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Sustainable Lake Management Framework for Performance Monitoring and Quality Assessment

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Abstract

Lake ecology and regional development require a sustainable lake management framework. Blue space was examined for its health and city sustainability benefits. Lake deterioration causes, levels, benefits, and degrees were analysed to develop a strategic framework. The proposed framework uses structural equation modelling (SEM) to analyse four categories. These categories address lake issues like management support, lake improvement, funding and lake visitor benefits. Path coefficients support two hypotheses; however, one hypothesis was not supported due to p-value of < 0.05. The most significant path T=3.262 was between concern (H.C) and benefits (B), followed by 2.147 for H.C and S, all with a p-value of 0.000. For lakes' sustainable management, the study found lakes development contribution is paramount. The lake encourages access to nearby facilities and raises awareness of residential development costs. Knowing regional and local lake changes enables sustainable lake management decisions which suit lake needs and surroundings.

Keywords: *Long-term regional development, Environment management, Sustainable management of lakes, Well-being of Communities.*

Introduction

Urban areas have diverse populations with different needs and priorities, which has increased the demand for healthy and sustainable living. Cities with sports, recreation, and tourism infrastructure acknowledge the importance of blue space for promoting healthy and sustainable living (Chang et al., 2019). Rapid global population growth and urbanisation cause environmental degradation and biodiversity loss (Moore et al., 2018). Blue space positively impacts mental health, stress levels, prosperity, social relations, and daily life. It promotes community engagement, connecting residents through shared spaces and enhancing quality of life. Integrating blue space into urban planning is essential for creating sustainable and resilient cities. However, academic inattentiveness towards blue space, defined as bodies of water, necessitates further research to integrate water considerations into landscape planning for holistic and sustainable management (Britton et al., 2020). Water, as a fundamental requirement for life, provides tranquillity to the landscape and supports well-being. Protecting water sources, including urban lakes, is

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imperative for ensuring the sustainability of human and natural communities. Urban lakes provide environmental benefits such as improving air and water quality, supporting biodiversity, regulating temperature, and enhancing urban aesthetics (Hossu et al., 2019). Urbanisation and development have led to the decline of many urban lakes, highlighting the importance of protecting and preserving these bodies of water. Urban lakes provide both ecological benefits and recreational opportunities for nearby residents, enhancing the overall aesthetic value of urban areas (Jacob et al., 2022). Urban lakes are important for recreation, tourism, biodiversity conservation, and water supply. Lakes are important in urban areas as they offer residents opportunities for recreation and environmental education. Despite the benefits, human activities can contaminate urban lakes, necessitating ongoing monitoring and management to safeguard public health. Understanding the challenges urban lakes face and implementing effective management strategies can enhance biodiversity and preserve valuable ecosystems. Human activities, including pollution, over-extraction of water resources and climate change, pose threats to the health and functioning of lakes globally (Ritchie & Roser, 2018). Comprehensive research on the distribution and attributes of urban lakes within the framework of swift urbanization is needed for informed decision-making and future urban development guidance (Pi et al., 2022).

The research findings can help lake managers make informed decisions and provide better guidance for future urban development. It is crucial to use sustainable management methodologies in order to safeguard and preserve crucial ecosystems. Protecting and preserving lakes has multiple benefits for both the environment and the surrounding communities. It can increase the value of real estate, create job opportunities through tourism and leisure activities, and improve public health by providing spaces for physical exercise and mental rejuvenation (Daulay et al., 2023). This paper aims to provide the framework as a fundamental tool for monitoring the performance and quality assessment of a sustainable lake management in order to achieve sustainable development and protect our essential natural resources.

Research Methods

The structural equation modeling (SEM) is a widely used statistical analysis technique in behavioural science. SEM includes traditional multivariate processes like regression analysis, canonical correlation, factor analysis, and differential analysis. Researchers can assess the relationships between hidden elements in a group setting. It determines if independent and dependent variables have relationships and their strength and direction. The Partial Least Square (PLS) approach was developed using an algorithm based on regression and weight factors to achieve convergence and satisfy a fixed-point equation. It estimates complex relationships between latent variables. Variance-based SEM is a widely used technique in various domains, such as business and social science, because it can model complex and multivariate interactions (Ali Raza et al., 2020). PLS-SEM is more effective to (covariance-based) CB SEM in cases where there is limited prior knowledge of structural model linkages or construct measurement properties, or when the focus is on exploration rather than confirmation. PLS-SEM is suitable for theory validation when CB-SEM requirements on distribution normality, minimum sample size, and maximum model complexity exceed and when methodological anomalies occur during model estimation. Therefore, given the appropriateness of PLS-SEM, it is adopted in the present study. SEM was used to develop a framework for sustainable lake management and conservation in this study. The study used SEM to identify the key benefits of lakes on quality of life, rank lake management strategy issues, and develop effective strategies for a sustainable lake management framework for blue space. SEM provides valuable insights into lake ecosystem dynamics by evaluating complex relationships among multiple contributing factors. It identifies key sustainability factors by modelling various hypothetical scenarios and their effects, this approach allows for the evaluation of management strategies to promote sustainable lake utilisation.

