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INTEGRATED LAKE BASIN MANAGEMENT (ILBM) OF HYDROLOGICAL ASSESSMENT CHARACTERISTICS IN KENYIR LAKE BASIN, TERENGGANU, MALAYSIA

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Abstract

Lake water is a vital resource in supporting life, which is important for the ecosystem of both flora and fauna. Monitoring lake-related programmes based on methodical decision-making and management tools are necessary for the sustainable use of lake water resources. This research's objectives include analysing the characteristics of hydrological quality to identify the current condition of the physical environment of the Kenyir Lake Basin, and providing integrated management methods for its water resources. 21 monitoring stations were chosen for sampling in three seasons (normal season, wet season and dry season) throughout the Kenyir Lake Basin. This study evaluates both in situ and ex situ methods for water quality, followed by a lab test according to American Public Health Association (APHA) standards. Water velocity is a major factor in erosion and the production of sediment, and it is determined by the quantity and intensity of rainfall. It is discovered that there is a significant deterioration in the quality of the water, elevating the rate of erosion with the remarkable water velocity and volume. Aside from that, the rapid urbanisation and population growth in Malaysia is contributing to an increasing level of pollution in the nation's lakes. The ILBM-based adaptive management solutions are adaptable and capable of adjusting to shifting environmental circumstances, which help in revising management plans based on data-monitoring as well as stakeholder feedback.

Keywords: American Public Health Association (APHA); Integrated Lake Basin Management (ILBM); Kenyir Lake Basin; data-monitoring

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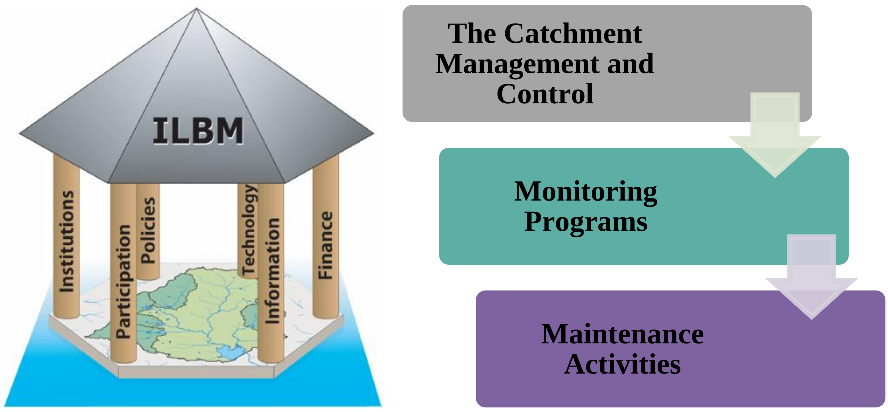
INTRODUCTION

As one of the essential components of life, lake water is used in household life, tourism, agriculture, commerce, and also for the preservation of flora and fauna. In addition, lake water resources are crucial to environmental processes, particularly those involving plant ecosystems and the supply of drinking water to humans and other animals. The study of hydrology focuses on the amount and quality of water—stream flow, sedimentation, hydraulics, and ecohydrology—in various phenomena and water sources. According to Camara et al. (2019), Abdulkareem et al. (2018) and Azlan et al. (2022), the study of hydrology is crucial to environmental sustainability management because it helps to manage water resources for public use, particularly for communities, the economy, flora and fauna, and the society.

