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ASSESSING TROPHIC STATE AND WATER QUALITY OF SMALL LAKES AND PONDS IN PERAK

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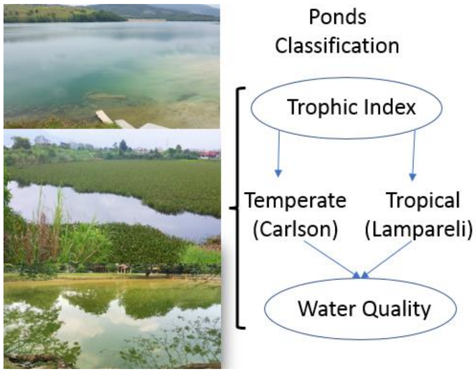
Graphical abstract



Abstract

There are thousands of ponds and small lakes in Perak created naturally or as a result of past mining activities in the 1800s and 1900s. Some of these small water bodies have been converted to lake park to provide other ecosystem services such as recreation besides having potential to be used as alternative water supply. Most of these lakes were not monitored nor evaluated in terms of their water quality or trophic conditions to enable better understanding of their safe application for recreation. Water quality sampling was performed at sixteen lakes and ponds in Perak involving *in situ* and ex-situ measurements of ten environmental parameters. About six lakes have very low dissolved oxygen (DO) levels needed to sustain aquatic life and few lakes have very low transparency levels (<0.3 m) to be compatible for primary contact recreational use. More than 75% of the study lakes and ponds were nutrient rich. Trophic state analyses using different indices developed for temperate and tropical environments showed one lake in oligotrophic condition, five lakes in mesotrophic to eutrophic conditions and 10 lakes in eutrophic to hypereutrophic conditions. Hypereutrophic lakes were characterised as having low DO, high nutrient, turbidity, and chlorophyll *a*. This study found some deviations among the trophic classification of lakes between temperate and tropical indices and suggests the use of a suitable trophic index to provide better understanding of the trophic conditions of waterbodies in Perak. Continuous monitoring using the specific water quality criteria and standards for lakes will support preservation of lake ecosystem health.

Keywords: Ecosystem health, eutrophication, ponds, water quality, waterbodies

Abstrak

Terdapat beribu kolam dan tasik kecil di Perak yang terbentuk secara semula jadi atau hasil daripada aktiviti perlombongan pada tahun 1800-an dan 1900-an. Sebahagian daripada badan air kecil ini telah ditukar kepada taman tasik untuk menyediakan perkhidmatan ekosistem lain seperti rekreasi selain berpotensi untuk digunakan sebagai bekalan air alternatif. Walau bagaimanapun, kebanyakan tasik ini tidak dipantau atau dinilai dari segi kualiti air atau keadaan trofik untuk membolehkan pemahaman yang lebih baik tentang penggunaan selamat untuk tujuan rekreasi. Persampelan kualiti air dilakukan di enam belas tasik dan kolam di Perak yang melibatkan pengukuran in situ dan exsitu bagi sepuluh parameter persekitaran. Kira-kira enam tasik mempunyai kandungan oksigen terlarut (DO) yang sangat rendah yang diperlukan untuk mengekalkan hidupan akuatik dan beberapa tasik mempunyai tahap kejernihan yang sangat rendah (<0.3 m) untuk sesuai bagi kegunaan rekreasi dengan sentuhan secara langsung. Lebih daripada 75%

tasik dan kolam yang dikaji adalah kaya dengan nutrien. Analisis trofik menggunakan indeks yang dibangunkan untuk persekitaran iklim sederhana dan tropika menunjukkan satu tasik berada dalam keadaan oligotrofik, lima dalam keadaan mesotrofik - eutrofik dan 10 tasik dalam keadaan eutrofik - hipereutropik. Tasik hipereutropik dicirikan sebagai mempunyai DO yang rendah, nutrien, kekeruhan dan klorofil a yang tinggi. Kajian ini mendapati beberapa perbezaan di antara klasifikasi tropik tasik antara indeks iklim sederhana dan tropika dan mencadangkan penggunaan indeks trofik yang sesuai untuk memberi pemahaman yang lebih baik tentang keadaan trofik badan air di Perak. Pemantauan berterusan menggunakan kriteria dan piawaian kualiti air tasik akan menyokong pemeliharaan kesihatan ekosistem tasik

Kata kunci: Kesihatan ekosistem, eutrofikasi, kolam, kualiti air, badan air

1.0 INTRODUCTION

Malaysia is rich with small water bodies that were created from tin mining activities during the colonial administration in the 1800s and 1900s [1]. The disused tin mining pools and pits stored rain water and formed water bodies and ecosystems for natural habitats. Some of these ponds were used for aquaculture activities and duck rearing while others were used for recreational purposes and flood mitigation [1]. According to Yusoff *et al*. (2006), about 6.3% of the 4300 disused mining ponds with a combined size of 11.6 km^2 are used for aquaculture [2]. The utilisation of former mining ponds as alternative water sources has increased as a result of the scarcity of water during prolonged low rainfall periods [3]. Small ponds were also essential habitats for flora and fauna, but they also had a big impact on climate control, carbon sequestration, and nutrient fluxes [4].

