS standard specifies that Category A's lakes should maintain an AN concentration below 0.1 mg/L. The average AN concentration for Kemajuan Lake was  $0.55 \pm 0.15$  mg/L, consistently exceeding the limit throughout the 40 weeks. This indicates that the AN concentration in Kemajuan Lake did not meet the NLWQS standard. An increase in ammonia levels renders water toxic to aquatic life, often leading to mortality among aquatic organisms [24].



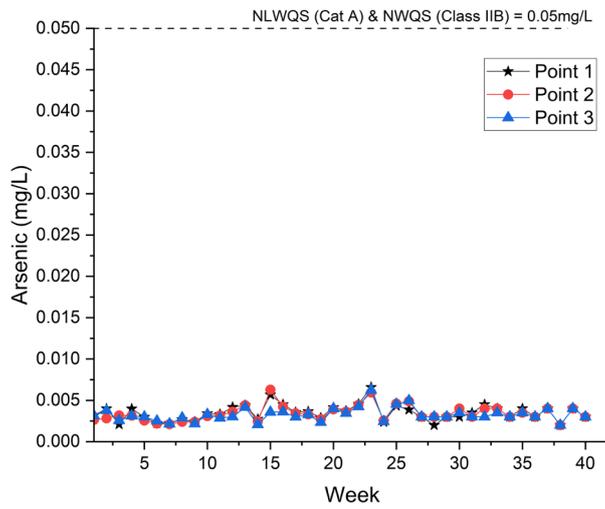
**Fig. 13** Ammoniacal nitrogen of Kemajuan Lake

Data on  $\text{NO}_3^-$  concentration in Kemajuan Lake was collected over 40 weeks, as shown in Fig. 14. The average  $\text{NO}_3^-$  concentrations for these points were  $0.38 \pm 0.16$  mg/L,  $0.36 \pm 0.15$  mg/L, and  $0.35 \pm 0.14$  mg/L. The NLWQS and NWQS standards specify that the  $\text{NO}_3^-$  concentration in Category A water bodies should not exceed 7 mg/L. Given that the average  $\text{NO}_3^-$  concentration for Kemajuan Lake was  $0.36 \pm 0.15$  mg/L and consistently remained well below the standard limit over 40 weeks, the  $\text{NO}_3^-$  levels in the lake are considered acceptable. Therefore, the water in Kemajuan Lake is safe for body contact activities based on this parameter.

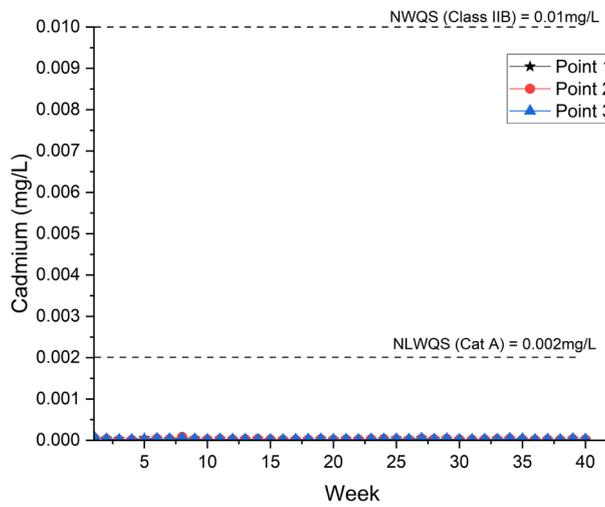


**Fig. 14** Nitrate of Kemajuan Lake

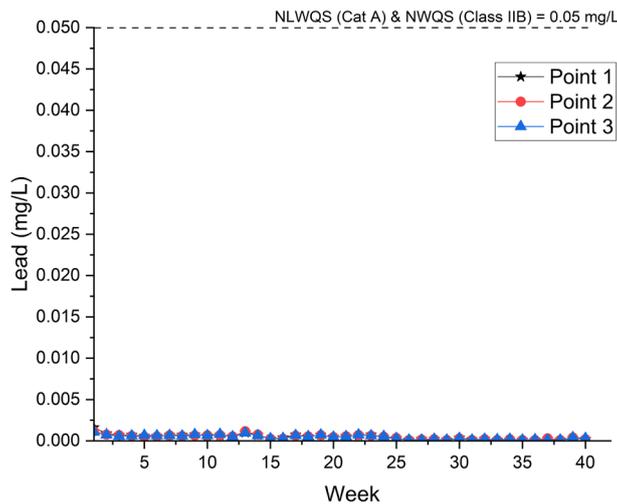
Heavy metal concentrations in Kemajuan Lake were monitored over 40 weeks at three points within the lake. The levels of heavy metals like arsenic (As), cadmium (Cd), lead (Pb), nickel (Ni), and mercury (Hg) were all within the acceptable limits set by the NLWQS, as shown in Fig. 15, Fig. 16, Fig. 17, Fig. 18 and Fig. 19, respectively.