Furthermore, the vast differences in climatological traits and the effects of land usage make them even more vulnerable to environmental change, particularly in the Terengganu River Basin and Kenyir Lake Basin, whose characteristics include high humidity, constant temperature, and intense rainfall. The anthropogenic consequences of human activities—tourism, urbanisation, deforestation, agriculture, domestic use, and residential development—along the basin are becoming more prevalent, changing specialised habitats and possibly making them non-sustainable (Kamarudin et al., 2023; Asmara et al., 2019; Bati et al., 2022; Ismail & Amin, 2020). Declining the management of environment would gradually worsen the consequences. The management process requires long-term participation from pertinent institutions managing the lake basin and their operations. Extreme weather brought on by global climate change is recognised to have a significant effect on the amount and quality of inland water bodies (Sabri & Ponrahono, 2024). In addition, the organisations involved in lake basin management must be prepared to provide long-term funds and taking part in ongoing activities. Precautionary management is required due to the long-term effects of the susceptibility of the lake environment. Therefore, it is necessary to develop and implement lake management interventions with a precautionary approach in order to safeguard them, as well as to make informed policy decisions on the extraction of natural resources and land use planning (Fitri et al., 2020; Fazli et al., 2018). Chidammodti and Muhandiki (2016) remark that the greatest way to accomplish the objectives of environmental sustainability is for everyone to thoroughly comprehend and value their various roles in relation to the issues (Ismail et al., 2023). The lessons gained from global research and studies show that an effective lake basin management necessitates: (1) Establishments to oversee the lake and its environs for the advantage of all users of the lake basin's resources; (2) Rules in controlling how people use lake resources and how it affects the lakes; (3) Participation of major stakeholders in the management of lake basin; (4) Practical technological options and constraints; (5) Traditional and scientific understanding; and (6) Maintaining stable resources to support all of the mentioned operations (refer to Figure 1). Furthermore, there are other components of the overall management of lake water quality that are connected to the real ecosystems. Figure 1(b) shows the successful use of the management aspects on planning, operation and control procedures (Duan et al., 2016; Pokharel & Nakamura, 2010).



(a) **(b)**

Figure 1(a): Six Pillars of the Governance Component of the ILBM Hexagonal Pagoda
*Source: International Lake Environment Committee (*ILEC) (2011)
Figure 1(b): Elements of Lake Management in Three Phases
Source: Pokharel and Nakamura, 2010

STUDY AREA AND RESEARCH METHODOLOGY

Study Area

Kenyir Lake is one of Terengganu's and Malaysia's most exquisite tourist destinations, generally considered as the tropical nature of the ancient rainforest. The primary aim of building this lake was to produce hydroelectric power to provide electricity to all states in the Peninsular Malaysia. The Kenyir Lake Basin serves as a fundamental infrastructure for subsistence and a means of transit throughout the basin, which has significantly benefited the local people (Kamarudin et al., 2017; Wahab et al., 2019; Wahab et al., 2023; Azlan et al., 2021; Osnin et al., 2017). The location focused in this research is situated at Kenyir Lake, Hulu Terengganu, the largest artificial lake in the Southeast Asia of over 36,900 hectares. By collecting water from the main rivers, the lake is situated at latitude 05°11'01.064"N until 05°07'34.463"N and longitude 102° 42'42.602"E until 102° 20'6.25"E, as big as the Terengganu River Basin (Rosle et al., 2018; Azlan et al., 2022; Wahab et al., 2017). To assess the hydrological quality features of the entire Kenyir Lake Basin, 21 sampling stations were chosen to represent

21 sub-catchments. The locations of the sampling stations for every season studied are all within Terengganu's Kenyir Lake Basin (refer to Figure 2).

