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Water Quality Dynamics in Kemajuan Lake: Statistical Evaluation Using CTSI and WQI

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Abstract

Kemajuan Lake, an artificial lake within Universiti Tun Hussein Onn Malaysia (UTHM), faces increasing anthropogenic stress from campus activities and surrounding infrastructure. This study statistically evaluates the lake's water quality using the Carlson Trophic State Index (CTSI) and the Malaysian Water Quality Index (WQI), supported by correlation analysis, hypothesis testing, ANOVA, F-tests, and paired sample t-tests. Weekly water samples were collected over 40 weeks, analysing physicochemical parameters including turbidity, total suspended solids (TSS), nitrate, ammoniacal nitrogen (AN), temperature, dissolved oxygen (DO), and pH. Based on descriptive analysis, Kemajuan Lake was classified as eutrophic (mean CTSI = 70.23) and slightly polluted (mean WQI = 72.57, Class III under NWQS). The average parameter values were turbidity = 20.70 NTU, TSS = 15.45 mg/L, nitrate = 0.36 mg/L, AN = 0.55 mg/L, temperature = 27.94°C, DO = 4.12 mg/L, and pH = 6.80. Pearson correlation showed a strong positive relationship between CTSI and turbidity ($r = 0.648$) and moderate negative correlations between WQI and both TSS ($r = -0.552$) and AN ($r = -0.413$). Hypothesis testing and ANOVA confirmed significant differences between CTSI and WQI, indicating they reflect distinct water quality attributes. This study concludes that both CTSI and WQI offer complementary insights into eutrophication and general pollution levels and should be applied in tandem for accurate water quality monitoring. The findings support the practical implementation of a dual index monitoring strategy for urban lake management, promoting more targeted remediation efforts, early detection of eutrophication, and sustainable aquatic ecosystem conservation.

1. Introduction

Freshwater lakes are vital ecosystems that support biodiversity, regulate local hydrology, and provide essential recreation, education, and water supply services [1]. However, lakes situated in urban or institutional environments are increasingly exposed to anthropogenic pressures such as nutrient loading, sediment deposition, and runoff pollution [2]. These disturbances can lead to a decline in water quality and the onset of eutrophication, a condition characterised by excessive nutrient enrichment, algal blooms, oxygen depletion, and the disruption of aquatic life [3].

Eutrophication is primarily driven by elevated concentrations of nitrogen and phosphorus, which are often sourced from point and non-point pollution such as stormwater runoff, untreated discharges, and surrounding land use activities [4]. Changes associated with eutrophication can be detected by monitoring of physicochemical parameters, including pH, dissolved oxygen (DO), ammoniacal nitrogen (AN), nitrate (NO_3^-), total suspended solids (TSS), turbidity, and temperature [5]. Monitoring these variables is critical to understanding a lake's trophic condition and ecological stability.

Kemajuan Lake, located within the main campus of Universiti Tun Hussein Onn Malaysia (UTHM), functions as an artificial lake intended for stormwater retention, campus aesthetics, and educational purposes [6]. Over time, the lake has been increasingly subjected to pollution from both point and non-point sources, including campus runoff, nearby construction activity, and discharges from the surrounding infrastructure. These inputs have introduced sediment, nutrients, and other pollutants into the water body, potentially triggering ecological imbalances [7]. Anecdotal evidence, such as murky water, sediment buildup, and possible algal growth, has raised concerns about the lake's trophic state and overall water quality. Despite its functional and ecological significance within the university environment, comprehensive studies assessing the water quality in Kemajuan Lake, mainly using quantitative and statistical approaches, remain limited.

The Carlson Trophic State Index (CTSI) is a widely used tool for evaluating the trophic condition of lakes, particularly for eutrophication. It is based on three key parameters: chlorophyll-a concentration, total phosphorus, and water transparency (Secchi depth) [8]. These indicators provide insight into algal biomass, nutrient status, and light penetration. The CTSI classifies lakes into the following trophic categories: oligotrophic (low productivity), mesotrophic (moderate productivity), and eutrophic (high productivity), which reflect the biological response to nutrient enrichment [8]. Although developed in temperate regions, the CTSI has been adopted in numerous studies across tropical and subtropical environments, including Malaysia, to assess the biological productivity in lakes and reservoirs.

Complementing the trophic assessment is the Malaysian Water Quality Index (WQI), a national classification system developed to evaluate and categorise water quality for river and lake systems [9]. The WQI is derived from six core parameters: DO, BOD, COD, pH, TSS, and ammoniacal nitrogen (AN). It provides a composite score that places water bodies into predefined classes ranging from clean (Class I) to heavily polluted (Class V). It serves as a practical tool for policymakers and environmental managers. The WQI is particularly relevant in the Malaysian context as it aligns with the National Water Quality Standards (NWQS). It is used extensively in water quality reporting by agencies such as the Department of Environment (DOE) [10].

