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Water Quality Assessment and Monitoring of the Tasik Aman and Tasik Harapan Water Bodies of the Universiti Sains Malaysia Using Physiocochemical and Biochemical Assessment Methods

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ABSTRACT: Tasik Aman (TA) and Tasik Harapan (TH) are critical water bodies located within the campus of Universiti Sains Malaysia (USM) that serve both ecological and flood management functions. They provide aquatic habitats for diverse species, support biodiversity and contribute to campus recreation and environmental aesthetics. However, these lakes are increasingly impacted by nutrient accumulation, primarily from the Sungai Gambir inflow, leading to algal proliferation and potential eutrophication. This study assessed the current water quality of TA and TH through physiochemical and biochemical parameters, including pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD), nitrite-nitrogen (NO_2-N), ammonium nitrogen (NH_4-N), chlorophyll-a, orthophosphate and water transparency. Most parameters were within the Malaysian National Water Quality Standard (NWQS), except for TSS, DO and BOD, which fell under Class IIB. Significant spatial variations in temperature, EC, BOD, NH_4-N and chlorophyll-a ($p < 0.05$). These findings highlight the ecological significance of these lakes and underscore the need for sustainable management strategies to maintain water quality, protect aquatic ecosystems and enhance the utility of campus water resources.

Keywords: assessment, monitoring, water, Tasik Aman and Tasik Harapan, physiochemical

1. INTRODUCTION

Freshwater ecosystems are vital resources that are increasingly threatened by global anthropogenic activities. Water quality assessment and monitoring of critical because water pollution is inextricably linked to public health risks and habitat degradation.[1-4] Although freshwater constitutes only 2.5% of the world's water, the scarcity of high-quality resources, intensified by urbanisation, population growth, industrial expansion and agricultural runoff.[5,6] In this context, lakes and reservoirs are particularly vulnerable, acting as sinks for accumulated pollutants.[7,8]

Eutrophication, which is driven by excessive nitrogen and phosphorus inputs, remains a primary cause of water quality deterioration in inland waters worldwide.[9] This process leads to algal blooms, reduced water transparency and dissolved oxygen depletion, ultimately harming aquatic biodiversity and compromising water use for recreation, aesthetics and ecosystem services.[10] Eutrophic lake management requires a nuanced understanding of nutrient dynamics, which is highly dependent on local catchment characteristics, climate and pollution sources.[11,12]

Many urban water bodies in Malaysia face significant pressure from development. The National Water Quality Standards (NWQS) and Water Quality Index (WQI) are essential tools for classifying the health of these ecosystems and guiding remediation efforts.[13] Recent studies have highlighted the persistent challenges of high-nutrient loads and organic pollution from domestic and surface runoff in Malaysian lakes and rivers, such as those in the Klang Valley.[12,14-16] For instance, research on Putrajaya Lake highlighted how agricultural runoff contributes to nutrient enrichment, altering the trophic state of the lake.[17] Moreover, studies on the Semenyih River reservoir system demonstrated the critical link between land use and water quality parameters.[18]

Tasik Aman (TA) and Tasik Harapan (TH), located within the main campus of Universiti Sains Malaysia (USM), are man-made lakes originally constructed for flood control and water retention.[19] These lakes provide crucial ecological services by supporting aquatic life, maintaining biodiversity and serving as recreational and educational resources for the campus community. They act as natural stormwater runoff buffers, playing a key role in campus sustainability initiatives.[19] However, these lakes are subject to nutrient enrichment, primarily from the inflow of Sungai Gambir, which conveys discharges from mixed sources in the catchment.[20]

Excess nutrient inputs can lead to eutrophication, which is characterised by high algal biomass, reduced water transparency and altered dissolved oxygen levels.[20,21] Such deterioration threatens aquatic biodiversity and diminishes the recreational and research value of lakes. Although previous studies, including Munirah et al.,[20] have provided foundational data on the physicochemical characteristics of TA alone, the current understanding of these characteristics remains limited. These earlier works often relied on a narrow range of parameters, offered limited spatial comparison across the lakes, and emphasised the evolving impact of anthropogenic pressures. An updated, comprehensive assessment that reflects current conditions and provides a robust baseline for effective management of TA and TH is clearly needed.