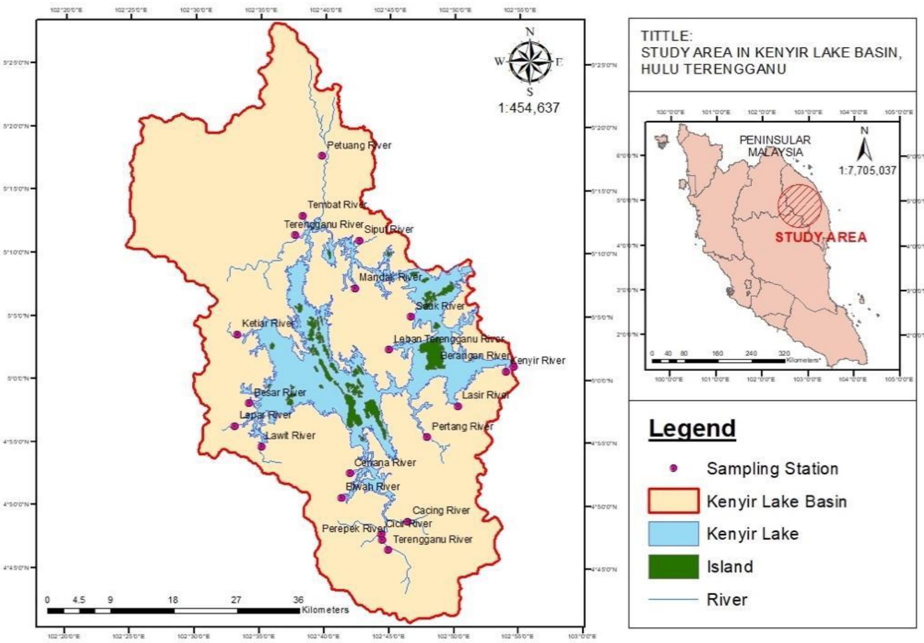


Figure 2: The Kenyir Lake Basin's Sampling Location Map of Wet, Dry, and Normal Seasons

Research Methodology

Water samples from 21 stations were taken at sampling points along the Kenyir Lake Basin, ranging from upstream to downstream. The river's cross-section is examined in order to calculate the river discharge (Q). In situ parameters consisting of Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Ammoniacal Nitrogen (AN) and pH were measured in the field directly. For ex situ parameters, TSS analysis using the Gravimetric method was employed, and COD Method 410 was used to analyse Chemical Oxygen Demand (COD). The standard method of analysis (APHA 2023) approach was followed in the laboratory analysis. As shown in equation 1 (Wahab et al., 2019; Tan et al., 2017), TSS is expressed in mg/L unit. The Water Quality Index (WQI) was enabled to condense intricate scientific data regarding the quality of water to more manageable format for evaluation, reporting, and sharing needs. Equation 2 below was used to determine the index, which was based on the DOE's judgement (DEO, 2023).

Equation 1
TSS = {(WBF+ DR) - WBF} (mg) x 1000 / VFW (mL)
= mg/L/1000/1000/1000
= tonne/L

Equation 2
WQI = (0.22 x SIDO) + (0.19 x SIBOD) + (0.16 x SICOD) + (0.15 x SIAN) + (0.16 x SITSS) + (0.12 x SIpH)
Where: SI = Sub Index for each parameter of WQI

ANALYSIS AND DISCUSSION

Hydrological Status

Figure 3 illustrates that during the rainy season, the value (Q) of water was the greatest at Petuang River (29.59 m3/sec) and the lowest at Lepar River (0.33 m3/sec). During the dry season, the Petuang River recorded the greatest value of 10.48 m3/sec, while the Bewah River recorded the lowest value of 0.07 m3/sec. The Terengganu River had a maximum discharge value of 16.78 m3/sec during the regular season, while the Lepar River recorded a minimum value of 0.33 m3/sec. A river's measurement is considered normal when the elevated upstream water velocity, or observed value (Q), is higher than the downstream water velocity. Excess water from the Terengganu River Basin flows into the Kenyir Lake Basin in flat places, and the river's flow value is greatly influenced by the variations in its width and depth. According to hydrology theory, more sediment is deposited in the downstream area at a higher discharge value and a lower water velocity. Rainfall intensity and frequency have an impact on erosion rates as well as the water level flow. It is suggested that there is a positive correlation between the rate of side and riverbank erosion, and sediment generation. As described by Katimon et al. (2018) and Uca et al. (2018), water velocity, which is influenced by the amount of rainfall, plays a significant part in erosion and sediment generation. In general, there would be significant erosion if the water volume and speed were high. The Kenyir Lake Basin's 21 sub-catchment distribution patterns show that it was evolving at a pace. Every lake has a different relative significance for each of the major sources. Stream and river flow are often seasonal in nature, influenced by both biological and hydrological forces. As stated by Abdullah et al. (2019), Dlamini et al. (2017) and Wahab et al. (2019), the fluctuations in stream flow indicate how the net water balance of a given lake varies based on changes in imports and outputs.