While CTSI and WQI have been widely used independently in lake and river water quality assessments, comparative applications of both indices in tandem remain limited, particularly in tropical climates like Malaysia [11]. Most existing studies adopt a single-index approach, which may overlook the nuanced differences between biological productivity (as captured by CTSI) and overall pollution levels (reflected in WQI). This study bridges this gap by statistically evaluating the relationship between the two indices within the same sampling regime. The integration of CTSI and WQI in this context contributes novel regional insight into how eutrophication and general pollution coexist or diverge in tropical, anthropogenically influenced lake systems. These findings hold practical significance for designing more responsive and adaptive lake monitoring frameworks, especially for urban water bodies susceptible to both nutrient enrichment and multiple pollution sources.

This study applies key statistical methods to analyse water quality in Kemajuan Lake. These include Pearson correlation to examine relationships between water quality parameters, t-tests and ANOVA to test for significant differences between the CTSI and WQI, and F-tests to check the equality of variances. These techniques provide a solid framework for understanding the interactions among water quality indicators and support informed lake management decisions.

2. Methodology

2.1 Study Area

Kemajuan Lake is an artificial lake located within the main campus of Universiti Tun Hussein Onn Malaysia (UTHM) in Parit Raja, Johor. The lake was initially constructed to control floods and retain stormwater. However, it now functions as a living laboratory for academic activities and an aesthetic feature. Its location in a semi-urban institutional setting exposes it to various environmental stressors, including runoff from nearby buildings, paved surfaces, and construction zones within the campus. These inputs introduce suspended solids, nutrients, and thermal variations that may contribute to the ecological imbalance in the lake. Given its multipurpose function and the increasing signs of water quality degradation, Kemajuan Lake was selected as the focus of this study.

2.2 Water Sampling and Analysis

Weekly water sampling was conducted at Kemajuan Lake for ten months (40 weeks) from May 14, 2023 to February 11, 2024, with all sampling consistently performed on Sundays to minimise temporal variability and anthropogenic influences. A GPS coordinate application determined the sampling points, which correspond to the following positions: Point A (01°51'34.6" N, 103°05'08.4" E), Point B (01°51'36.9" N, 103°05'10.9" E), and Point C (01°51'39.9" N, 103°05'12.1" E). Fig. 1 displays a top view of the lake, showing the distribution of these sampling locations. Field measurements utilising a calibrated HI98194 multiparameter meter provided in-situ readings of pH, dissolved oxygen (DO), and water temperature, while Secchi disk measurements determined water transparency. Composite samples were prepared to capture spatial variability by combining grab samples from multiple predefined locations across the lake, enabling the integrated assessment of water quality parameters [12]. Laboratory analyses followed standard protocols for biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), ammoniacal nitrogen (AN), nitrate (NO_3^-), total phosphorus (TP), and chlorophyll-a (Chl-a), with complete method details summarised in Table 1. This comprehensive approach ensured a representative evaluation of the lake's water quality dynamics.

Fig. 1 *Sampling location*

Table 1 *Water parameters and the method for analysis*

Water Parameter	Method
pH, Dissolved oxygen, Temperature	Hanna Instrument 98194 Multiparameter meter
Water transparency	Secchi Disc
Total suspended solids	DR6000 (HACH Method 8006)
Turbidity	TB400 Turbidity Meter
Chlorophyll-a	Based on the methanol extraction method of Pearson *et al.*, (1987) [13]
Total phosphorus	DR6000 (HACH Method 8190)
Ammoniacal nitrogen	DR6000 (HACH Method 8038)
Nitrate	Ion Chromatography

2.3 Carlson Trophic State Index (CTSI) and the Water Quality Index (WQI)

Two well-established indices, the Carlson Trophic State Index (CTSI) and the Malaysian Water Quality Index (WQI), were utilised to evaluate the trophic status and overall water quality of Kemajuan Lake. The CTSI, developed by Carlson (1977) [8], is commonly used to classify lake productivity levels based on nutrient availability and algal biomass. The formulation incorporates chlorophyll-a, total phosphorus, and Secchi disk transparency. The formula of the CTSI is shown in Equation (1) to Equation (4), and the lake was categorised as oligotrophic, mesotrophic, eutrophic, and hypertrophic based on the calculated index.

$$TSI\ (SD) = 10(6 - (\ln \frac{SD}{\ln 2})) \tag{1}$$

$$TSI(Chl - a) = 10\left(\frac{6 - 2.04 - 0.68\ \ln Chl - a}{\ln 2}\right) \tag{2}$$

$$TSI\ (TP) = 10(6 - (\ln \frac{48\,TP}{\ln 2})) \tag{3}$$

$$CTSI = \frac{(TSI(SD) + TSI(Chl - a) + TSI(TP))}{3} \tag{4}$$

Where; SD = Secchi Disk Transparency (m), Chl-a = Chlorophyll-a (µg/L) and TP = Total Phosphorus (µg/L)

Although initially developed for temperate lakes, the CTSI has been widely applied in tropical and subtropical countries with suitable adaptations. Several Malaysian studies have demonstrated its reliability in identifying eutrophic conditions in urban lakes, albeit with contextual limitations. The selection of CTSI in this study is justified by its capacity to track nutrient-driven productivity trends using chlorophyll-a, total phosphorus, and transparency, equally relevant parameters in tropical lake dynamics. Furthermore, combining CTSI with WQI offers a broader evaluation, accommodating biological productivity and physicochemical pollution in tropical environments.