SEM is used to analyse causal relationships between variables in developing a framework for sustainable lake management (Xing et al., 2022). Collect data through questionnaires distributed to lake management, including community members, scientists, and policymakers. The data collection has detailed information on the lake ecosystem, including water quality, ecological services, seasonal variations, and lake management approaches. After the data collection one-sample t-test was carried to determine the mean value. The data analysis involves subtracting the population mean from the sample average and dividing it by the expected standard error, which is then analysed with SEM. The first step in model analysis is evaluating the measuring model's effectiveness. This involves assessing construct reliability using Cronbach's Alpha and composite reliability tests. Additionally, convergent and discriminant reliability are assessed to determine composite and discriminant validity. Factor analysis was used to analyse the relationships between observed variables and their latent constructs. The outer model is used to measure the relationship between observed variables and their underlying constructs. Use confirmatory factor analysis to validate the relationship between observed and latent variables.

Figure 1 shows the analysis process used in model development. The analysis begins with using SEM for framework analysis of lake management. It aims to collect data on various factors that affect lake management. Data on water quality conditions, including reduced lake depth and murky water, can be collected to assess the threat to the lake ecosystem. Data on lake support and water quality can provide insights into water resource availability and sustainability. Data on lake benefits, including lake contributions and nearby recreational areas, were collected to understand their impact on the urban lake ecosystem. The study also considers financial support for lake improvement, such as willingness to pay for environmental goods and services. SEM is used to create a statistical model for lake management after data collection. The model includes latent factors for lake management: water quality, lake improvement, benefits and financial support. SEM enables causal relationship exploration and hypothesis testing. SEM analysed water quality and its relationships with factors like lake support, benefits, and financial support. SEM can assess environmental conditions' impact on urban lake management. The model is calibrated and validated to ensure accuracy and reliability.