**Fig. 15** Arsenic of Kemajuan Lake



**Fig. 16** Cadmium concentration of Kemajuan Lake



**Fig. 17** Lead concentration of Kemajuan Lake

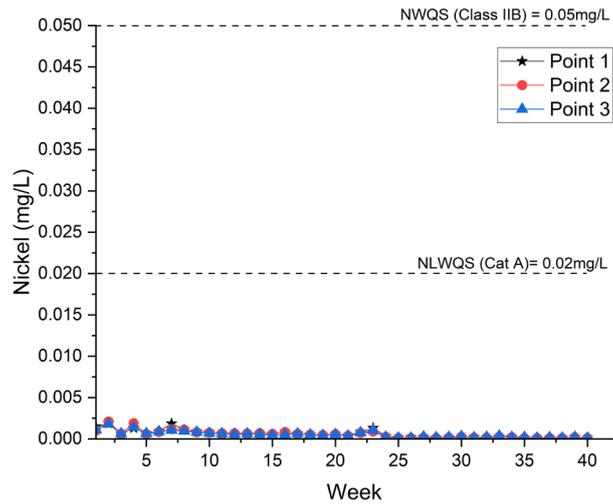


Fig. 18 Nickel concentration of Kemajuan Lake

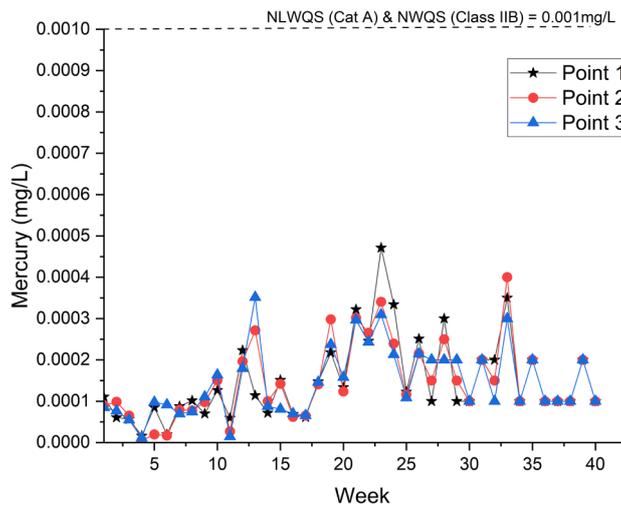


Fig. 19 Mercury concentration of Kemajuan Lake

As levels averaged  $0.003 \pm 0.001$  mg/L, below the 0.05 mg/L set by NLWQS. Similarly, Cd concentrations were low, with averages between  $0.00002 \pm 0.00001$  mg/L and  $0.00003 \pm 0.00001$  mg/L, much lower than the NLWQS threshold of 0.002 mg/L. Ni levels averaged between  $0.0005 \pm 0.0003$  mg/L and  $0.0006 \pm 0.0005$  mg/L, well within the acceptable range of 0.02 mg/L set by the NLWQS. The Pb levels were consistently low, averaging  $0.0001 \pm 0.0000$  mg/L, below the NLWQS limit of 0.05 mg/L. Hg levels were also within the acceptable range, averaging  $0.0001 \pm 0.0001$  mg/L, which is lower than the NLWQS limit of 0.001 mg/L.

Although the presence of these heavy metals, even at low concentrations, may be attributed to surface runoff from anthropogenic activities such as urbanisation and industrialisation, the water quality of Kemajuan Lake remains within the NLWQS limits. The presence of heavy metals in Kemajuan Lake, even at low concentrations, may be attributed to surface runoff. Anthropogenic activities, such as urbanisation and industrialisation, are likely to contribute. It has been suggested that land-use changes and increased pollution in the lake area have led to higher concentrations of heavy metals in the lake, primarily through runoff from road surfaces [25].

#### 4. Conclusion

Assessing and controlling lake water quality is necessary for ensuring the sustainability of aquatic ecosystems and water safety for recreational and other purposes. Adopting standards such as the NLWQS provides a valuable framework for evaluating and maintaining water quality, offering clear benchmarks for identifying and addressing parameters that exceed acceptable limits. Implementing these standards helps safeguard water bodies and supports effective decision-making in managing water resources for present and future needs. Based on the NLWQS (Category A), parameters such as pH, temperature, turbidity, TSS, water transparency, nitrate, As, Cd, Pb,

Ni, and Hg complied with the standard limits, indicating their safety for body contact. However, DO, DO % saturation, COD, BOD<sub>5</sub>, Chl-a, TP, and AN exceeded the standard limits, making these parameters unsuitable for body contact. The overall analysis concluded that Kemajuan Lake is unsafe for recreational activities because of the non-compliance of specific key parameters with the standard.

The key pollutants identified were TP, AN, Chl-a, BOD<sub>5</sub>, COD, and DO. These parameters consistently exceeded the NLWQS limits. High nutrient levels and organic matter inputs are likely due to surface runoff, sludge accumulation, and organic waste from surrounding activities. Regularly cleaning sludges at the lake bottom, controlling fertiliser use in nearby areas, managing surface runoff, and periodically removing aquatic plants and algae are recommended to improve water quality. These actions may help reduce nutrient enrichment and restore the lake to a condition suitable for recreational use.

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## Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

## Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Muhammad Hafiq Afifi Azman, Rafidah Hamdan, Zarina Md Ali; **data collection:** Muhammad Hafiq Afifi Azman, Rafidah Hamdan; **analysis and interpretation of results:** Muhammad Hafiq Afifi Azman, Rafidah Hamdan, Zarina Md Ali, Zuhair Siddiqui; **draft manuscript preparation:** Muhammad Hafiq Afifi Azman Rafidah Hamdan. All authors reviewed the results and approved the final version of the manuscript.

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