

Article

The Assessment of Sedimentation Problems in Kenyir Hydropower Reservoir, Malaysia

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Abstract: Lakes may take a while to respond to management interventions because of the management implications of incremental development and degradation issues. This includes the requirement for the ongoing participation of key lake basin management institutions and their operations. This study's objective is to assess the impacts of land use activities along the Kenyir Lake Basin based on the sedimentation problem level. There are a few hydrological methods that are necessary indicators to measure the level of sediment production, such as Total Suspended Solid (TSS), area of sub-catchment, river discharge measurement, and annual sediment load production. The results showed that the sub-catchment of Besar River released the lowest annual average estimation at 3833.70 kg/km²/year, and the sub-catchment of Kenyir River produced the highest annual average estimation at 128,070.86 kg/km²/year for annual sediment load flow produced from tributary rivers into Kenyir Lake. Kenyir Lake Basin's downstream and midstream regions had higher sediment load values than its upstream regions. This study highlighted the significance of the effects of anthropogenic factors, hydrological, geomorphological, growth, and developmental factors, and climate changes as the key variables attributing to the sedimentation phenomenon along the Kenyir Lake Basin. The construction of a long-term lake or reservoir catchment development and management plan, combined with the formation of a vision and comprehensive strategic plan, are vital components of sound management practice. The efficient implementation of the suggested watershed management programmes depends on the active involvement of all significant catchment stakeholders.

Keywords: sedimentation; Kenyir Hydropower Reservoir; Kenyir Lake Basin; Total Suspended Solid (TSS); annual sediment load production

1. Introduction

Tenaga Nasional Berhad (TNB) maintains and manages twelve lakes to support hydropower generation through its three major hydroelectric schemes, namely the Cameron

Highlands-Batang Padang, Perak River, and Kenyir Lake Basin. The Department of Irrigation and Drainage (DID) is responsible for maintaining natural waterways, although TNB is in charge of maintaining lakes, for example. Additionally, despite the catchment area being designated as an Environmentally Sensitive Area (ESA) of rank 1 under the National Physical Plan, TNB is powerless when it comes to regulating development in the catchment, and the rates of eutrophication, heaving erosion, poor water quality, poor ecosystem, and waste dumping are rising daily [1]. The following narrative provides an overview of the physical environment, physical and biological issues in the Kenyir Lake Basin, socioeconomics and culture, land use activities, Environmental Impact Assessments (EIA), infrastructure and utilities, governance, the tourism industry, green technology in architecture, and architecture. Recent events in the Kenyir Lake Basin areas showed how difficult it was to manage a lake and ultimately prevent tragedy from occurring due to the lack of a governing organization and appropriate jurisdiction [1–6].

When the composition or condition of the lake's waters are altered due to anthropogenic activity such as agricultural, domestic, residential, industrial, and urban development along the Kenyir Lake Basin, including the overall areas through the lake's inlet and outlet rivers, they are considered polluted. These are some of the main pollutants that affect how well the rivers are balanced. Deforestation may have increased river and overland flow in recent years due to decreased evaporation capability, and land use conversion from forestry to mixed agriculture occurred in the upstream region. However, some conversion to building land was also visible near Terengganu State. From a socio-economic perspective, among the benefits in the study area from the administration centre are improvements to the residents' socio-economy (the creation of employment and business opportunities for local communities), facilities, and infrastructure around the basin areas. As for disadvantages, residents' safety (social conflict between locals and foreign workers that would happen), environmental pollution, water resources for irrigation, and fisheries aspects are the main concerns. The movement of sediment is a major factor in the issues that occurred in managing the river, as the ability of the small rivers in the lake basin will decrease. This will lead to an irregular shape change of the riverbed, and flooding can ultimately occur due to the process of sedimentation. As the flood water decreased, the lake level dried out, causing problems with the lake's management from March to June. At stations close to sand mining operations (particularly downstream regions of the Terengganu River), the highly rough and coarse sediments required increased flow energy. A significant river in the state that flows straight into Kenyir Lake is the Terengganu River. Without strategic supervision, it will have an adverse effect on the environment and society in the long run and disturb the river ecosystem. Increased turbidity and smells in the water could result from the increased sedimentation [4–7]. Figure 1 illustrates the land use operations carried out in the Terengganu River Basin, which is directly related to Kenyir Lake upstream, in the middle stream, and downstream.