However, many of these small ponds in Malaysia were not monitored nor assessed in terms of its water quality and trophic state to enable determination of the overall lake ecosystem health. The assessment of water quality offers details on the degree of contamination and the suitability of the lake's water for various beneficial purposes, including the supply of drinking water, recreation, and other economic benefits like irrigation and livestock. The chlorophyll *a* and nutrient levels that support growth are measured by the trophic state, which offers information on the biological productivity of the lake.

Increasing water quality studies were noted in many reservoirs and large lakes in Malaysia [3]. Few research on ponds focuses on heavy metal contents due to concerns on the effects of dissolution of mine tailing or waste to human consumption [4, 5, 6, 7]. High concentrations of heavy metals such as lead, cadmium, and arsenic were reported in few ex-mining ponds [5]. Similarly, heavy metals assessment in Taiping Lake, an ex-tin mine, indicated that heavy metals concentration namely leads, cadmium and ferum exceeded the standards limit set by the Department of Environment of Malaysia and Ministry of Health Malaysia [7]. Sulaiman *et al.* (2018) found significant variation of water quality and heavy metals in two ex-mining ponds, one located in rural and another in urban areas induced by natural and anthropogenic processes [8]. High acidity level was recorded in the ex-tin mining in Bukit Besi making it unsuitable for direct recreation contact uses [8]. High arsenic content was reported in Klang Valley ponds that posed both non-carcinogenic and carcinogenic risk to adults if ingested while no health concerns reported for dermal contact [6].

Similarly, increasing studies on eutrophication status in Malaysia were focused on lakes and reservoirs [3, 9]. The findings from this study showed more than 60% were nutrient-rich, which is a concern if no action is taken to monitor and manage the water bodies. As eutrophication is a global aquatic concern [10, 11], measures were taken to promote integrated management of the lake basin to reduce the wickedness of the challenges it postured [12]. As few studies showed that eutrophication will increase due to climate factors such as increasing precipitation and temperature [10, 13], measures to monitor and assess the condition of all types of lentic water bodies is necessary.

There is a need to assess the potential impacts of eutrophication in small water bodies due to their wide distribution and socio-economic contributions [4]. Compared to bigger water bodies, these small water bodies also have distinctive qualities and greater vulnerability. Few studies in stormwater ponds indicate small water bodies are a sequestration of nutrient and carbon [14], but due to their small size they have a reduced capacity to trap phosphorus [15] while some ponds can release previously trapped phosphorus and become a source to downstream areas [16]. Some studies showed that increased nutrient and eutrophication in these small water bodies or ponds led to favourable growth of more specialized species, reduced differentiation of aquatic composition leading to a loss of ecosystem processes and increased vulnerability of these ecosystems [17]. Studies on the trophic state of small water bodies such as ex-mining lakes are scarce in

Malaysia. Few studies found that some ex-mining ponds in Slim River and Kampar to be nutrient rich and experience algae bloom occasionally and posed health risk [18, 19].

The main objective of this study was to evaluate the trophic status and relevant water quality parameters in different ex-mining ponds in Perak, Malaysia. The selection on Perak's small water bodies is due to some records that reported the state to have the greatest number of ex-mining ponds in the country [1, 2]. The second objective of this study was to compare the use of different trophic state index to determine the trophic status of these lakes and their relationship to water quality in order to support their use for various purposes as well as to guide management efforts. Two trophic indices were studied namely the Carlson trophic index, which was designed for temperate environments but still widely used index applied worldwide and the Lamparelli trophic index which was developed for tropical environments. The selection of these indices is due to its similarity of parameters for assessing trophic status. These indices have advantages as they only use a small number of parameters.

2.0 METHODOLOGY

Field surveys were undertaken to various ex-mining ponds and lakes in Perak in August to October 2020. During the field survey, some of the ponds were inaccessible as they have already become private lands and barricaded. Due to resource limitation and the enforcement of Movement Control Order (MCO) in Malaysia to curb Covid-19 spread, a total of sixteen lakes and ponds located within Kinta, Kampar and Larut, Matang & Selama districts in Perak were selected for evaluation of water quality and trophic conditions as shown in Figure 1 and Table 1.

Figure 1 Location of study lakes and ponds

Table 1 Study area

Waterbodies	Abbre-viation	Size (hectare)	Function
Taiping Lake	TLG	19.8	Recreation
Tekkah pond	TP	5.9	Flood mitigation
Kamunting Lake	KL	16.2	Flood mitigation
KTM Kampar pond	KTM	30.6	Flood mitigation
Kampar pond	KP	4.8	Flood mitigation
Gopeng pond	GP	12.3	Flood mitigation
Kinta Lake	KLP	70.9	Habitat
Paradise Valley lake	PVL	7.8	Recreation
Siber pond	SP	1.2	Flood mitigation
Seri Botani Lake	SBP	3.8	Recreation
Impiana Adril Lake	IAL	30.6	Flood mitigation
Gunung Lang Lake	GL	5	Recreation
Cemerlang Emas pond	CE	0.7	Flood mitigation
Bercham pond	BP	5.3	Flood mitigation
Tg Tualang Pond	TTP	30.3	Flood mitigation
Lahat pond	LP	51.1	Flood mitigation

In Situ measurements of dissolved oxygen (DO), temperature, pH, conductivity, turbidity, and salinity were undertaken using a multi-parameter probe (YSI). Samples were collected using a van Dorn sampler, preserved at 4°C and transported to an accredited laboratory for analysis of total phosphorus (TP), chlorophyll *a* and total nitrogen (TN) following Standard Methods [20]. All measurements were taken at 0.5 m from the water surface. The multi-parameter probe was carefully lowered into the water at each site to minimise error, and data were recorded after the probe measurement was steady. Transparency was measured by lowering the 20 cm Secchi disk into the water of each lake. Trophic states were analysed using two trophic indexes namely Carlson TSI [21] and Lamparelli TSI [22]. The trophic state was based on three parameters namely Chlorophyll *a*, total phosphorus, and Secchi depth transparency.