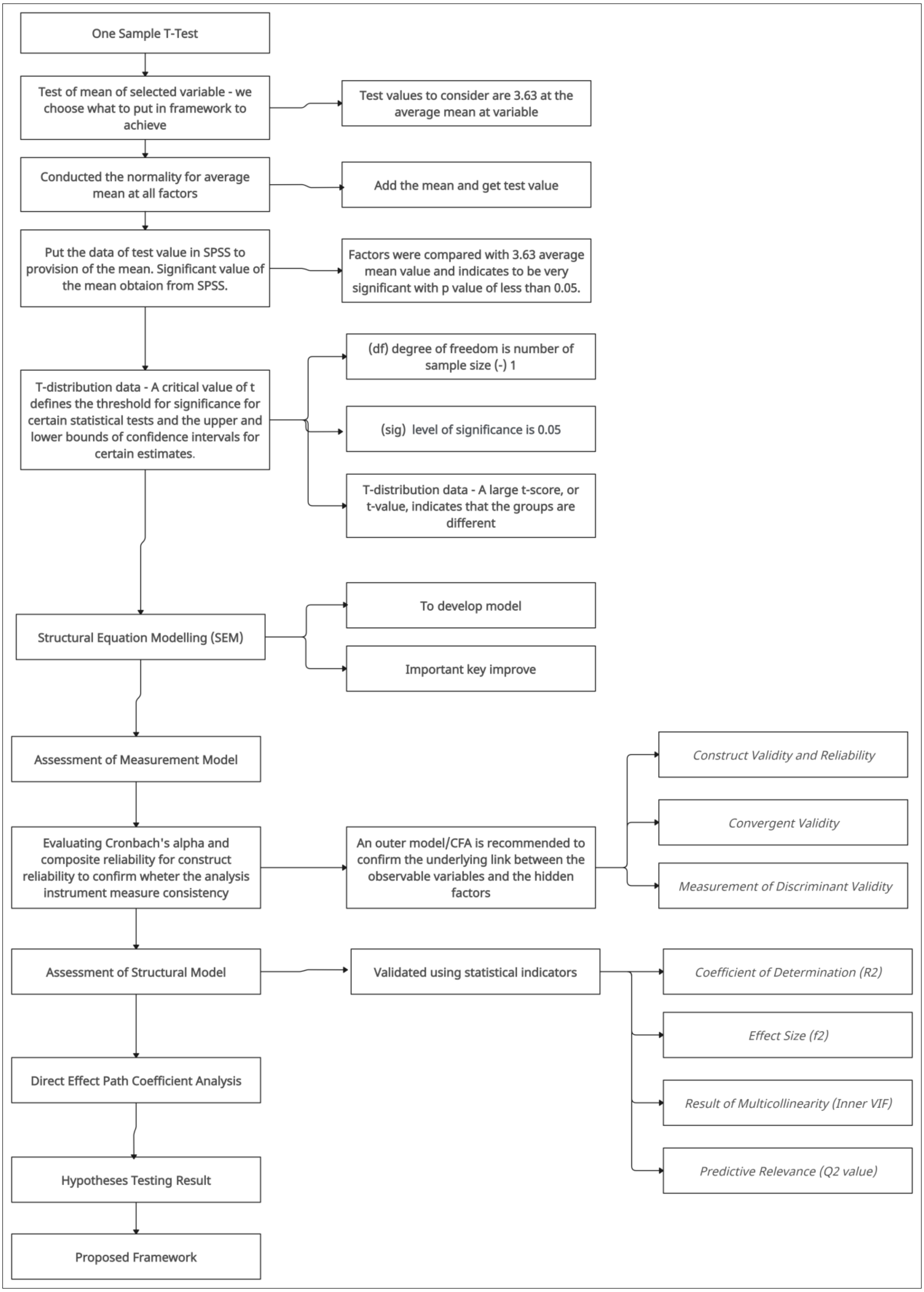

Figure 1: Analysis Process Chart to Develop Mode

Results and Discussion

Figure 2 depicts each item's factor loadings/outer loadings determined using the PLS-SEM algorithm. The initial step in analyzing the model involves evaluating the construct reliability and convergent and discriminant validity. Based on the outcome of the previous step, the outer model is then used to establish the relationship between the factors and their responses.