This study aims to provide a contemporary water quality assessment of TA and TH by evaluating a comprehensive set of physiochemical and biochemical parameters, including pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD), nitrite-nitrogen (NO_4-N), ammonium nitrogen (NH_4-N), chlorophyll-a, orthophosphate and water transparency. By incorporating broader spatial sampling and comparing findings with the Malaysian NWQS, this study updates previous assessments and offers new insights into the temporal trends and spatial dynamics of pollution in these lakes. The findings provide a scientific foundation for informed management decisions, helping mitigate eutrophication, maintain ecological balance and enhance the sustainability of these vital campus water resources.

2. MATERIALS AND METHODS

2.1 Study Area

The study areas of TA and TH are located on the side of the USM Main Campus and could serve as key catchment areas in flood prevention and mitigation efforts for the surrounding areas.[20] These lakes also serve as recreational areas for residents of the USM for jogging, cycling and kayaking. Geographically, TA is located at a coordinate point of 5.3545° north (N), 100.2982° east (E) (see Figure 1a) with a sampling area size of 0.6 ha (6,000 m²), while TH is located at a coordinate point of 5.3535° N, 100.3004° E (see Figure 1b) with a surface area of 6,070 m² (1.5 acres) and from 1.0 m–1.5 m deep.[21] The red arrows in Figure 1a and Figure 1b indicate the three sampling points (TApt-1, TApt-2 and TApt-3; THpt-1, THpt-2 and THpt-3) that were used in this study around TA and TH.

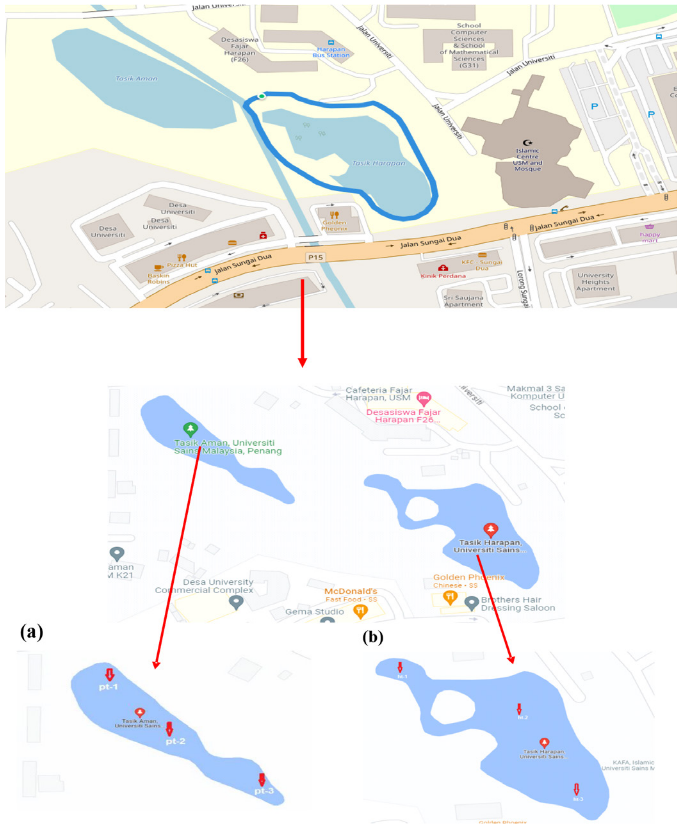

Figure 1: Geographic location and sampling stations of the study sites within USM, Pulau Pinang, Malaysia. (a) for TA and (b) for TH.

2.2 Water Parameters, Quality Parameters and Analytical Methods

Water quality sampling was conducted weekly over a six-week period from 29 August 2023 to 9 October 2023. This period falls within the typical inter-monsoon season in Penang, which is characterised by predictable rainfall patterns. To minimise the immediate influence of runoff, all sampling events were scheduled to occur approximately 24 h after a recorded rainfall event. Water samples were collected from a depth of 0.5 m below the surface at three designated points in each lake (TApt-1, TApt-2 and TApt-3; THpt-1, THpt-2 and THpt-3). In this study, 12 parameters were used according to the Malaysia Water Quality Index (WQI). The selected parameters include key physicochemical indicators (pH, temperature, EC, TDS, TSS, DO and transparency) and biochemical indicators (BOD, chlorophyll-a, NO_2-N and NH_4-N), with orthophosphate serving as a primary nutrient source that fuels biochemical processes. Three replicate samples were collected at each sampling point to ensure statistical robustness.