The Carlson TSI was based on the mean values of TSI chlorophyll a (Equation 1), TSI total phosphorus (Equation 2) and TSI Secchi depth (Equation 3) as follows:

$$TSI\ (Chlorophyll\ a) = 9.81 \times Ln\,Chla + 30.6 \tag{1}$$

$$TSI\ (Total\ phosphorus) = 14.42 \times Ln\,TP + 4.15 \tag{2}$$

$$TSI\ (Secchi\ depth) = 60 - 14.41 \times Ln\,SD \tag{3}$$

The Lamparelli TSI was based on the mean values of TSI (chlorophyll *a*) (Equation 4), and TSI (total phosphorus) (Equation 5) as follows:

$$TSI\ (Chlorophyll\ a) = 10\left\{6 - \left[0.92 - \frac{0.34 \times Ln\ Chla}{Ln\ 2}\right]\right\} \quad (4)$$

$$TSI\ (Total\ phosphorus) = 10\left\{6 - \left[1.77 - \frac{0.42\ \times Ln\ TP}{Ln\ 2}\right]\right\} \quad (5)$$

Where SD is the value of Secchi depth transparency in meter, TP is total phosphorus and Chla is chlorophyll *a*, both values in µg/L. The classification of the trophic states for both methods is given in Table 2.

The water quality status was referred to the National Lake Water Quality Criteria and Standards (NLWQS) for Malaysia [23].

Table 2 Trophic state classification

Carlson TSI (Temperate)		Lamparelli TSI (Tropical)	
Oligotrophic	TSI ≤ 40	Ultraoligotrophic	TSI ≤ 47
Mesotrophic	40 – 50	Oligotrophic	47 – 52
Eutrophic	50 – 60	Mesotrophic	52 – 59
Hypereutrophic	TSI ≥ 60	Eutrophic	59 – 63
		Supereutrophic	63 – 67
		Hypereutrophic	TSI ≥ 67

All data were initially cleaned and processed using the exploratory data analysis in SPSS software, version 22. Skewed data namely chlorophyll *a*, TP and TN were log-transformed prior to statistical analysis. Spearman correlation coefficient was used to measure the strength of the linear relationship between study variables. Data for each lake were pooled to provide average values prior to relationship testing. Analysis of variances (ANOVA) were undertaken to assess the relationship between the trophic classifications (four groups - 1: ultraoligotrophic – oligotrophic, 2: Mesotrophic, 3: Eutrophic, 4: Supereutrophic – hypereutrophic) with other environmental variables. Significant relationship is considered at $p < 0.05$.

3.0 RESULTS AND DISCUSSION

3.1 Water Quality Characteristics

About six lakes have very low DO levels needed to sustain aquatic life (< 3 mg/L, Table 3). The lowest DO concentration was recorded at Cemerlang Emas pond followed by Bercham pond. These low DO levels affect ecosystem health as it can lead to fish kills, increase decomposition process, and induce internal loading which led to explosion of aquatic species that tolerate low DO, and subsequently reduced further biodiversity (17, 24). Low DO concentration in Cemerlang Emas pond was likely from organic waste pollution. Many ponds in urban areas have been found to experience organic waste issues such as food waste and sullage from restaurants, wet markets, and housing areas, and sewage from inadequate wastewater treatment facilities [9, 25, 26]. For Gopeng and Bercham ponds, the low DO levels were likely induced by the floating macrophytes cover that blocked penetration of light for photosynthesis [27]. In both lakes, water hyacinth was dense, covering more than 70% of the lake cover during the sampling. Few studies have shown similar hypoxic conditions in lakes covered by vegetation [27, 28] The pH levels in most ponds were alkaline and ranged between 6.9 to 9.4.

Table 3 Mean environmental variables in study lakes and ponds

Lake	DO (mg/L)	pH	Temp (°C)	Turbidity (NTU)	Cond (µS/cm)	Secchi depth (m)
TLG	8.0	7.5	31.2	5.3	26	0.9
TP	4.9	7.0	33	4.1	61.8	1.6
KL	8.3	8.5	33	3.6	52.2	2
KTM	8.9	8.9	32.2	8.7	255.4	0.7
KP	7.8	8.0	31.3	8.4	145	0.6
GP	2.9	7.1	29.1	57.1	86.7	0.3
KLP	9.3	9.4	31.7	12.6	204.8	0.6
PVL	2.6	7.7	30.5	9.5	244.6	0.7
SP	1.9	7.4	29.7	83	342.6	0.2
SBP	6.9	7.6	32.5	5.9	77.5	0.8
IAL	9.0	9.4	31.9	6.8	188.2	1.3
GL	7.8	8.4	32	5.4	223.2	1.2
CE	0.9	7.3	28.8	43.5	380.5	0.3
BP	1.1	6.9	27.7	7.3	246.2	0.6
TTP	2.8	7.4	30.3	12.1	301.8	0.9
LP	8.0	7.9	31	4	199	5.4