To determine the total suspended solid (TSS) in tonnes per day (tonnes/day), the production of suspended sediment was calculated daily. The highest flow value and the highest TSS are the reasons for the maximum river basin's daily output of suspended sediment from Terengganu River in wet and normal seasons, and from Tembat River in the dry season. Figure 4 displays Terengganu River's estimated TSS and its suspended sediment load, which are of 1.58 and 43.24 tonnes/day respectively. The discharge value (Q), or water velocity, in the elevated downstream is higher than the upstream in the normal reading of the hydrological theory, and when a basin's water flow is higher than its lower flow, more energy is available to transport concentrated suspended sediment load, which leads to an increment in TSS production (Chow et al., 2020; Kamarudin et al., 2017). Nonetheless, the variations in stream flow level, suspended load and meteorological changes (humidity, evaporation and rainfall intensity) brought on by climate change, particularly in areas with active anthropogenic activities, has led to maximum values recorded during the dry season being higher than normal. The primary factor of decreasing surface erosion, which increases the amount of silt load produced in a river basin, is the density of water at the top of the forest canopy. The total suspended sediment load (TSS) in a basin rises in proportion to the water flow because larger flows have more energy to move concentrated suspended sediment loads relative to lower flow levels, as well as because they accelerate erosion. The water level flow and the rates of erosion were impacted by the frequency and severity of rainfall. Additionally, the population's rapid growth and urbanisation have increased the demand for water (Nafi'Shehab et al., 2021), which has led to higher levels on pollution of water in lakes.

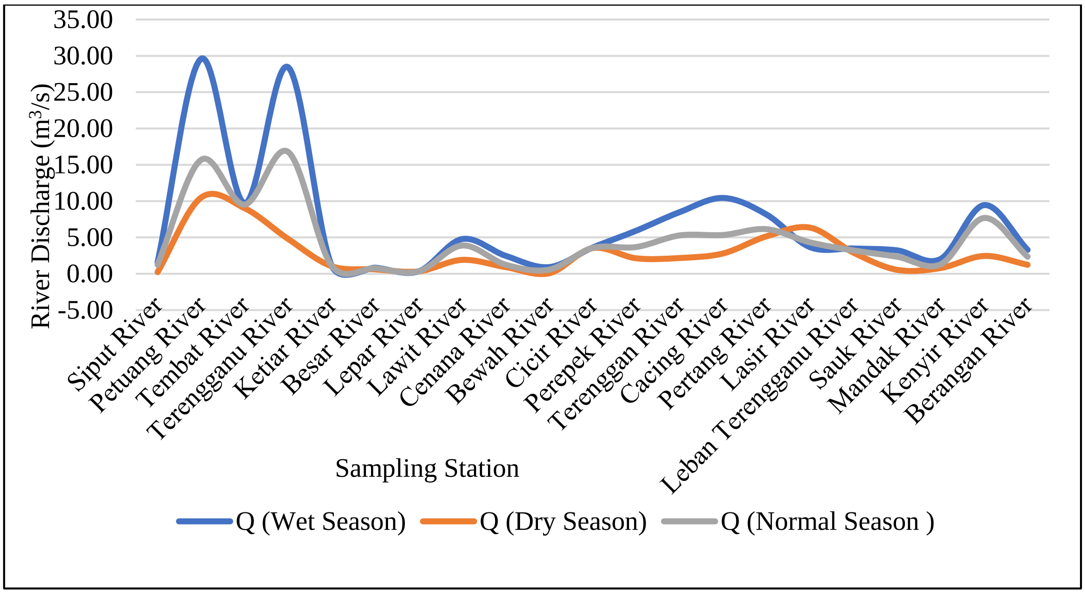


Figure 3: The 21 Sampling Stations (Feeder Rivers) in the Kenyir Lake Basin's Stream Flow