On-site Analysis: parameters, including pH, temperature, EC, DO and TDS were measured directly in the field using a pre-calibrated YSI ProPlus multi-parameter metre (Model 550).

Ex-situ analysis: for laboratory analysis, water samples were collected in pre-cleaned 1 L polyethylene bottles. Samples for nutrient analysis (NO_2-N, NH_4-N and orthophosphate) were immediately filtered through 0.45 µm membrane filters and preserved by cooling to 4°C. All samples were transported to the laboratory in dark iceboxes at ~4°C and analysed within 24 h of collection.

The analytical methods, corresponding American Public Health Association (APHA) standard references, and key quality control measures are detailed in Table 1.[22] Table 2 presents the physical descriptions of the various sampling points.

Table 1: Method for determining water quality determination

S/No	Parameters of water quality	Determination method (APHA, 2012)	Model number	Quality control measures
1	pH	Method 4500 H+ B	Model 550	3-point calibration before each use
2	Temperature	Method 2550 B	Model 550	–
3	EC	Method 2510 B	Model 550	Calibration using a standard KCl solution
4	TDS	Method 2540 C	Model 550	–
5	TSS	Method 2540 D		Duplicate sample analysis; results accepted if < 5% RPD
6	DO	Method 4500-O G	Model 550	Calibration with a zero solution and water saturated with air
7	BOD	Method 5210 B	Model 550	Analysis of duplicate samples and a glucose-glutamic acid check standard; results accepted if within 198 ± 30.5 mg/L
8	NO_2-N	Method 4500-NO_2 B diazotisation.	Spectrophotometry	Calibration curve (r^2 > 0.995); analysis of duplicate and blank samples

(*continue on next page*)

Table 1: (*continued*)

S/No	Parameters of water quality	Determination method (APHA, 2012)	Model number	Quality control measures
9	NH_4-N	Method 4500-NH4 G (Phenate)	Spectrophotometry	Calibration curve ($r^2 > 0.995$); analysis of duplicate and blank samples
10	Chlorophyll-a	Method 10200 H (Trichromatic)	Spectrophotometry	Duplicate sample analysis
11	Orthophosphate	4500-P E (ascorbic acid)	Spectrophotometry	Calibration curve ($r^2 >$ 0.995); duplicate, blank and matrix spike samples were analysed
12	Transparency	Method 2020 C	Secchi Disc	–

Table 2: Physical description of various sampling points

Sampling Point		Physical Description
TApt-1	THpt-1	Region of the lake's flow inlet where water intrusion occurs from Sungai Gambir
TApt-2	THpt-2	The region around the flow of bamboo trees in TA and the region around the coconut trees in TH
TApt-3	THpt-3	Region of the lake outlet in TA and close to the USM fence

2.3 Data Analysis

The data obtained from this study were subjected to statistical analysis using Statistical Package for the Social Sciences version 25. Descriptive statistics (mean and standard deviation) were calculated for all parameters from the replicate measurements ($n = 3$ per point per week). The overall mean values for each parameter across the six weeks were compared against the Malaysian NWQS. A one-way analysis of variance (ANOVA) was employed to test for significant differences in the mean values among the different sampling stations within each lake, with a significance level set at $p < 0.05$. Where ANOVA indicated significance, Duncan's post hoc test was used to identify which specific stations differed. Pearson's correlation analysis was performed to examine the relationships between various physicochemical parameters.

3. RESULTS AND DISCUSSION

Table 3 presents the results of physicochemical and biochemical parameters of the TA and TH water samples. pH plays a vital role in the chemical processes that occur in natural water and is a significant indicator of chemical and biological changes in a body of water.[23] In this study, the mean pH ranged from 9.00 ± 0.15 (Pt-2) to 9.07 ± 0.12 (Pt-1) at TAs and 8.95 ± 0.07 (Ht-3) to 9.20 ± 0.28 (Ht-1) at TH. This indicates that the water samples from TAs and TH were slightly alkaline. These findings are similar to those of the water samples in Aman, which showed a similar trend in the alkaline nature.[20] The mean pH values showed no significant difference among stations ($p > 0.05$) from both TA and TH. Alkaline waters can favour algal growth, particularly cyanobacteria, which may explain the observed dense algal populations. While fish can tolerate pH 6.5–9.0, prolonged alkalinity combined with nutrient enrichment may stress sensitive species, reducing overall biodiversity.[23] Maintaining pH within acceptable ranges is crucial for aquatic life and recreational use. The obtained values fall under Class IIB compared with the NWQS. This finding is consistent with those of studies on other water bodies experiencing nutrient enrichment. For instance, research on the Hindon River in India, which receives significant urban and agricultural discharge, also reported alkaline conditions (pH 7.8–8.5), albeit slightly lower than TA and TH, highlighting a shared characteristic of nutrient-impacted systems.[24] The sustained high pH in the USM lakes underscores the persistent pressure on algal productivity.