In parallel, the Malaysian Water Quality Index (WQI) was used to evaluate the general water quality status of the lake. The WQI was calculated based on six core parameters: dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, total suspended solids (TSS), and ammoniacal nitrogen (AN). The WQI was calculated using the formula in Equation (5):

$$WQI = (0.22 \times SIDO) + (0.19 \times SIBOD) + (0.16 \times SICOD) + (0.15 \times SIAN) + (0.16SISS) + (0.12 \times SIpH) \tag{5}$$

In this formula, each sub-index (SI) is computed on the basis transformation curves developed by the Department of Environment (DOE) Malaysia [14], and the weights reflect the relative importance of each parameter. The resulting WQI score classified water into five classes: Class I (clean), Class II (good), Class III (moderate), Class IV (polluted), and Class V (very polluted). This index provides a broad assessment of water usability and environmental health. CTSI and WQI offer a dual perspective on Kemajuan Lake's condition, combining productivity level analysis with pollution level classification.

2.4 Correlation Analysis

Correlation analysis serves as a fundamental statistical method for assessing the strength and direction of the linear relationship between two variables: the independent variable (X) and the dependent variable (Y) [15]. This relationship is quantified using the correlation coefficient (r), which measures the variables' magnitude and direction of association. The calculation of the correlation coefficient, expressed as the r-value, is derived from the observed data points of X and Y, offering a precise numerical representation of their interdependence. This analytical approach facilitates a deeper understanding of the extent to which variations in the independent variable correspond to changes in the dependent variable. The formula of the correlation is shown in Equation (6). Fig. 2 displays the summary of the direction and strength of r.

$$r = \frac{n(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{[N9\Sigma X^2) - (\Sigma X)^2][N(\Sigma Y^2) - (\Sigma Y)^2]}} \tag{6}$$

Where, X=independent variable, Y= dependent variable, and n = number of samples

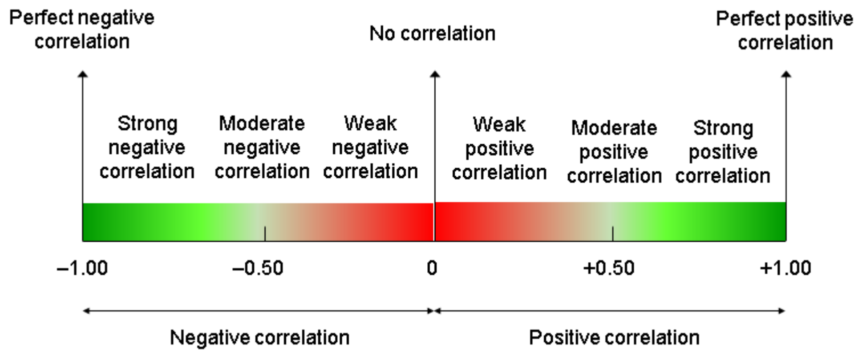


Fig. 2 *Summary of the strength of the correlation [16]*

As illustrated in Fig. 2, if r is near zero, it suggests a weak association between the variables. In contrast, as r approaches ±1.00, the relationship strengthens, indicating a near-perfect correlation. Under such conditions, an individual's score on one variable can reliably predict their score on the other [16]. However, a value of r = 0 denotes the complete absence of any linear relationship. Prior study suggests that correlation coefficients falling within the range of ±3.5 are generally acceptable [16]. Consequently, the optimal interpretive range for r lies between -3.5 and 3.5, as demonstrated in Fig. 3.