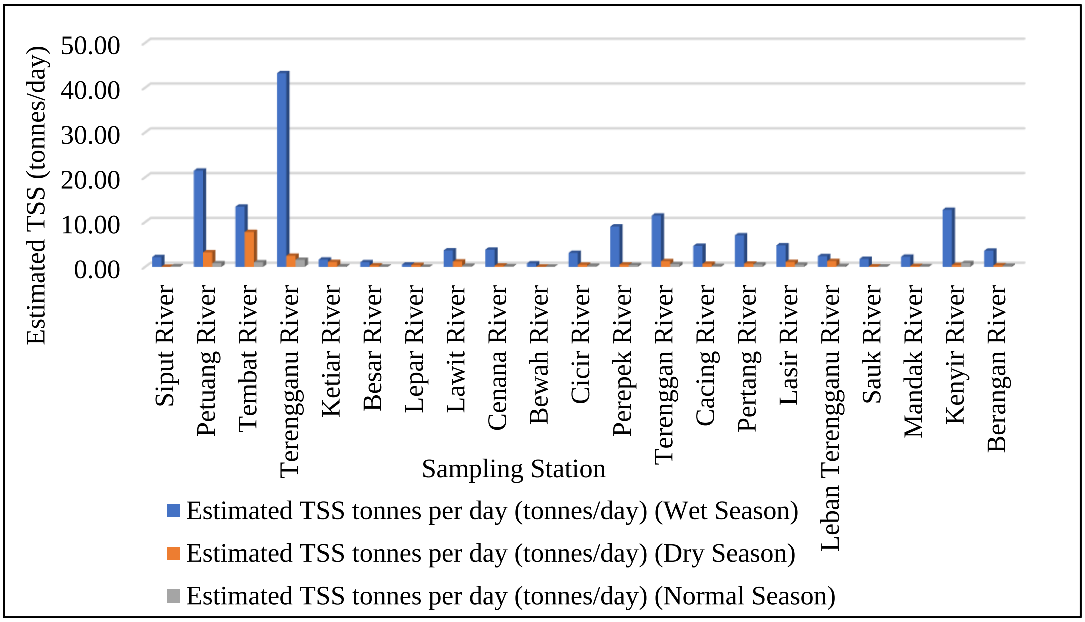


Figure 4: The Projected Suspended Load in Hulu Terengganu's Kenyir Lake Basin

Water Quality Status

The maximum BOD concentrations were 1.40 mg/L during the dry season and 1.32 mg/L during the normal season. As compared to other sample stations, Lepar River recorded the highest number during the wet season, at 0.51 mg/L. In comparison to the wet season, the trend distribution of BOD revealed larger concentrations during the dry season.

The increased warmth and increased metabolic activity of microorganisms resulted in a significant drop in water level, which in turn caused the concentration of BOD to rise throughout the dry season. Additionally, as described by Bati et al. (2022), the high volume of lake water during the rainy season would disperse organic materials, which would lead to a decrease in the BOD. The wet season (10 mg/L), dry season (5 mg/L) and normal season (6 mg/L) all had high COD values. As a result, other stations were designated as Class I, while Lasir River was placed in Class II for its COD level for the wet season. The parameter in all sample stations showed an improvement to reach the Class I's acceptable limit during the dry season and the regular season. The increased amount of wastewater from anthropogenic activities and household sewage entering the river was the cause of the high COD value seen downstream (Sutadian et al., 2017). The value of COD increases as the organic materials' quantity increases in the water. The wet season's DO concentration ranged from 58.17% to 89.10%, the dry season's from 75.17% to 88.84%, and the normal season's from 69.90% to 88.30%. These findings show that photosynthetic activity, organic matter breakdown rate and seasonal variations (climate changes) are the primary drivers for the DO level in water. Moreover, the lowering of the DO level may cause significant changes in the types of aquatic creatures present in the body of water, which would have an immediate impact on the quality of the river water. High TSS loads are resulted from rising river water velocity, flow and discharge levels. When the TSS production in a river basin reaches a critical level, it can accelerate sedimentation issues, which can have negative consequences to aquatic ecosystems and plant populations, owing to the changes in water quality and hydrology.