The physical, biological and chemical characteristics of aquatic ecosystems are regulated by the temperature of the water.[2] In this study, the mean water temperature ranged from 30.13°C ± 0.18°C (Pt-1) – 33.21°C ± 0.28°C (Pt-2) at TA and 30.51°C ± 0.38°C (Ht-2) – 33.20°C ± 0.98°C (Ht-3) at TH. Pt-1 recorded the lowest value of 30.13°C ± 0.18°C and the highest value of 33.21°C ± 0.2°C in Ht-3, with significant differences among stations ($p < 0.05$). Higher temperatures accelerate metabolic and photosynthetic rates, thereby increasing the oxygen demand and nutrient cycling. Warmer water may enhance algal growth in the inlet regions, contributing to the observed eutrophic conditions.

Conductivity indicates the presence and purity of dissolved solids and other contaminants, particularly electrolytes, in water and how pure it is.[25] The lowest conductivity of 133.10 ± 11.46 was recorded at Pt-3, and the highest concentration of 159.61 ± 23.33 μS/cm (Ht-3) was recorded. Ht-3, which is the outflow of TH, had higher conductivity because it carries dissolved salt from the entire lake to the outflow. EC was highest at lake outlets, reflecting the accumulation of dissolved ions and nutrients transported through the lake system. Significant differences between the sampling stations were observed ($p > 0.05$).

The number of dissolved materials, such as metal ions, in the water is indicated by the TDS. The TDS ranged from 28.35 ± 0.78 (Pt-1) to 30.60 ± 0.85 (Pt-3) at TA and 28.55 ± 5.02 (Ht-2) to 30.05 ± 2.76 (Ht-3) at TH. Pt-3 and Ht-3, which were located at the outlet of the lake, recorded the highest TDS concentrations during the study. Because of the increased precipitation and decreased lake outflow, this event may alter the water balance and raise the TDS content.[26] Elevated EC-TDS levels indicate nutrient enrichment, likely from upstream inflows, contributing to eutrophication. Monitoring these parameters can identify hotspots for nutrient reduction interventions. The mean concentration showed a significant difference among sampling stations ($p < 0.05$), whereas the mean TSS concentration ranged from 55.60 ± 0.71 (Pt-1) to 61.65 ± 0.64 (Pt-3) at TA and from 57.28 ± 2.89 (Ht-3) to 60.95 ± 5.73 (Ht-2) at TH. The TSS values were relatively uniform across stations (55.6 mgh/L–61.7 mg/L), indicating consistent turbidity throughout the lakes. High TSS, coupled with algal blooms, reduces light penetration, potentially limiting submerged macrophyte growth and altering aquatic habitat structure. Upstream sediment management and erosion control may help reduce TSS. This finding is consistent with monitoring data from other shallow, polymictic eutrophic lakes, where wind-induced sediment resuspension can intensify turbidity, creating a feedback loop that favours phytoplankton over macrophytes.[27,28]

The DO reading of TAs recorded the lowest concentration of 4.70 mg/L ± 0.85 mg/L (Pt-3) to the highest concentration of 4.84 mg/L ± 0.42 mg/L (Pt-1), whereas the DO value of TH ranged from 4.21 mg/L ± 0.16 mg/L to 5.14 mg/L ± 1.19 mg/L. The mean values were significantly different among the sampling stations ($p < 0.05$). Pt-1, Pt-2, Ht-2 and Ht-3 were positioned in a clear space that supported the microalgae's photosynthetic activity, which added oxygen to the water column. The inlet and open areas had higher DO, likely due to active photosynthesis by microalgae. The result is in conformity with that of Munirah et al., who found a similar result in their work on water quality characteristics and modelling in TA.[20]