Three lakes had turbidity levels exceeding the lake standard and criteria for primary contact recreation (40 NTU) namely Gopeng, Siber, and Cemerlang Emas ponds. Few lakes have very low transparency levels (<0.3 m) to be compatible for primary contact recreational use [23]. The highest Secchi depth transparency was found in Lahat pond followed by Kamunting pond. The transparency level recorded here is much higher compared to other findings such as Kenyir Lake [26] but lower than the records in Puteri Lake [29]. Conductivity levels in most of these small water bodies were relatively higher >100 µS/cm. Such high conductivity levels indicate highly dissolved ions and salts in the water similar to observations in other ex-mining ponds [10, 30]. TP concentrations were high in most lakes (≥ 0.05 mg/L) that can promote eutrophication. Only two lakes namely Kamunting and Bandar Seri Botani lakes have TP <0.01 mg/L. Siber and Cemerlang Emas ponds have high TN concentrations exceeding 10 mg/L while Kinta, Kampar and Tg Tualang ponds have TN levels around 3 mg/L.

3.2 Trophic State Analyses

Trophic state analyses using index developed for temperate environments showed at least four lakes were in oligotrophic to mesotrophic conditions and 12 lakes in eutrophic to hypereutrophic conditions (Table 4). Trophic state analyses using index developed for tropical environments showed at least five lakes were in oligotrophic to mesotrophic conditions and 11 lakes in eutrophic to hypereutrophic conditions. There are three lakes with contrasting classification of trophic states. Only one lake namely Lahat pond (Figure 2) was very different in terms of their TSI values. This lake has high Secchi depth transparency but the exclusion of transparency parameters in the Lamparelli trophic index calculation makes the lake supereutrophic.

Figure 1 Photo of oligotrophic – mesotrophic lake (top) and eutrophic – hypereutrophic lake (bottom)

Overall, one water body was oligotrophic, five water bodies mesotrophic to eutrophic and ten water bodies were eutrophic to hypereutrophic. This means that more than 75% of the study lakes were nutrient-rich with phosphorus and nitrogen. Among the potential consequences of high nutrient levels (eutrophication) in the lakes and ponds include excessive growth and blooms of certain phytoplankton species namely cyanobacteria such as *Microcystis* spp. that can produce toxin which are harmful to human and aquatic life [18, 31]. These harmful algal blooms not only affect water quality but also the overall ecosystem health.

3.3 Relationship between Trophic State and Water Quality

Statistical analysis indicated that chlorophyll *a* were positively correlated to TP ($R^2 = 0.444$), and TN ($R^2 = 0.490$) and negatively correlated to Secchi depth transparency ($R^2 = 0.619$) (Table 5). Increase in TP and TN will increase biological productivity [21]. On the other hand, an increase in chlorophyll *a* will decrease the transparency of the lake making it more turbid. Both Carlson TSI and Lamparelli TSI showed significant positive correlation with turbidity, conductivity, TP and TN and negative correlation with transparency. Lakes with higher nutrient concentrations (TP and TN) are also classified as more eutrophic based on the trophic state indices used in the study.

Figure 3 showed the relationship between TSI (chlorophyll *a*) and TSI (TP) for both methods. In this study both Lamparelli and Carlson's TSI (chlorophyll *a*) was significantly different from their TSI (TP) ($p < 0.05$). According to Cunha *et al.*, [32], averaging both chlorophyll *a* and TP in a single TSI value are probably not appropriate when this deviation occurred [32]. Deviation among equations and trophic classification systems between the two indices (temperate and tropical settings) have been observed in other studies and likely induced by differences in other factors such as turbidity, water temperature, and cyanobacterial biomass [32].

Table 4 Trophic state classification of study lakes and ponds

Lake/ pond	Carlson TSI (CTSI)	Status	Lamparelli TSI (LTSI)	Status
TLG	56	Eutrophic	61	Eutrophic
TP	51	Eutrophic	59	Eutrophic
KL	31	Oligotrophic	46	Oligotrophic
KTM	66	Eutrophic	66	Supereutrophic
KP	68	Eutrophic	67	Hypereutrophic
GP	59	Eutrophic	58	Mesotrophic
KLP	65	Eutrophic	65	Supereutrophic
PVL	65	Eutrophic	65	Supereutrophic
SP	85	Hypereutrophic	75	Hypereutrophic
SBP	47	Mesotrophic	55	Mesotrophic
IAL	58	Eutrophic	62	Eutrophic
GL	48	Mesotrophic	56	Mesotrophic
CE	83	Hypereutrophic	74	Hypereutrophic
BP	69	Eutrophic	67	Hypereutrophic
TTP	58	Eutrophic	56	Mesotrophic
LP	42	Mesotrophic	63	Supereutrophic