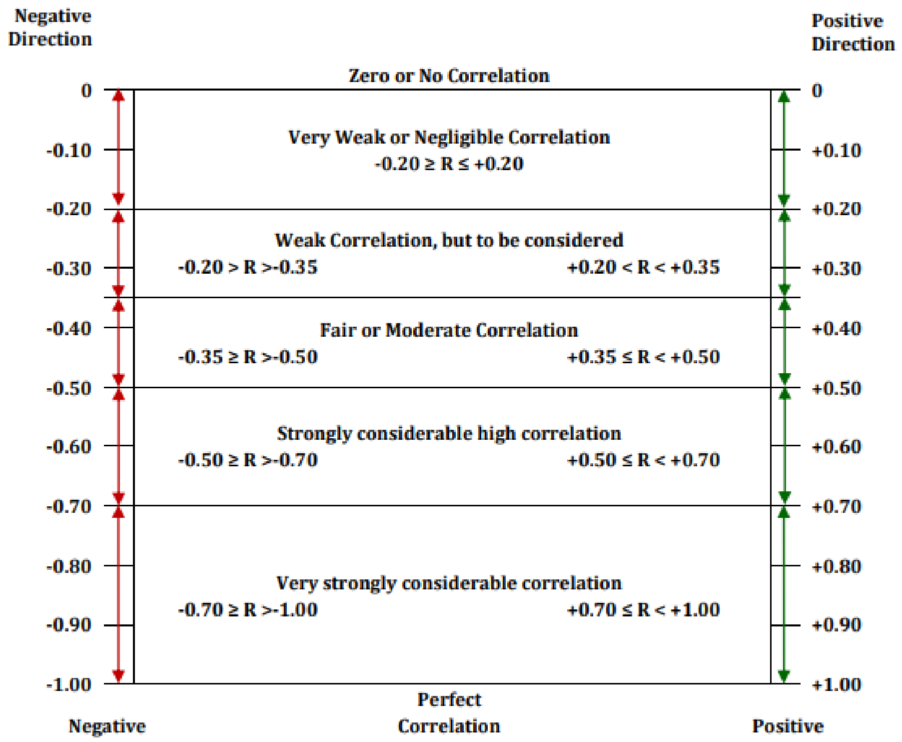


Fig. 3 *Recommended interpretation range for correlation coefficients [16]*

2.5 Hypothesis Testing

Hypothesis testing, also known alternatively as significance testing, employs probabilistic methods and sample data to evaluate the validity of statistical claims [17]. The approach requires the formulation of two competing propositions: the null hypothesis (H_0) and the alternative hypothesis (H_a). By convention, H_0 represents the default position unless contradicted by sufficient empirical evidence. The null hypothesis makes specific claims about population parameters, while the alternative hypothesis (frequently representing the research hypothesis) gains credence when the sample data provide compelling evidence against H_0. This study conducted two-sample hypothesis testing to assess whether significant differences existed between the population means. The complete testing procedure is illustrated in Fig. 4.

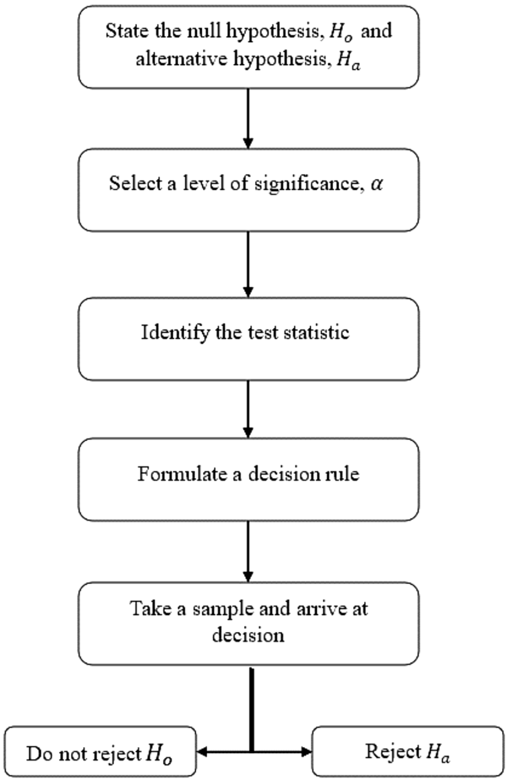


Fig. 4 *Procedure for hypothesis testing*

Hypothesis testing evaluated the potential associations between the CTSI and WQI indices. These complementary metrics serve distinct but interrelated functions in water quality assessment. The CTSI quantifies the eutrophication status through Chl-a concentration, TP levels, and SD measurements. The WQI comprehensively evaluates the DO, BOD, COD, TSS, AN, and pH values. The H_0 states no significant relationship exists between the CTSI and WQI values, while the H_a suggests a statistically meaningful association. Statistical analysis assessed whether variations in eutrophication levels, measured via CTSI, corresponded to changes in overall water quality, represented by WQI scores [11].

Establishing this relationship is critical for understanding how nutrient-driven eutrophication processes influence general water quality parameters. The findings may inform more effective management strategies to address nutrient enrichment in lacustrine ecosystems, potentially enabling targeted interventions to mitigate ecological impacts while maintaining broader water quality standards.

2.6 Analysis of Variance (ANOVA)

To further validate the comparison between WQI and CTSI, a one-way Analysis of Variance (ANOVA) was conducted. While the t-test compares two means directly, ANOVA provides a broader framework for comparing means across multiple groups and confirms consistency in findings [18]. In this case, it was applied to verify the difference in means between the WQI and CTSI datasets. The ANOVA F-statistic is computed as in Equation (7):

$$F = \frac{MS_{between}}{MS_{within}} \quad (7)$$

Where:
$MS_{between} = SS_{between} / df_{between}$: mean square between groups
$MS_{within} = SS_{within} / df_{within}$: mean square within groups

Hypothesis for ANOVA:

H_0: $\mu_{WQI} = \mu_{CTSI}$ (no difference between group means)
H_a: At least one group mean is different

If the *p*-value from the ANOVA output is less than the significance level (0.05), it indicates that a statistically significant difference exists between the means of WQI and CTSI.