The mean BOD concentration obtained ranged from 2.39 mg/L ± 0.06 mg/L to 3.32 mg/L ± 0.47 mg/L at TAs, with the lowest concentration was 2.39 mg/L ± 0.06 mg/L (Pt-2) and the highest concentration was 3.32 mg/L ± 0.47 mg/L (Pt-1), while the mean value ranged from 2.48 mg/L ± 0.14 mg/L to 2.73 mg/L ± 0.55 mg/L at TH, with the lowest concentration was 2.48 mg/L ± 0.14 mg/L (Ht-1) and the highest concentration was 2.73 mg/L ± 0.55 mg/L (Ht-2). The abundance of algae in the water ecosystem led to a significant volume of algae decomposition, which increased the oxygen level during the process.[29] The overabundance of nutrients from their excretions may be impacted by aquatic creatures that suppress the ecology of this lake. The BOD level of the lake increased because of plant decomposition processes.[13] Elevated BOD, reflecting organic matter decomposition, can deplete oxygen in deeper or stagnant zones, threatening aquatic fauna. Lake management could include aeration or controlled water mixing to maintain oxygen levels and support biodiversity. Duncan's post hoc analysis revealed that the BOD values at Pt-1 and Pt-2 were significantly different from those at the other sampling stations. A study on a campus lake in a temperate region reported similar BOD values (2.5 mg/L–4.0 mg/L) and attributed them to organic matter from catchment runoff and internal production, mirroring the processes observed in TA and TH.[30,31]

Table 3: Biochemical and physicochemical parameters of TAs and Harapan Lakes

Locations	pH	Temperature (°C)	EC	TDS	TSS	DO	BOD	NO_2-N	NH_4-N	Chlorophyll-a	Orthophosphate	Transparency
TA-1	9.07 ± 0.12	30.13 ± 0.18	140.55 ± 3.75	28.35 ± 0.78	55.60 ± 0.71	4.84 ± 0.42	3.32 ± 0.47	0.022 ± 0.001	0.33 ± 0.01	0.33 ± 0.01	0.022 ± 0.001	0.31 ± 0.02
TA-2	9.30 ± 0.42	33.21 ± 1.28	128.40 ± 6.37	28.95 ± 3.04	56.68 ± 0.32	4.80 ± 0.42	2.39 ± 0.06	0.021 ± 0.003	0.27 ± 0.07	0.27 ± 0.07	0.024 ± 0.002	0.28 ± 0.05
TA-3	9.00 ± 0.15	30.90 ± 1.56	133.10 ± 11.46	30.60 ± 0.85	61.65 ± 0.64	4.70 ± 0.85	3.00 ± 0.15	0.020 ± 0.001	0.32 ± 0.00	0.32 ± 0.00	0.024 ± 0.002	0.30 ± 0.02
TH-1	9.20 ± 0.28	31.50 ± 0.71	133.85 ± 1.77	29.50 ± 0.71	60.16 ± 1.35	4.21 ± 0.16	2.48 ± 0.14	0.022 ± 0.001	0.23 ± 0.01	0.23 ± 0.01	0.022 ± 0.001	0.28 ± 0.04
TH-2	9.04 ± 0.08	30.51 ± 0.69	142.15 ± 1.48	28.55 ± 5.02	60.95 ± 5.73	4.60 ± 0.57	2.73 ± 0.55	0.024 ± 0.002	0.32 ± 0.00	0.32 ± 0.00	0.021 ± 0.003	0.31 ± 0.01
TH-3	8.95 ± 0.07	33.20 ± 0.98	159.61 ± 23.33	30.05 ± 2.76	57.28 ± 2.89	5.14 ± 1.19	2.60 ± 0.38	0.024 ± 0.002	0.24 ± 0.02	0.24 ± 0.02	0.020 ± 0.001	0.28 ± 0.05

Nitrite-nitrogen of TA recorded the lowest concentration of 0.020 mg/L ± 0.001 mg/L (Pt-3) to the highest concentration of 0.022 mg/L ± 0.001 mg/L (Pt-1), whereas the lowest concentration of 0.022 ± 0.001 mg/L (Ht-1) to the highest concentration of 0.024 mg/L ± 0.002 mg/L (Ht-3) at TH. The lake absorbs manure, plant litter, trash and nitrate sources from the Sungai Gambir campus. ANOVA revealed no significant difference among the sampling stations ($p < 0.05$). A recent assessment of urban lakes in Yushan, China, with concentrations (NH_4-N > 0.5 mg/L) was an order of magnitude higher than those in TA and TH.[32,33]