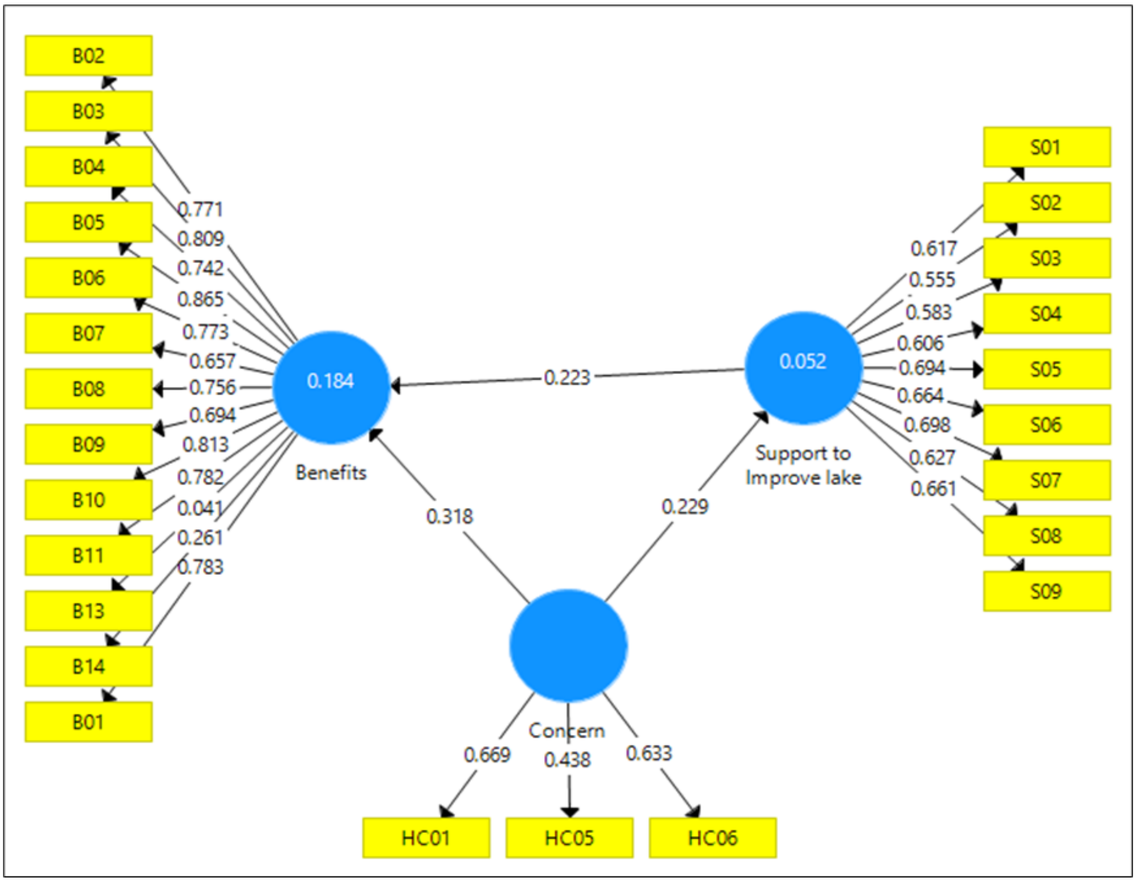

Figure 2: Factor Loadings/Outer Loadings of each Item Calculated through PLS-Algorithm

Although individual item reliability was deemed satisfactory, assessing construct reliability to measure the reliability of group items within the same construct was still recommended. The construct-level reliability, demonstrated by the internal relationship between items assigned to the same construct, was higher. Composite reliability and Cronbach's Alpha were adopted to evaluate the construct-level reliability. The composite reliability score reflected how accurately the assigned items represented the constructs. Table 1 revealed that the composite reliability exceeded the threshold of 0.70, and Cronbach's Alpha was higher than the recommended value of 0.7.

Table 1: Constructs and their corresponding Cronbach's Alpha values

Construct	Number of Items	Cronbach's Alpha
Identify the significant benefits that the public derives from lakes and the role and impact of the lakes on quality of life	27	0.875
Priorities' the issue about lake management that leads to adverse effects on water quality	31	0.798

(Hair, et al., 2016) opined that convergent validity encompasses a collection of observed items that effectively encapsulate the underlying theoretical concept. The principle of convergent validity posits that consistent responses obtained from different measurements indicate a shared construct. Consequently, the group elements should consistently represent the same underlying construct, demonstrating uni-dimensionality. The widely adopted Average Variance Extracted (AVE) approach was employed to evaluate convergent validity in the study. The assessment of internal consistency and convergent validity is presented in Table 2.

Table 2: Results of internal consistency and convergence validity results

Constructs/Items	Code	F.L	CA	CR	AVE
Benefits Derived	Bx		0.903	0.923	0.507
Exercise/improve fitness	B01	0.783			
Enjoy tranquillity	B02	0.771			
Rest/relax	B03	0.809			
Spend time outdoors	B04	0.742			
Escape stress or pressure	B05	0.865			
Enjoy the sounds and smells of nature	B06	0.773			
Spend time with friends	B07	0.657			
Connect with family	B08	0.694			
Be around people who are like me	B09	0.813			
Think/Reflect	B10	0.782			
Observe nature and wildlife	B11	0.041			
The physical benefit you derive from a typical visit to the lake	B12	0.689			
Visit to the lake would have a very negative effect on my stress level	B13	0.261			
A visit to the lake would have a positive effect on my mood	B14	0.783			
Concern Factors	HC		0.512	0.607	0.443
Concerned about the change	HC01	0.669			
The water in the lake emits a very unpleasant odor	HC05	0.438			
A decline in the aesthetic beauty of the lake	HC06	0.633			
Support to Improve the Lake	S		0.822	0.858	0.506
Planting more shoreline vegetation, such as reeds	S01	0.617			
Draining the lake to clean out accumulated waste	S02	0.555			
Banning public use of the water body for sport and fishing	S03	0.583			
Installing floating islands of aquatic plants	S04	0.606			
Filling in the lake and converting it into a public park/green space	S05	0.694			

Pumping in clean water to artificially raise the water level	S06	0.664			
Introducing a virus to kill the carp (exotic fish) in the lake	S07	0.698			
Adding chemicals such as algae control agents to clean the water	S08	0.627			
Leaving the lake as it is and not changing anything	S09	0.661			

Discriminant validity pertains to the ability of the construct to differentiate itself from other constructs. Several methods establish discriminant validity, including Fornell-Larcker, Hetero Trait-Mono Trait (HTMT), and Cross Loadings. According to (Henseler et al., 2015), the Fornell-Larcker criterion is one of the most widely used methods for assessing discriminant validity.