2.7 F-test

Before conducting the paired t-test, an F-test was employed to assess whether the variances of the two datasets (WQI and CTSI) were statistically equal. This step is critical as it determines whether the assumption of equal variances holds, which informs the choice of subsequent t-test parameters [18].
The F-statistic is calculated using the formula shown in Equation (8):

$$F = \frac{s^2_{WQI}}{s^2_{CTSI}} \quad (8)$$

Where:
s^2_{WQI} = variance of the first sample (WQI)
s^2_{CTSI} = variance of the second sample (CTSI)
F follows the F-distribution with degrees of freedom $df_1=n_1-1$ and $df_2=n_2-1$

Hypothesis for the F-test:
H_0: $\sigma^2_{WQI} = \sigma^2_{CTSI}$ (equal variances)
H_a: $\sigma^2_{WQI} \neq \sigma^2_{CTSI}$ (unequal variances)

If the p-value < 0.05, the null hypothesis of equal variances is rejected, and the analysis proceeds under the assumption of unequal variances in the subsequent t-test.

2.8 Paired Sample t-test

The paired sample t-test was employed to compare the means of WQI and CTSI, as the measurements were collected from the exact sampling locations and under similar conditions. This test is suitable for identifying whether a significant difference exists between the two related groups [19]. The test statistic is calculated as shown in Equation (9):

$$t = \frac{\bar{d}}{s_d/\sqrt{n}} \quad (9)$$

Where:
$\bar{d}$= mean of the differences between paired observations
s_d=standard deviation of the differences
n = number of pairs
t follows the t-distribution with $n-1$ degrees of freedom

Hypothesis for paired t-test:
H0: $\mu_d = 0$ (no difference in means between WQI and CTSI)
Ha: $\mu_d \neq 0$ (significant difference in means)

If the p-value obtained is less than 0.05, the null hypothesis is rejected, indicating a statistically significant difference between WQI and CTSI values.

3. Results and Discussion

3.1 Descriptive Statistics

Table 2 presents the descriptive statistics for the key water quality parameters assessed in this study, including the CTSI, WQI, and supporting physicochemical variables such as turbidity, TSS, nitrate, AN, temperature, DO, and pH. Each parameter was measured from 40 samples (N = 40), with the mean and standard deviation calculated to provide insight into the central tendency and variability of the data.

The WQI recorded a mean of 72.57 (±3.54), indicating that the water quality condition of Kemajuan Lake was slightly polluted according to the Malaysian National Water Quality Standards (NWQS). The relatively low standard deviation suggests consistency across the sampling points. In parallel, the CTSI yielded a mean value of 70.23 (±3.99), classifying the lake as eutrophic, reflecting elevated biological productivity likely due to increased nutrient enrichment, consistent with prior eutrophication concerns identified in this study area [20].

The turbidity and TSS showed mean values of 20.70 NTU and 15.45 mg/L, respectively, which are moderately high and may indicate suspended particulate matter or algae proliferation [21]. These values correlate with the eutrophic status suggested by the CTSI. Nutrient levels, particularly nitrate (0.3625 mg/L) and AN (0.554 mg/L), were present in low concentrations yet sufficient to sustain algal growth. Although the levels appear within acceptable limits individually, their combined presence can still support eutrophication processes.

The average temperature was 27.94°C, within the optimal range for freshwater ecosystems, but may influence the metabolic rates and oxygen solubility of aquatic organisms [22]. DO recorded a mean of 4.12 mg/L, which, while not critically low, approaches the lower threshold necessary to support aquatic life. The relatively small standard deviation (±0.54) shows uniformity in the oxygen distribution, potentially influenced by the algae photosynthesis and decomposition processes [23]. pH levels of this lake average 6.80, with minimal fluctuation (±0.38), aligning with typical freshwater bodies in tropical climates.

The descriptive statistics provide an initial understanding of the lake's water quality. The results suggest eutrophic water conditions, driven by nutrient enrichment and characterised by suspended solids, moderate DO levels, and slightly alkaline pH. These findings form a basis for subsequent inferential analysis (e.g., t-tests, ANOVA, f-test, correlation, hypothesis testing) to evaluate significant relationships and differences between indices such as WQI and CTSI and their influencing parameters.

Table 2 *Descriptive statistics*

	Mean	Standard Deviation	N
CTSI	70.23	3.99	40
Turbidity	20.70	3.19	40
TSS	15.45	4.43	40
Nitrate	0.36	0.15	40
AN	0.55	0.15	40
Temperature	27.94	2.03	40
DO	4.12	0.54	40
pH	6.80	0.38	40
WQI	72.57	3.54	40

3.2 Correlation Analysis

Pearson's correlation analysis was conducted to examine the linear relationships between the CTSI, WQI, and a suite of water quality parameters, including turbidity, TSS, nitrate, AN, temperature, DO, and pH. The strength and direction of the correlation coefficients (r-values) were interpreted on the basis of the standard classification of correlation strength, ranging from negligible to very strong correlations. Table 3 shows the Pearson correlation coefficients among all parameters analysed in this study.