Ammonia-nitrogen of TA recorded the lowest concentration of 0.27 mg/L ± 0.07 mg/L (Pt-1) to the highest concentration of 0.33 mg/L ± 0.01 mg/L (Ht-2), while the lowest concentration of 0.23 mg/L ± 0.01 mg/L (Ht-1) to the highest concentration of 0.32 mg/L ± 0.00 mg/L (Ht-2) at TH. Both TA and TH had somewhat lower ammonia-nitrogen concentrations because of the profusion of algae, which may have absorbed the ammonia and raised the pH while lowering the lake's ammonia content.[34] A significant difference was observed between the sampling stations ($p > 0.05$). Vegetation, denitrification, and sedimentation have been reported to increase nitrite-nitrogen, particularly at Ht-2, which is located at the inlet of TH and where sediments may reach the lake from Sungai Gambir.[15]

Chlorophyll-a is an essential component of photosynthesis through sunlight absorption. The lowest concentration of chlorophyll-a was recorded to be 0.27 mg/L ± 0.07 mg/L (Pt-2) and the highest concentration of 0.33 mg/L ± 0.01 mg/L (Pt-1) at TA, whereas TH recorded its highest chlorophyll-a concentration of 0.32 ± 0.00 (Ht-2) and the lowest of 0.23 ± 0.01 (Ht-1). A high density of algae causes chlorophyll-a concentrations ranging from 0.026 mg/L–0.075 mg/L to be classified as eutrophic.[35] However, TA and TH have quite high chlorophyll-a concentrations due to an algal bloom that covers the entire lake. Higher chlorophyll-a levels indicate eutrophic conditions, with dense algal blooms observed throughout the lakes. Spatial variation (significant at $p < 0.05$) reflects nutrient hotspots, especially at inlets. These blooms reduce water transparency, alter thermal stratification and lead to hypoxia upon decomposition. Controlling nutrient inflows is essential for preventing harmful algal blooms and maintaining ecosystem health. The mean chlorophyll-a concentration in this study (0.23 mg/L–0.33 mg/L) was substantially higher than the typical eutrophic threshold of 0.026 mg/L–0.075 mg/L,[35] confirming a state of hypereutrophication. This result is consistent with the visual observation of algal blooms covering the lakes.

The orthophosphate recorded the lowest concentration of 0.022 mg/L ± 0.001 mg/L (Pt-1) to the highest value of 0.024 mg/L ± 0.002 mg/L (Pt-1 and Pt-3) at TA, whereas TH recorded its highest orthophosphate concentration of 0.022 ± 0.001 (Ht-1) and the lowest of 0.021 ± 0.003 (Ht-2). High-nutrient wastewater encourages algae growth, which lowers the amount of oxygen released during the breakdown of the algae.[14] Phosphate enters the reservoir directly from the deposition of organic materials in the sediment by the primary producers, eventually settling in the water.[36,37]ANOVA revelled a significant difference among the sampling stations ($p > 0.05$).

Water scarcity is an essential constraint on the vegetation and fauna dispersal of a water body. The orthophosphate levels recorded in this study are comparable to those found in heavily impacted coastal lagoons, where sediment release plays a major role.[38,39] The mean water transparency was the highest at Pt-1 (0.31 m ± 0.02 m) and the lowest at Pt-2 (0.28 m ± 0.05 m) at TA, and the highest at Ht-2 (0.31 m ± 0.01 m) and the lowest at Ht-1 and 3 (0.28 m ± 0.04 m) at TH. The mean concentration showed no significant difference among the sampling stations ($p < 0.05$). The water samples from both TH and TAs are green in colour; thus, the low water transparency was due to the heavy suspended particles that are made more turbid by a dense population of algae.[40] Recent studies highlight sediment–water phosphorus exchange as a major challenge in lake restoration, often sustaining eutrophication even after external inputs are reduced.[41,42]