The TSS distribution in the Kenyir Lake Basin was found to be 18 mg/L in the Cenana River during the wet season and 1.20 mg/L in the Siput River during the dry season. TSS concentrations varied, but generally speaking, as one moved from upstream to downstream sites, the concentration of TSS would increase. Berangan River's concentration of 0.58 mg/L during the wet season, Besar River's, Ketiar River's, Lawit River's and Lepar River's of 0.1 mg/L during the dry season, and Kenyir River's of 0.42 mg/L during the normal season all had the highest mean for ammoniacal nitrogen (AN), indicating an increase in trend. Nevertheless, the upstream AN concentration was still below the Class I NWQS's allowable limit of 0.10 mg/l. The concentration of AN was somewhat lower near midstream (Kenyir Lake Dam), particularly during the dry season. This demonstrates that throughout both the dry season and the regular season in the Kenyir Lake Basin, the level of AN concentration stayed within Class I NWQS. The pH level upstream of the Kenyir Lake Basin fell into Class I NWQS (>7.0), with a small number of samples falling in Class II (6–7). Most of the pH readings were within Class I NWQS at the midpoint, however, it fell under the ranges of 6.04 to 8.1 in the wet season (Petuang River: 6.04; Besar River: 8.1), 7.6 to 8.6 in the dry season (Cacing River: 7.6; Leban Terengganu River: 8.6), and 7.2 to 8.4 in the normal season (Lasir River: 7.2; Lepar River: 8.4). Overall, the majority of the pH measurements were at the neutral range, indicating that the trash discharge had no effect on the pH of the water in any of the stream stations. The findings demonstrate that the distribution trends of turbidity (TUR) and total suspended solids (TSS), which are greater in the Kenyir Lake Basin's middle and downstream streams than in its upstream part, are the same. The TUR distribution is higher in the wet season than in the dry and normal seasons due to hydrological, geomorphological, and human variables around the Kenyir Lake Basin, as well as the climate change factor. The process of photosynthesis by aquatic plants may be negatively impacted by the rising suspended sediment load in river basins, which may cause increased turbidity, high alkali content, the release of offensive odours, water discoloration, shallow flow, and less sunlight penetration. The water samples that were taken over the three seasons showed trends in total dissolve solids (TDS) concentrations that were within WHO's acceptable range. Stations upstream have lower TDS primarily because there is more freshwater available there, hence less salinity, since there is not much seawater intrusion. Sefie et al. (2018) affirms that upstream areas would have lesser waste discharges when compared to downstream locations, since human activity, which is a primary factor contributing to the high TDS concentrations, is more prevalent in the latter.

Table 1: The Water quality parameter range and mean values for each sampling station during the wet, dry, and normal seasons

Parameters	Wet Season	Dry Season	Normal Season
(BOD)	0.31-0.51	0.85-1.40	0.57-1.32
(COD) (mg/L)	2-10	1-5	2-6
(DO) (%)	58.17-97.10	75.17-98.30	69.90-96.54
(TSS)	5.20-18.0	1.20-15.0	4.10-14.5
(AN)	0.17-0.58	0.07-0.10	0.08-0.42
pH	6.04-8.1	7.6-8.6	7.2-8.4
(TUR)	6.65-19.87	2.25-15.22	5.12-15.55
(TDS)	7.69-21.9	2.89-16.15	6.66-16.56

Leave One-Out Method (LOOCV) was used in identifying the quality of water, which have a major impact on the variation in river discharge. Tables 2(a), 2(b), and 2(c) present the results for the analysis of the linear association between the water quality metrics and the discharge of river to the Kenyir Lake Basin on the rainy, normal and dry seasons. 60.12%, 67.94% and 63.95% were the biggest percentage contributions (%) in wet, dry and normal seasons respectively for the DO parameter in this linear relationship based on the examination of significant factors. Furthermore, throughout the three seasons, the TSS parameter had the second-highest percentage contribution (%) values, which were 17.85% for the dry season, 30.32% for the normal season, and 34.46% for the wet season. The amount of rainfall and water velocity during the wet season caused the maximum concentration of DO in the river water flow. Typically, larger rates of water volume and velocity would cause erosion to occur more quickly (Wahab et al., 2023; Nalado et al., 2017). The velocity of the water flow has a significant effect on the DO concentration reading. The river's flow and speed determine the amount of oxygen in the water, causing the DO concentration value to increase along with the discharge value. Additionally, according to the hydrological theory, stagnant water might also be resulted from reduced water velocity. This explains why the percentage contribution of DO concentration increased slightly to 67.94% during the dry season. The TSS value during the dry season was also at the lowest point compared to those in rainy and normal seasons, while the TSS's percentage contribution (%) was the highest. This was caused by the trees' increased complexity in absorbing both organic and inorganic components as water flowed slowly.