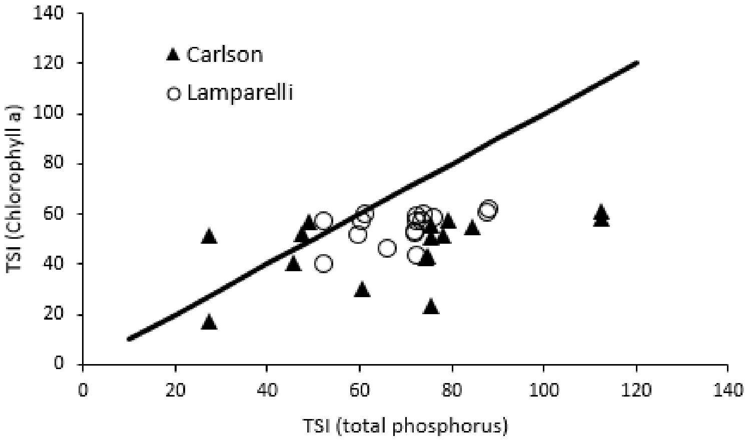


Figure 2 Relationship among the Lamparelli and Carlson TSI components

Table 5 Spearman Correlation between parameters

Parameter	DO	Temp	Turb	Cond	pH	Chl *a*	SD	TP	TN	CTSI	LTSI
DO	1										
Temp	**.660**	1									
Turb	*-.455*	**-.567**	1								
Cond	*-.482*	**.544**	**.573**	1							
pH	**.825**	**.558**	-.270	-.163	1						
Chl *a*	-.310	-.147	.395	.245	-.235	1					
SD	**.526**	**.519**	.351	**-.461**	.351	**-.619**	1				
TP	-.368	**-.680**	**.714**	**.600**	-.110	**.444**	**-.671**	1			
TN	-.354	-.424	**.707**	**.640**	-.112	**.490**	**-.659**	**.647**	1		
CTSI	*-.420*	**-.521**	**.769**	**.510**	-.190	**.760**	**-.861**	**.873**	**.684**	1	
LTSI	-.337	*-.452*	**.638**	**.508**	-.095	**.769**	**-.702**	**.890**	**.675**	**.956**	1

Note: DO – Dissolved oxygen, Temp – Temperature, Turb – turbidity, Chl *a* – chlorophyll a, TP – total phosphorus, TN – Total nitrogen, CTSI – Carlson TSI, LTSI – Lamparelli TSI, item in bold: p<0.01, item in italic: p <0.05

ANOVA on Carlson trophic classification showed significant differences in Secchi depth ($p < 0.01$), chlorophyll *a* ($p < 0.001$) and total nitrogen ($p < 0.05$). However, ANOVA on Lamparelli trophic classification only showed significant differences in chlorophyll *a* ($p < 0.01$). Findings from Cunha *et al*., [32] also observed similar divergences in TSI components resulting in different trophic state classifications. Transparency is not taken into account in the Lamparelli TSI calculation, probably because other suspended particles in addition to algae biomass also have an impact on transparency [22,32]. It is well known that suspended particles carried from the degraded catchment cause substantial turbidity problems in many tropical lakes and reservoirs [26]. As a result, the Lamparelli TSI primarily considers the relationship between algal biomass and nutrient. This study was solely based on Perak's small water bodies with short-term data collection thus limited to enable generalization.

Figure 4 illustrates the relationship between certain environmental parameters and trophic classification. Hypereutrophic conditions were associated with low DO, and high turbidity, total phosphorus and chlorophyll *a*. Water having low DO content or hypoxia are unsafe for aquatic life and together with low transparency hinder direct contact recreation activities. Eutrophic water may have an adverse effect on human health when harmful algal blooms (HAB) produce toxin that can cause poisoning and illness such as gastrointestinal and skin disease and eventually mortality [31]. Worldwide reports indicated that HABs were causing taste and odour issues as well as posing a concern to the security of drinking water [10, 31]. Eutrophication and HAB have been linked to economic losses in lakes in the United States of America, including decreased lakefront home values, losses from fish kills and tourism, rising costs for water treatment and purchases of bottled water due to taste and odour issues, loss of biodiversity and cost associated with protecting endangered species and their habitats [31].

3.4 Summary of Findings

This study documented that more than 75% of the study lakes were nutrient-rich with phosphorus and nitrogen. Eutrophic lakes have poor water quality including low DO content, clarity, and excessive turbidity. The potential risks to human health, aquatic life, and recreational activities are higher in these lakes, which could result in socioeconomic losses from fisheries, water supply, and tourism. Assessment using different trophic indices, instead of single averaged TSI, will improve understanding on the trophic classifications for individual lakes. Water bodies that meet all the criteria for all nine common parameters of NLWQS were Taiping Lake Garden, Kamunting Lake, Gunung Lang Lake, Bandar Seri Botani and Lahat ponds. Further study should evaluate the microbiological and heavy metals levels of these lakes to confirm their suitability for primary contact recreation. In this study, the most polluted water bodies were Cemerlang Emas pond and Siber pond consistent with low water quality and high nutrient (TP and TN), subsequently hypereutrophic conditions.

Qualitative observation showed these two ponds were also polluted with solid waste likely transported by stormwater drains those discharges from nearby residential areas. Two ponds have issues of water hyacinth infestation namely Bercham pond and Gopeng pond. High nutrient content in lakes can promote the excessive growth of macrophytes [28], such as water hyacinth, as reported in many other lakes such Victoria Lake, Kenya [33], Tana Lake, Ethiopia [34], and Rawapening Lake, Indonesia [35]. In hypereutrophic Siber pond, algal blooms were noted at the lake surface (Figure 2). Additionally, long-term monitoring of water quality and trophic parameters in these lakes and ponds will provide better understanding of the seasonal changes of trophic conditions.