The results revealed a strongly considerable positive correlation between CTSI and turbidity (r = 0.648), indicating that the lake's trophic status increases as turbidity levels increase. This relationship is expected, as higher turbidity typically results from elevated concentrations of suspended particles, including algal biomass, characteristic of eutrophic conditions [18]. In contrast, a moderate negative correlation was observed between CTSI and DO (r = -0.445), suggesting that higher trophic states are associated with lower dissolved oxygen levels. This is consistent with the ecological processes involved in eutrophication, where oxygen is depleted due to the microbial decomposition of organic matter following algal blooms [24]. CTSI also showed a weak negative correlation with nitrate (r = -0.280), implying that nitrate concentrations tend to decrease slightly as eutrophication intensifies, possibly due to nutrient uptake by phytoplankton. The relationship between CTSI and ammoniacal nitrogen (r = 0.129) and pH (r = 0.054) was found to be very weak, indicating a minimal linear association. The correlation between CTSI and temperature was also weak (r = 0.240), suggesting that temperature may influence algal growth and metabolic rates [25]. However, it was not a dominant driver of trophic state variation in this study. Notably, the correlation between CTSI and WQI was negligible (r = 0.008), which suggests that although both are water quality indicators, they likely reflect different aspects of lake conditions and rely on different parameter weightings.

Regarding WQI, the strongest correlation was a considerable negative one with TSS (r = -0.552), highlighting the significant impact of suspended solids on the perceived water quality. As TSS increases, water quality deteriorates, likely due to the reduction in light penetration and the potential transportation of pollutants [18]. A moderate negative correlation was also observed between WQI and ammoniacal nitrogen (r = -0.413), further supporting the role of nutrient pollution in degrading water quality. Additionally, weak negative correlations were found between WQI and nitrate (r = -0.290), turbidity (r = -0.240), and temperature (r = -0.213), indicating that increased nutrient loads and warmer conditions are weakly associated with lower WQI scores. On the other hand, pH exhibited a weak positive correlation with WQI (r = 0.234), suggesting that slightly alkaline conditions may be favourable to water quality within the observed range. Dissolved oxygen showed a very weak positive correlation with WQI (r = 0.095), suggesting that DO alone may not substantially influence the index, although it remains ecologically important. The negligible correlation coefficient (r = 0.008) between CTSI and WQI not only highlights their methodological differences but also has important ecological implications. CTSI is sensitive to biological productivity (e.g., algal blooms), while WQI integrates a wider range of physicochemical stressors, some of which may not directly correlate with nutrient-driven eutrophication. In tropical lakes, where organic pollution, sediment load, and thermal stratification vary independently from nutrient dynamics, it is plausible for CTSI and WQI to diverge. This reinforces the idea that relying solely on one index could lead to an incomplete understanding of lake health, particularly in systems influenced by biological and chemical stress.

These findings indicate that different water quality parameters contribute distinctly to classifying trophic status and general water quality. CTSI and WQI provide a more holistic assessment of lake health, allowing for improved monitoring and management of eutrophication and water pollution in Kemajuan Lake.

Table 3 *Pearson's correlation analysis*

	CTSI	Turbidity	TSS	Nitrate	AN	Temperature	DO	pH	WQI
CTSI	1.000	0.648	-0.115	-0.280	0.129	0.240	-0.445	0.054	0.008
Turbidity	0.648	1.000	0.254	-0.181	0.240	0.139	-0.276	0.110	-0.240
TSS	-0.115	0.254	1.000	0.072	0.002	-0.137	0.046	-0.396	-0.552
Nitrate	-0.280	-0.181	0.072	1.000	0.095	-0.044	0.327	0.004	-0.290
AN	0.129	0.240	0.002	0.095	1.000	0.289	-0.262	0.115	-0.413
Temperature	0.240	0.139	-0.137	-0.044	0.289	1.000	-0.637	-0.005	-0.213
DO	-0.445	-0.276	0.046	0.327	-0.262	-0.637	1.000	-0.050	0.095
pH	0.054	.0110	-0.396	0.004	0.115	-0.005	-0.050	1.000	0.234
WQI	0.008	-0.240	-0.552	-0.290	-0.413	-0.213	0.095	0.234	1.000

3.3 Hypothesis Testing

The hypothesis tested in this study is shown below:

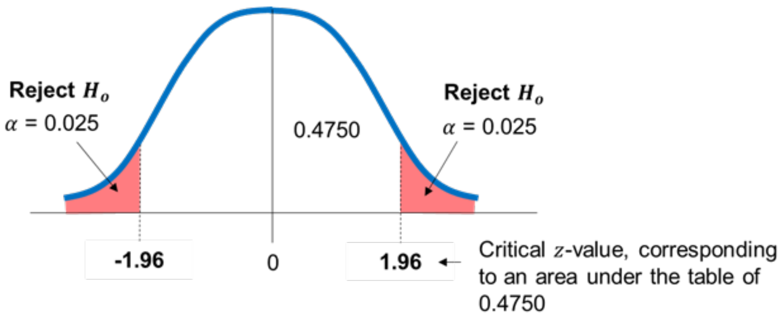
H_o: There is no significant relationship between CTSI and WQI
H_a: There is a significant relationship between CTSI and WQI

Table 4 presents the calculated mean values, variances, and sample sizes for the CTSI and WQI measurements. As the sample sizes n and m satisfy the requirements for normal distribution of the sample means, the analysis employs the z-statistic as defined in Equation (10). The hypothesis testing procedure adopts a conventional significance level of α=0.05, utilising a two-tailed test approach.