Table 2(a): Factors of importance in a linear relationship to forecast River Discharge (Q) characteristics during the rainy season in the Kenyir Lake Basin

R-Square Reference = 0.9760			
Leave Variable	**R-Square Leave Variable**	**R-Square Difference**	**Percent Contribution (%)**
(BOD)	0.9722	0.0038	0.84
(TDS)	0.9711	0.0049	1.08
(NH3-N)	0.9744	0.0016	0.35
(DO)	0.704	0.272	60.12
(TSS)	0.8201	0.1559	34.46
Turbidity	0.9646	0.0114	2.52
(COD)	0.9747	0.0013	0.29
pH	0.9745	0.0015	0.33
Total	7.3556	0.4524	100

Table 2(b): Factors of importance in a linear relationship to predict River Discharge (Q) Charcteristics for Dry Season at Kenyir Lake Basin

R-Square Reference =0.9849			
Leave Variable	**R-Square Leave Variable**	**R-Square Difference**	**Percent Contribution (%)**
(BOD)	0.9848	1E-04	0.02
(TDS)	0.9667	0.0182	4.25
(NH3-N)	0.9706	0.0143	3.34
(DO)	0.6937	0.2912	67.94
(TSS)	0.9084	0.0765	17.85
Turbidity	0.9568	0.0281	6.56
(COD)	0.9848	1E-04	0.02
pH	0.9848	1E-04	0.02
Total	7.4506	0.4286	100

Table 2(c): Factor of importance in a linear relationship to predict River Discharge (Q) charcteristics for normal season at Kenyir Lake Basin

R-Square Reference = 0.9475			
Leave Variable	**R-Square Leave Variable**	**R-Square Difference**	**Percent Contribution (%)**
(BOD)	0.9458	0.0017	0.21
(TDS)	0.9397	0.0078	0.98
(NH3-N)	0.9445	0.003	0.38
(DO)	0.445	0.5025	63.45
(TSS)	0.7074	0.2401	30.32
Turbidity	0.9148	0.0327	4.13
(COD)	0.9475	0	0.00
pH	0.9433	0.0042	0.53
Total	6.788	0.792	100

The Hydrological Analysis-Based Strategic Management

Certain areas are significantly affected by the factors of land use and climate, while some other areas are far more vulnerable to environmental change. Furthermore, the unintentional or intentional introduction of non-native invasive species might also have a detrimental effect on the native species communities in the study regions. Natural occurrences might as well cause abrupt changes to the areas. Additionally, anthropogenic factors from human endeavours like intense farming, deforestation, urbanisation and tourism also contribute in driving specialised habitats to shift, contract and splinter, possibly to the point where they can no longer support themselves. Chow et al. (2020) expresses the researchers' collective primary goal accurately, which is to address and promote sustainable development in order to preserve, protect and improve biodiversity. Preserving the current fragile natural environment is crucial to maintain the interactions between humans and the environment. The consequences from gradual degradation problems and the possible extended response time of lakes to management interventions necessitate the long-term commitment from pertinent lake basin management organisations. The possibility of long-term effects also points to the necessity of taking precautions when planning and executing lake management initiatives. In order to preserve these unique settings and make well-informed policy decisions on land use and the extraction of natural resources, collaborative study to determine the resilience of these environments is essential (Chidammodzi & Muhandiki, 2016; Pokharel & Nakamura, 2010).

CONCLUSION

Lakes' place in the global hydrologic cycle and system depends on the balance between the amount of water they receive from the sources and the amount they lose. Limitation on the amount of water used, all throughout the normal, dry, and wet seasons, is important in order to improve water quantity and quality. The local community has taken up a number of initiatives to preserve and restore Kenyir Lake, including planting new trees, working with certain organisations to reforest the areas around the lake, reporting any pollution or encroachment to the authorities, requesting assistance from the concerned parties in cleaning the lake, instructing locals and visitors on keeping the areas clean and free from pollution, and carrying out waste management tasks like recycling and carrying the waste out. When the locals engage in these activities, their awareness and comprehension will grow, and their capability to manage the resources sustainably will be strengthened. Therefore, there is a great need to increase the locals' participation in the conservation and rehabilitation of the Kenyir Lake Basin areas, as well as to increase their awareness on these issues.

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