This study reported one lake to be nutrient poor namely Tekkah Lake in Larut, Matang and Selama District. The use of a different trophic index will provide better understanding of the trophic conditions of lakes and ponds in Perak.

Numerous eutrophic and hypereutrophic lakes have an impacts of the state's water resource management and conservation effort since they could impact the lakes' suitability as alternative water sources or recreational areas. The findings of this study may have potential governance implications, requiring management strategies be developed to control eutrophication in all eutrophic and hypereutrophic water bodies. Efforts should be undertaken by the relevant authorities to locate and control pollution sources to these lakes and devise measures to enhance or restore the lake water quality. Among the strategies in reducing nutrient and controlling pollution from flowing into the lake includes improvement in municipal wastewater treatment, reducing organic pollutants from wet markets and restaurants, and adopting best management practices in erosion control and fertilizer application of agriculture lands [9, 26, 31]. Another recommendation for preserving water quality and mitigating eutrophication is to undertake continuous monitoring of water quality based on the criteria and standards for lakes.

The improvement of municipal wastewater treatment, the reduction of organic pollutants from wet markets and restaurants, and the adoption of best management practises in erosion control and fertiliser application of agricultural lands are some of the strategies in reducing nutrients and controlling pollution from flowing into the lake [9, 26, 31]. Continuous water quality monitoring based on the requirements for lakes is another suggestion for protecting water quality and reducing eutrophication.

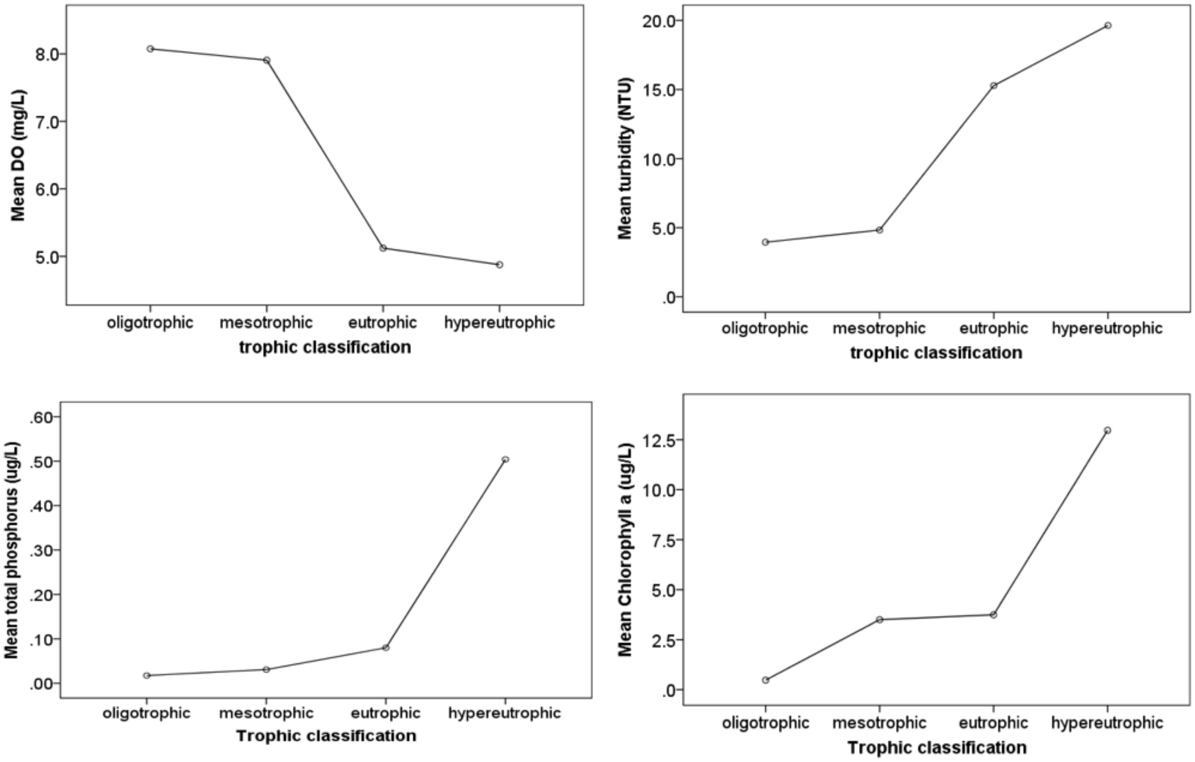


Figure 4 Water quality variables in relation to Carlson trophic classification

4.0 CONCLUSION

This study documented trophic status of different ex-mining ponds in Perak; one pond was categorised as oligotrophic, five were meso-eutrophic and ten were eutrophic to hypereutrophic. Hypereutrophic ponds were consistently more polluted; besides nutrient-rich but also having poor water quality. High chlorophyll *a* and algal productivity were positively correlated to nutrients which negatively affect the transparency. These low water quality in some of the water bodies are not suitable for body contact recreation and have potential health and ecological risk. This work compared the trophic status of the studied ponds in Perak based on two different indices, with some deviation among trophic classification systems between the two due to other factors. Overall, this study advances knowledge of the trophic state, and ecological conditions of these small water bodies as well as their water quality. The health of the lake ecosystem can be better understood through ongoing parameter monitoring utilising the water quality criteria and standards for lakes, which will also help identify management strategies for lakes for different human uses.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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References

[1] Ahmad, S., Jones, D. 2013. Investigating the Mining Heritage Significance for Kinta District, the Industrial Heritage Legacy of Malaysia. *Procedia - Social and Behavioral Sciences*. 105: 445-457. Doi: http://dx.doi.org/10.1016/j.sbspro.2013.11.047.