According to the criterion, the square root of the AVE for a construct should exceed the inter-correlation values between the constructs. The variance within elements of a construct should be greater than that observed between other constructs in the model. Table 3 provides evidence that the square roots of the AVEs surpass their respective inter-correlations. Consequently, the measurement model demonstrates favorable validity and reliability.

Table 3: Results of discriminant validity – Fornell and Lacker Criterion

The off-diagonal values are the correlations between latent variables, and the diagonal is the square root of AVE

Constructs	Benefits (Bx)	Concern (H.C.)	Support to Improve Lake (S)
Benefits (Bx)	0.712		
Concern (H.C.)	0.369	0.589	
Support to Improve Lake (S)	0.296	0.446	0.636

HTMT was the second method employed to assess discriminant validity, considered superior to the Fornell-Larcker criterion. As suggested by (Fatoki, 2022), an HTMT value of below 0.90 is required. As revealed in Table 4, given that the obtained values were below 0.90, which is well within the specified threshold, it aligns with the criteria for discriminant validity.

Table 4: Results of Heterotrait-Monotrait Ratio (HTMT)

Constructs	Benefits (Bx)	Concern (H.C.)	Support to Improve Lake (S)
Benefits (Bx)			
Concern (H.C.)	0.838		
Support to Improve Lake (S)	0.314	0.610	

The third approach, a cross-loading matrix, was utilized to test discriminant validity, where the item loading of a specific construct should exceed that of other constructs. The items under examination were evaluated for their intended construct. The cross-loading analysis, as presented in Table 5, supports the discriminant validity of the approach, with all items exhibiting higher loadings on their respective constructs.

Table 5: Discriminant Validity - Cross Loadings

Items	Bx	H.C.	S
B01	0.783	0.269	0.248
B02	0.771	0.279	0.402
B03	0.809	0.270	0.426
B04	0.742	0.662	0.298
B05	0.865	0.698	0.627
B06	0.773	0.790	0.430
B07	0.657	0.801	0.420
B08	0.756	0.645	0.557
B09	0.694	0.751	0.408
B10	0.813	0.771	0.337
B11	0.782	0.746	0.322
B12	0.689	0.730	0.327
B13	0.041	0.780	0.357
B14	0.261	0.592	0.417
HC01	0.319	0.594	0.535
HC02	0.098	0.614	0.461
HC03	0.188	0.545	0.617
S01	0.244	0.575	0.555
S02	0.059	0.586	0.583
S03	0.164	0.581	0.606
S04	0.128	0.593	0.694
S05	0.223	0.445	0.698
S06	0.050	0.452	0.627
S07	0.222	0.463	0.661
S08	0.160	0.487	0.614
S09	0.260	0.446	0.789

Several statistical indicators, namely Predictive Relevance (Q2), Path Coefficient (Bp), Effect Size (f2), and Coefficient of Determination (R^2), were employed to validate the significance of the model once it was deemed fit. After that, a casual path was established between the independent (exogenous) and dependent (endogenous) variables, resulting in a linear covariance link. The structural model was then analyzed through structural equations, and the inner path model analyzed the direct and indirect effects of different variables on lake sustainability. The R^2 is the most significant criterion for assessing structural models. An R^2 value of 0.26 or higher indicates significant results. If the R^2 value falls between 0.13 and 0.25, it is considered moderate, while a value between 0.02 and 0.12 suggests a weak association (Roemer et al., 2021). As shown in Table 6, the R^2 results indicate that benefits achieved a score of 0.184, indicating a moderate strength, while support to improve the lake obtained a value of 0.271, indicating a high strength. As depicted in Table 6, the findings support the model's acceptability.

Table 6: R^2 Results

Endogenous Variables	R^2	R^2 Adjusted
Benefits (Bx)	0.184	0.172
Support to Improve Lake (S)	0.271	0.312

The f^2 predominantly evaluates the effect of a predictive construct on an endogenous component. On the other hand, R^2 primarily examines the extent to which an external construct contributes to explaining a specific endogenous component. Effect sizes are categorized as large, medium, and small for f^2 values of 0.35, 0.15, and 0.02, respectively. As depicted in Table 7, the effects observed are of medium and small sizes.