Table 4 *Mean, variance and sample size for CTSI and WQI of Kemajuan Lake*

	CTSI	WQI
Mean, $\bar{X}$	70.228	72.575
Variance, s^2	15.957	12.561
Sample size, n	40	40

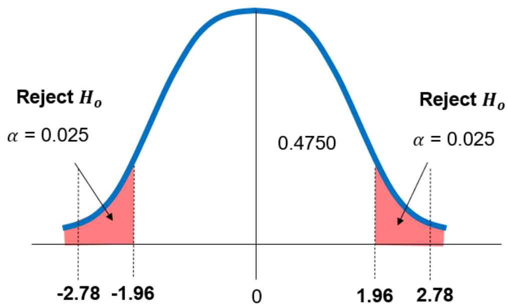
Critical z-value = 0.5-0.025 = 0.475



$$z = \frac{\bar{X}_X - \bar{X}_Y}{\sqrt{\frac{{s_X}^2}{n} + \frac{{s_Y}^2}{m}}} \tag{10}$$

Where:
$\bar{X}_X$ = mean of the first sample X
$\bar{X}_Y$ = mean of the second sample Y
${s_X}^2$ = variance of the first sample X
${s_Y}^2$ = variance of the second sample Y
n = size of the first sample X
m = size of the second sample Y

$$z_{calculated} = \frac{70.228 - 72.575}{\sqrt{\frac{15.975}{40} + \frac{12.561}{40}}} = -2.78$$



The analysis yielded a calculated z-value of -2.78, which exceeds the critical threshold of -1.97 magnitude and falls within the rejection region. This result necessitates rejecting the H_0 in favour of the alternative hypothesis H_a, indicating a statistically significant association between the CTSI and WQI measurements. The inverse relationship demonstrates that elevated CTSI values, indicative of worsening eutrophic conditions, correspond with decreased WQI scores, reflecting deteriorating water quality [11]. These findings confirm that nutrient concentrations, as measured through the CTSI framework, impact the comprehensive water quality parameters encapsulated by the WQI. Such a quantitative understanding of this relationship provides valuable insights for developing evidence-based water resource management protocols and targeted intervention strategies.

3.4 Analysis of Variance (ANOVA)

To assess whether the mean differences between the WQI and CTSI were statistically significant, a one-way Analysis of Variance (ANOVA) was performed. The test was structured under the following hypothesis:

H_o: There is no significant difference in the mean values between WQI and CTSI ($\mu_1 = \mu_2$)
H_a: There is a significant difference in the mean values between WQI and CTSI ($\mu_1 \neq \mu_2$).

As summarised in Table 5, the average value of WQI (72.5747) is slightly higher than that of CTSI (70.2277), with variances of 12.56136 and 15.95666, respectively. Despite the relatively close numerical proximity, the ANOVA confirms that this difference is unlikely due to random sampling variation and is statistically meaningful. The ANOVA results in Table 6 show an F-statistic of 7.72621, with a p-value of 0.0068. This p-value is well below the 0.05 significance level, and the F-statistic exceeds the critical F-value ($F_{critical}$ = 3.96347). Therefore, the null hypothesis is rejected, indicating a statistically significant difference in the mean values of WQI and CTSI.

Table 5 *Descriptive statistics of WQI and CTSI for the single-factor ANOVA analysis*

Groups	Count	Sum	Average	Variance
WQI	40	2902.99	72.57	12.56
CTSI	40	2809.11	70.23	15.96

Table 6 *ANOVA results comparing the means of WQI and CTSI values*

Source of variation	SS	df	MS	F	p-value	$F_{critical}$
Between groups	110.17	1	110.17	7.73	0.0068	3.96
Within groups	1112.20	78	14.26			
Total	1222.37	79				

The analysis of variance also showed the between-group sum of squares (SS) = 110.1681, while the within-group SS = 1112.203, highlighting that the variability between the two indices is measurable despite more considerable intra-group variability. The mean square (MS) between the groups was substantially higher than within the groups (110.17 vs. 14.26), further supporting the conclusion of significant divergence in index performance.

These findings are consistent with the paired t-test outcome, reinforcing that WQI and CTSI do not yield identical assessments for the same water bodies. This result is important for water quality monitoring, particularly in nutrient-sensitive environments. While WQI reflects general water usability based on a broader range of physicochemical parameters, CTSI focuses narrowly on trophic status and eutrophication indicators, such as chlorophyll-a, Secchi depth (water clarity), and total phosphorus. The statistically significant difference in their means indicates that the two indices should not be used interchangeably. Instead, they offer complementary perspectives on water quality.

3.5 F-test

An F-test was conducted to evaluate whether there was a significant difference in the WQI and the CTSI variances. The hypothesis for the F-test was as follows:

H_0: The variances of WQI and CTSI are equal.
H_a: The variances of WQI and CTSI are unequal.