Correlation analysis: the results of (r) for the parameters of the water samples ($p < 0.01$ and $p < 0.05$) are presented in Table 4. The results revealed that the pair parameters have a positive correlation ($r > 0.7$) with EC-NO_2-N ($r = 0.713$, $p < 0.01$): Suggests that nutrient inputs are concentrated in areas with higher ionic content, highlighting potential inflow sources, and NH_4-N-Chlorophyll-a, at $p < 0.01$. The strong positive correlation between NH_4-N and chlorophyll-a ($r = 1.00$, $p < 0.01$) confirms that nitrogen inputs drive algal growth. Management actions could target nutrient reduction at inlets through buffer strips or sediment traps. While pH-Orthophosphate, BOD-NH_4-N and BOD-Chlorophyll-a at $p < 0.05$. This signifies their concurrent discharge from a similar source. The NO_2-N, orthophosphate, pH, transparency, and temperature BOD showed a negative correlation ($r > –0.5$) at $p < 0.01$ and $p < 0.05$, respectively; this may not have originated from the same sources. Negative correlations (e.g., pH–transparency, $r = –0.578$, $p < 0.05$): Alkaline conditions favour algal proliferation and reduce water clarity. These relationships reveal the interdependence of nutrient loading, algal growth and water quality deterioration. Targeting nutrient sources, particularly at inlets, is critical for restoring the ecological balance. The negative correlation between NO_2-N and orthophosphate ($r = –0.752$, $p < 0.01$) is complex and may indicate different redox-dependent release mechanisms from the sediment or preferential uptake by different functional groups. This aligns with the findings of the reservoir studies, which emphasise that the internal phosphorus loading sediments sustain' eutrophication long after the external inputs are controlled.[11]

Table 4: Correlation analysis (*r*) parameters of water samples

Parameters	pH	Temp	EC	TDS	TSS	DO	BOD	NO_2-N	NH_4-N	Chlorophyll-a	Orthophosphate	Transparency
Ph	1	0.272	–0.298	0.298	–0.241	–0.008	–0.153	–0.480	0.103	0.103	0.615*	–0.578*
Temp		1	–0.075	–0.003	–0.209	0.154	–0.590*	–0.190	–0.482	–0.482	–0.086	–0.519
EC			1	0.195	0.010	–0.031	0.172	0.713**	–0.154	–0.154	–0.364	–0.120
TDS				1	–0.159	0.118	0.387	–0.319	0.114	0.114	0.558	–0.454
TSS					1	–0.558	–0.219	0.268	0.127	0.127	–0.225	0.011
DO						1	–0.074	–0.322	0.052	0.052	0.242	0.260
BOD							1	–0.038	0.593*	0.593*	0.112	0.209
NO2-N								1	–0.241	–0.241	–0.752**	0.291
NH4-N									1	1.000**	0.284	0.154
Chlorophyll-a										1	0.284	0.154
Orthophosphate											1	–0.357
Transparency												1

Note: * = Correlation is significant at the 0.05 level (2-tailed); ** = Correlation is significant at the 0.01 level (2-tailed).

4. CONCLUSION

This study successfully assessed the physicochemical and biochemical characteristics of TA and TH and established their current water quality status relative to the Malaysian NWQS. Both lakes were classified as Class IIB, indicating moderate pollution and clear signs of eutrophication. The study's quantitative findings indicate that TSS exceeded Class IIB guidelines at all stations, with levels ranging from 55.60 mg/L–61.65 mg/L in TA and 57.28 mg/L–60.95 mg/L in TH. The BOD values were also within the Class IIB range, indicating moderate organic pollution. DO levels were low, particularly at THpt-1, with a measure of 4.21 mg/L, near the threshold for aquatic life. Nutrient enrichment was marked, with ammonia-nitrogen and nitrite-nitrogen levels indicating advanced eutrophication, evident through high chlorophyll-a concentrations far exceeding typical thresholds. The highest nutrient concentrations were found at the inlets, confirming that Sungai Gambir is the primary source of pollution. The correlation analysis revealed strong relationships between nutrient levels and algal proliferation, indicating a feedback loop that requires intervention. The TAs and TH can be restored to healthier ecological states by integrating nutrient load reduction, sediment management, ecosystem restoration, and sustained monitoring. This will enhance their vital functions in flood mitigation, recreation, and biodiversity support within the USM campus.

4.1 Recommendation

1. Pollutant interception at inlets through constructed wetlands, sediment traps, or biofiltration units, particularly in the Sungai Gambir inflow zones.

2. Source reduction strategies, including identification and control of agricultural runoff and upstream sewage leakage, and stormwater nutrient inputs.

3. Internal load management, such as sediment dredging in nutrient-rich zones, to reduce internal nutrient recycling. Algal bloom control and aeration enhancement, given the low DO and high chlorophyll-a values across both lakes.

4. Continuous monitoring and finer spatial segmentation of the lakes to support predictive modelling and evaluate remediation effectiveness.

5. ACKNOWLEDGEMENTS

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