[2] Yusoff, F. M., Shariff, M., & Gopinath, N. 2006. Diversity of Malaysian Aquatic Ecosystems and Resources. *Aquatic Ecosystem Health & Management*. 9(2): 119-135. Doi: http://dx.doi.org/10.1080/14634980600713315.

[3] Sharip, Z., Zulkifli, M. H., Johar, Z., Amin, M. Z. M., Md Noh, M. N. 2020. A reassessment on the Inventory of Water Bodies in Malaysia and Trophic Status of Selected Lake Types. *Malaysia Water Research Journal*. 10: 70-79.

[4] Mullins, M. L., Doyle, R. D. 2019. Big Things Come in Small Packages: Why Limnologists Should Care about Small Ponds. *Acta Limnologica Brasiliensia*. 31. Doi: http://dx.doi.org/10.1590/S2179-975X4119.

[5] Low, K. H., Koki, I. B., Juahir, H., Azid, A., Behkami, S., Ikram, R., Mohammed, H. A., Zain, S. M. 2016. Evaluation of Water Quality Variation in Lakes, Rivers, and Ex-mining Ponds in Malaysia. *Desalination and Water Treatment*. 57: 28215-28239. Doi: http://dx.doi.org/10.1080/19443994.2016.1185382.

[6] Koki, I. B., Hin, L. K., Juahir, H., Zali, M. A., Azid, A., Zain, S. M. 2017. Consumption of Water from Ex-mining Ponds in Klang Valley and Melaka, Malaysia: A Health Risk Study. *Chemosphere*. 195: 641-652 Doi: http://dx.doi.org/10.1016/j.chemosphere.2017.12.112.

[7] Nasir, N., Mohmadisa, H., Yazid, S., Kamarul, I., Hanifah, M., See, K. 2016. The Concentration Levels of Heavy Metals in the Recreational Lake, Taiping Lake Gardens, Perak. *Geografi*. 4: 36-45

[8] Sulaiman, N. H., Khalit, S. I., Sharip, Z., Samsudin, M. S., Azid, A. 2018. Seasonal Variations of Water Quality and Heavy Metals in Two Ex-mining Lakes using Chemometric Assessment Approach. *Malaysian Journal of Fundamental and Applied Sciences*. 14: 67-72.

[9] NAHRIM. 2009. *Study on the Status of Eutrophication of Lakes in Malaysia*. Seri Kembangan: NAHRIM.

[10] Chakrabarti, S. 2018. Eutrophication—A Global Aquatic Environmental Problem: A Review. *Research & Review: Journals of Ecology and Environmental Science*. 6: 1-6.

[11] Nakamura, M. 1997. Preserving the Health of the World Lakes. *Environment*. 39: 16-40.
Doi: http://dx.doi.org/10.1080/00139159709603645.

[12] Thornton, J. A., Harding, W. R., Dent, M., Hart, R. C., Lin, H., Rast, C. L., Rast, W., Ryding, S-O., Slawski, T. M. 2013. Eutrophication as a 'Wicked' Problem. *Lakes & Reservoirs: Research & Management*. 18: 298-316.
Doi: http://dx.doi.org/10.1111/lre.12044.

[13] Sinha, E., Michalak, A. M., Balaji, V. 2017. Eutrophication will Increase During the 21st Century as a Result of Precipitation Changes. *Science*. 357: 405.
Doi: http://dx.doi.org/10.1126/science.aan2409.

[14] Ljung, K., Lin, S. 2023. Organic Carbon Burial in Constructed Ponds in Southern Sweden. *Earth Science, Systems and Society*. 3.
Doi: https://doi.org/10.3389/esss.2023.10061.

[15] Schroer, W. F., Benitez-Nelson, C. R., Smith, E. M., Ziolkowski, L. A. 2018. Drivers of Sediment Accumulation and Nutrient Burial in Coastal Stormwater Detention Ponds, South Carolina, USA. *Ecosystems*. 21(6): 1118-1138. Doi: http://dx.doi.org/10.1007/s10021-017-0207-z.

[16] Taguchi, V. J., Olsen, T. A., Natarajan, P., Janke, B. D., Gulliver, J. S., Finlay, J. C., Stefan, H. G. 2020. Internal Loading in Stormwater Ponds as a Phosphorus Source to Downstream Waters. *Limnology and Oceanography Letters*. 5(4): 322-330.
Doi: https://doi.org/10.1002/lol2.10155.

[17] Duré, G. A. V., Simões, N. R., Braghin, LdSM, Ribeiro, S. M. M. S. 2021. Effect of Eutrophication on the Functional Diversity of Zooplankton in Shallow Ponds in Northeast Brazil. *Journal of Plankton Research*. 43(6): 894-907.
Doi: http://dx.doi.org/10.1093/plankt/fbab064.