Table 7: F-square Results

Exogenous Variables	Benefits (Bx)	Concern (H.C.)	Support to Improve Lake (S)
Benefits (Bx)			
Concern (H.C.)	0.118		0.055
Support to Improve Lake (S)	0.058		

Multicollinearity refers to the presence of two or more independent yet highly interconnected entities. If common indicators exist across multiple constructs, it may indicate a multicollinearity problem. Before proceeding with model testing, (Yoo et al., 2014) strongly recommend that researchers investigate potential multicollinearity. Collinearity issues are assumed to arise when values of the correlation coefficient are more significant than 0.9. Variance Inflation Tolerance (VIF) was utilized as an alternative to the correlation coefficient to recognize and solve collinearity concerns. The value of VIF is limited to an upper bound of five (5) as per Smart-PLS, indicating the absence of collinearity among variables in the model. Considering the low values of VIF obtained as presented in Table 8, multicollinearity was not observed as the highest VIF recorded is 1.055 and the lowest is 1.000. The values suggest the absence of multicollinearity, as VIF is below the threshold per the standard requirement.

Table 8: Multicollinearity – Inner VIF Values

Exogenous Variables	Benefits (Bx)	Concern (H.C.)	Support to Improve Lake (S)
Benefits (Bx)			
Concern (H.C.)	1.055		1.000
Support to Improve Lake (S)	1.055		

For estimating the predictive capabilities of the endogenous variables by assessing the performance of the structural model, the blindfolding Q2 test was utilized. The result revealed that the developed model indicates a predictive utility. A Q2 value greater than zero signifies sufficient predictive relevance for the model. With the values of Q2 obtained as presented in Table 9, it can be concluded that the model favorably fits with a robust predictive significance.

Table 9: Decision Parameters from Predictive Relevance Analysis

Endogenous Variables	CCR* Q² (=1-SSE/SSO)	CCC** Q² (=1-SSE/SSO)
Benefits (Bx)	0.076	0.397
Concern (H.C.)		0.426
Support to Improve Lake (S)	0.009	0.271

*CCR = Construct Cross-Validated Redundancy

**CCC = Construct Cross-Validated Communality

The bootstrapping approach was employed to obtain t-statistics and confidence intervals, as PLS does not necessitate distribution assumptions. Path estimation was used to examine the significant relationships in the inner path model. Each potential path in the framework was investigated using the regression coefficient. For testing the hypotheses proposed in the structural model, the PLS Bootstrap technique was employed to assess the significance of the values. Previous research suggests that a path coefficient value of at least 0.1 is required to account for a specific effect in the model. The study's path coefficient (Bp) results are presented in Table 10, indicating support for two hypotheses and non-support for one hypothesis, with the supported hypotheses displaying a p-value of less than 0.05.

Table 10: Path Coefficient Results

Hypotheses	O.S. (Bp)	SM	SD	T	p-Values	Decision
HC -> Bx	0.318	0.331	0.098	3.262	0.001	Significant
HC -> S	0.229	0.252	0.107	2.147	0.032	Significant
S -> Bx	0.223	0.247	0.132	1.695	1.695	Not Significant

The most notable path (T = 3.262) was observed between Concern (H.C.) and Benefits (Bx), followed by H.C. and S, with values of 2.147, all having a p-value of 0.000, indicating statistical significance. The least significant path, however, was found between S and Bx, with a p-value exceeding 0.05, leading to non-support of their respective hypotheses. A summary of the hypotheses testing is presented in Table 11, which shows that two of the hypotheses are accepted and one is rejected.

Table 11: Outcome of Hypotheses

Number	Hypotheses	Outcome
H1	The presence of H.C. exerts a notable impact on Bx	Validated
H2	The presence of H.C. exerts a notable impact on S	Validated
H3	The presence of S exerts a notable impact on Bx	Rejected