Table 7 shows the F-test results comparing the variances between WQI and CTSI. The calculated F-statistic was 0.787, with the corresponding p-value = 0.2292 (one-tailed). The critical F-value at the 0.05 significance level was 0.5867. The null hypothesis is not rejected since the p-value is greater than 0.05 and the F-statistic is greater than the critical value. This indicates no statistically significant difference in the variances between the WQI and CTSI.

Table 7 *F-test results comparing the variances between WQI and CTSI*

	WQI	CTSI
Mean	72.574	70.228
Variance	12.561	15.957
Observations	40	40
df	39	39
F	0.787	
P(F<=f) one-tail	0.229	
F Critical one-tail	0.587	

These results imply that the variability in the assessments provided by both indices is statistically comparable. Despite the earlier paired t-test revealing a significant difference in their mean values, the similar variance suggests that both indices show a relatively consistent spread in their respective scores across the observed data.

In practical terms, while WQI and CTSI differ in evaluating water quality, WQI being a general index and CTSI being specific to eutrophication, the fluctuation (or variability) in their values across different sampling points is statistically similar. This supports the suitability of the parallel use of both indices in monitoring programmes, mainly when aiming to balance general water quality assessment with eutrophication-focused evaluation.

3.6 Paired Two-Sample t-test

A paired sample t-test was conducted to determine whether there was a statistically significant difference between the mean values of the WQI and the CTSI. This test evaluates the hypothesis that the two means are equal, considering paired observations for the same sampling points in Kemajuan Lake. The hypothesis tested were as follows:

H_0: There is no significant difference between the means of WQI and CTSI ($\mu_1 = \mu_2$).
H_a: There is a significant difference between the means of WQI and CTSI ($\mu_1 \neq \mu_2$).

As presented in Table 8, the mean values of WQI and CTSI were 72.57 and 70.23, respectively, with variances of 12.56 and 15.96. The test statistic t was calculated as 2.7913, which exceeds the critical t value of 2.0227 for a two-tailed test at the 0.05 significance level with 39 degrees of freedom. Furthermore, the associated p-value for the two-tailed test was 0.008, which is less than 0.05. Since the test statistic exceeds the critical value and the p-value is below the significance level, the null hypothesis is rejected in favour of the alternative hypothesis.

Table 8 *t-test results comparing the variances between WQI and CTSI*

	WQI	CTSI
Mean	72.57	70.23
Variance	12.56	15.96
Observations	40	40
Pearson Correlation	0.008	
Hypothesised Mean Difference	0	
df	39	
t Stat	2.79	
P(T<=t) one-tail	0.004	
t Critical one-tail	1.68	
P(T<=t) two-tail	0.008	
t Critical two-tail	2.02	

This result confirms a statistically significant difference between the average values of the WQI and CTSI. The negligible Pearson correlation coefficient (r = 0.0084) between the two indices further suggests that WQI and CTSI quantify distinct water quality characteristics in Kemajuan Lake. While WQI integrates multiple physicochemical parameters with assigned weights to assess general water quality, CTSI focuses on eutrophication-related indicators such as chlorophyll-a, total phosphorus, and Secchi depth. The significant difference in their mean values, 72.57 for WQI and 70.23 for CTSI, underscores the conceptual and computational differences between the two indices. Both indices should be interpreted in pairs for a more comprehensive understanding of lake health. These findings support the application of both indices in environmental monitoring and lake management, especially in settings where eutrophication and general pollution may co-exist but manifest differently in the indicator values.

4. Conclusion

This study evaluated the water quality of Kemajuan Lake using the CTSI and the Malaysian WQI based on weekly sampling over 40 weeks. The lake was classified as eutrophic (mean CTSI = 70.23) and slightly polluted (mean WQI = 72.57). The mean values of key water quality parameters were: turbidity = 20.70 NTU, TSS = 15.45 mg/L, nitrate = 0.36 mg/L, AN = 0.55 mg/L, temperature = 27.94°C, DO = 4.12 mg/L, and pH = 6.80. Statistical analysis revealed a strong correlation between CTSI and turbidity (r = 0.648) and moderate negative correlations between WQI and both TSS (r = -0.552) and ammoniacal nitrogen (r = -0.413). A negligible correlation between CTSI and WQI (r = 0.008), confirmed by hypothesis testing, ANOVA, and t-tests, indicates that the indices measure different aspects of water quality. These findings highlight the value of applying CTSI and WQI to better understand both eutrophication dynamics and general pollution in urban lake systems. This dual-index approach enables more effective water quality monitoring, supports targeted remediation, and contributes to long-term ecological sustainability.

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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, Azme Khamis, Nur Ain Ebas;* ***data collection:*** *Muhammad Hafiq Afifi Azman, Rafidah Hamdan;* ***analysis and interpretation of results:*** *Muhammad Hafiq Afifi Azman, Azme Khamis, Nur Ain Ebas;* ***draft manuscript preparation:*** *Muhammad Hafiq Afifi Azman, Zuhaib Siddiqui. All authors reviewed the results and approved the final version of the manuscript.*

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