[18] Kitan, Y. A., Sinang, S. C. 2020. Evaluation of Eutrophication Indicators in Slim River Lake, Perak – Malaysia. *International Journal of Multidisciplinary*. 5.
Doi: http://dx.doi.org/10.31305/rrijm.2020.v05.i11.001.

[19] Pin, D. C. M., Guo, X., Wang, K., Chng, L-M., Wong. L-P., Zhao, X. 2019. Assessment of Water Eutrophication in Kampar, Malaysia. Pages 020022. *AIP Conference Proceedings*, AIP Publishing LLC.
Doi: http://dx.doi.org/10.1063/1.5126557.

[20] APHA. 2012. Standard Methods for the Examination of Water and Waste Water. American Public Health Association (APHA).

[21] Carlson, R. E. 1977. A Trophic State Index for Lakes. *Limnology and Oceanography*. 22: 361-369.

[22] Lamparelli, M. C. 2004. *Trophic Status in Sao Paolo Waterbodies - Evaluation Of Monitoring Methodologies*. University of Sao Paolo.

[23] NAHRIM. 2015. *National Lake Water Quality Criteria and Standards,* in Water Quality and Environment Division, ed. Seri Kembangan: National Hydraulic Research Institute of Malaysia.

[24] Miranda, L. E., Hargreaves, J. A., & Raborn, S. W. 2001. Predicting and Managing Risk of Unsuitable Dissolved Oxygen in a Eutrophic Lake. *Hydrobiologia*. 457: 177-185.

[25] Sharip, Z., & Mohamad, M. F. 2019. Microbial Contamination in Urban Tropical Lentic Water Bodies and Ponds along Urbanisation Gradient. *Journal of Tropical Agriculture Science*. 42(1): 165-184.

[26] Sharip, Z., Zaki, A. T. A., Shapai, M. A. H., Suratman, S., Shaaban, A. J. 2014. Lakes of Malaysia: Water Quality, Eutrophication and Management. *Lakes & Reservoirs: Research & Management*. 19: 130-141.
Doi: http://dx.doi.org/10.1111/lre.12059.

[27] Goodwin, K., Caraco, N., & Cole, J. 2008. Temporal Dynamics of Dissolved Oxygen in a Floating-leaved Macrophyte Bed. *Freshwater Biology*. 53(8): 1632-1641. Doi:10.1111/j.1365-2427.2008.01983.x.

[28] Dersseh, M., Steenhuis, T., Kibret, A., Eneyew, B., Kebedew, M., Zimale, F., Worqlul, A., Moges, M., Abebe, W., Mhiret, D. 2022. Water Quality Characteristics of a Water Hyacinth Infested Tropical Highland Lake: Lake Tana, Ethiopia. *Frontiers in Water*. 4: 774710.
Doi: http://dx.doi.org/*10.3389/frwa*.

[29] Sharip, Z., Salmah, Z., Amin, M. Z. M. 2021. Assessing Lakes using Specific Lake Water Quality Criteria and Standard for Malaysia. *Malaysian Journal of Biochemistry and Molecular Biology*. *International E-Conference of Science and Biosphere Reserve*. 164-171.

[30] Ashraf, M. A., Maah, M. J., Yusoff, I. 2012. Morphology, Geology and Water Quality Assessment of Former Tin Mining Catchment. *The Scientific World Journal*. 369206.
Doi: http://dx.doi.org/10.1100/2012/369206.

[31] Wurtsbaugh, W. A., Paerl, H. W., Dodds, W. K. 2019. Nutrients, Eutrophication and Harmful Algal Blooms along the Freshwater to Marine Continuum. *Wiley Interdisciplinary Reviews: Water*. 6(5): e1373.
Doi: http://dx.doi.org/10.1002/wat2.1373.

[32] Cunha, D. G. F., Finkler, N. R., Lamparelli, M. C., Calijuri, MdC, Dodds, W. K., Carlson, R. E. 2021. Characterizing Trophic State in Tropical/Subtropical Reservoirs: Deviations among Indexes in the Lower Latitudes. *Environmental Management*. 68: 491-504.
Doi: http://dx.doi.org/10.1007/s00267-021-01521-7.

[33] Bick, E., de Lange, E. S., Kron, C. R., da Silva, Soler, L., Liu, J., Nguyen, H. D. 2020. Effects of Salinity and Nutrients on Water Hyacinth and Its Biological Control Agent. Neochetina bruchi. *Hydrobiologia*. 847: 3213-3224.
Doi: http://dx.doi.org/ 10.1007/s10750-020-04314-x.

[34] Otieno, D., Nyaboke, H., Nyamweya, C. S., Odoli, C. O., Aura, C. M., Outa, N. O. 2022. Water Hyacinth (Eichhornia crassipes) Infestation Cycle and Interactions with Nutrients and Aquatic Biota in Winam Gulf (Kenya), Lake Victoria. *Lakes & Reservoirs: Science, Policy and Management for Sustainable Use*. 27: e12391.
Doi: http://dx.doi.org/10.1111/lre.12391.

[35] Prasetyo, S., Anggoro, S., Soeprobowati, T. R. 2021. The Growth Rate of Water Hyacinth (Eichhornia crassipes (Mart.) Solms) in Rawapening Lake, Central Java. *Journal of Ecological Engineering*. 22: 222-231
Doi: http://dx.doi.org/10.12911/22998993/137678.