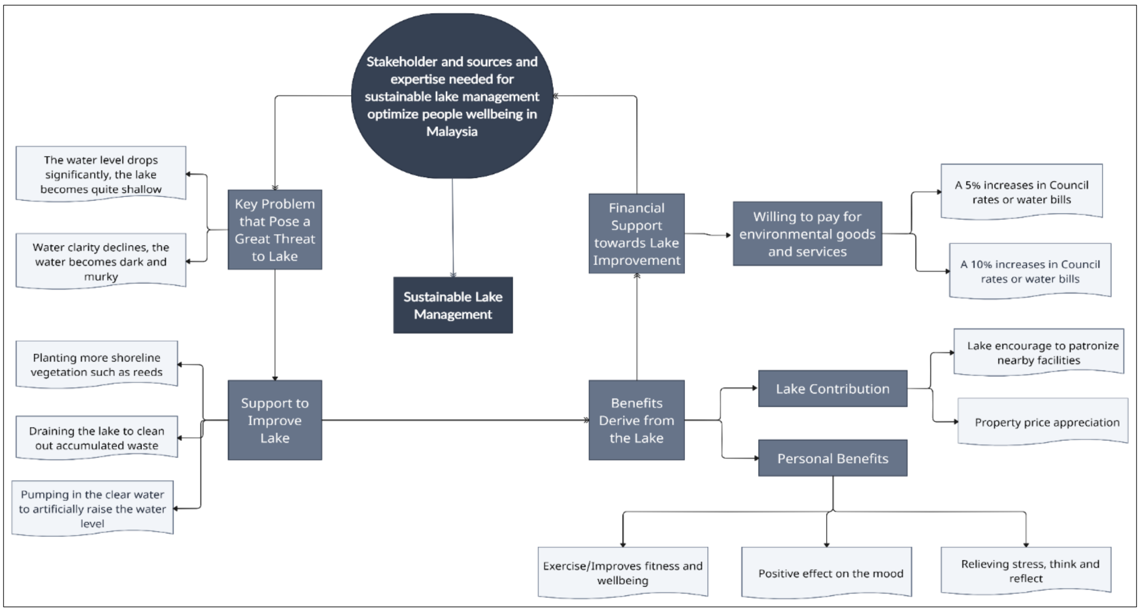

Figure 3: Prospective Sustainable Lake Management Framework

Figure 3 shows the prospect of a sustainable lake management framework. In implementing the prospective sustainable lake management framework, the first step is to address the fundamental problems that pose a significant threat to lakes, when the water level drops significantly. The water becomes murky or dark due to a decline in water clarity. Implementing the process per the framework may include regular monitoring, efforts to protect the system, and restoration of damaged natural habitats.

The second step is to improve the lake water quality by protecting natural habitats, such as wetlands and forested areas, to prevent erosion and reduce nutrient runoff. The remedies include draining the water to remove accumulated waste, pumping clean water to raise the water level artificially, and planting more shoreline vegetation, such as reeds.

The third step involves comprehending the contributions and advantages of the sustainable lake management framework. The findings of this study indicate that the presence of lakes in a community has a positive impact on the level of physical activity among its residents. This increased engagement in exercise has been shown to have significant implications for individuals' overall fitness levels and well-being, thereby offering a range of both physical and psychological advantages.

The final step is the willingness to fund the improvement in water quality and lake restoration, which involves sustainable exploitation of the lakes and reservoirs. Due to their economic benefits, lakes, and reservoirs require policies for sustainable exploitation that can sustain their beneficial uses in the long term, which can help to secure funding for sustainable lake management initiatives, such as pollution reduction and habitat restoration projects.

Conclusions

Lake management has become an increasingly critical issue worldwide as the continued degradation of lake ecosystems threatens the local community and environmental integrity. Understanding the nature of lake changes, long-term monitoring data, and predictive models are essential for developing a sustainable lake management framework. The following conclusions can be drawn from the study.

i. The validity and reliability of the measurement model using various methods indicate satisfactory construct reliability and demonstrate the ability of the observed items to capture the underlying theoretical constructs for developing a sustainable lake management framework.

ii. The structural model evaluated using the statistical indicators reveals significant relationships between variables, supporting some hypotheses while rejecting others. The significant paths identified highlighted the influence of certain factors on the outcome of interest. They can inform the development of a sustainable lake management framework.

iii. Results from bootstrapping, t-statistics, and confidence intervals provided a comprehensive understanding of the inner path model, allowing for the identification of essential relationships and assessing the overall predictive power of the structural model pathways, which can then be used to develop a framework for sustainable lake management.

iv. Completing a sustainable lake management framework substantially enhances decision-making regarding water-resource management strategies and regional land-use planning. Moreover, lake ecosystems' adequate protection, management, and sustainable use necessitate a comprehensive understanding of their functioning and the factors impacting their development.

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