There is a mitigation process for this problem, such as the need for a proper governing body to take responsibility for governing the lake and its catchment, a reliable monitoring system to monitor the lake at all times, and a decision support system to assist the governing body in taking necessary actions [2–4]. TNB and TNB Research Sdn. Bhd. (TNBR) have characterized their main goal as addressing and promoting sustainable development towards preserving, protecting, and enhancing biodiversity in Kenyir Lake in order to conserve the currently fragile natural environment. Over the past 20 years, there have been major changes to the natural ecosystem around Kenyir Lake. Due to influences from anthropogenic activities such as sand mining and deforestation along the Terengganu River Basin, environmental processes and reactions in the Kenyir Lake Basin have remained in balance [5–7]. Figure 2 shows the proposed framework result of ecosystem services provided by lakes and reservoirs, which will be applied by all countries in the world as one of the essential procedures for enhancing basin management in the direction towards coordinated lakes and the management of reservoirs. There are few important parts of one framework, such as resource provision, that are valued monetarily, while other services

(such as regulatory, cultural, and supporting services) are difficult to value in monetary terms, and their degradation is often neglected. These integrated supportive items in one framework also contributed to general human development and wellbeing based on the preservation and conservation of lakes using integrated lake management [8].

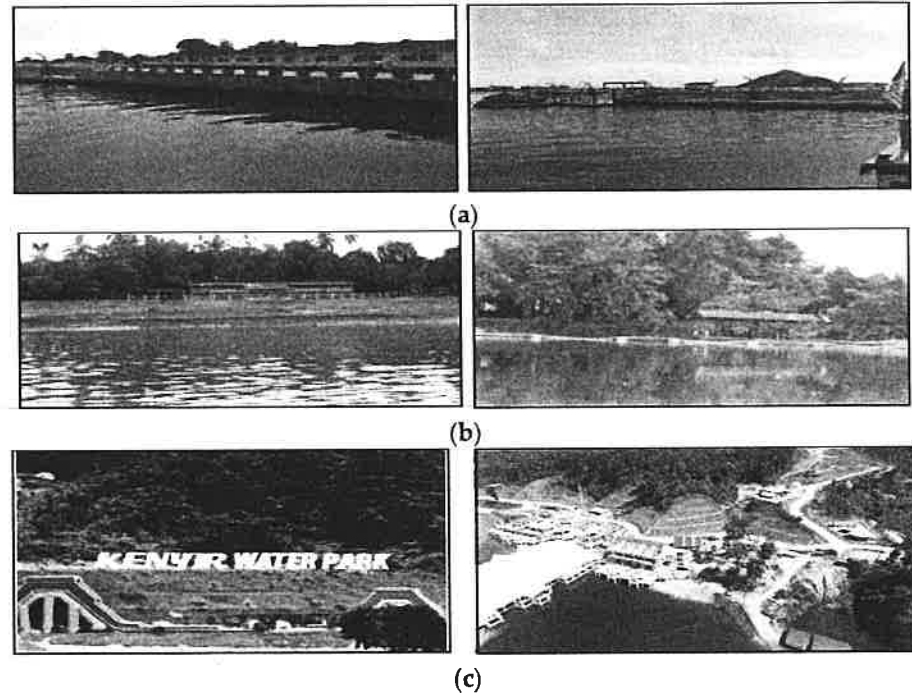


Figure 1. The illustration of land use activities covered (a) downstream, (b) middle stream, and (c) upstream of the Terengganu River Basin (visualisation along the Kenyir Lake Basin taken during fieldwork).

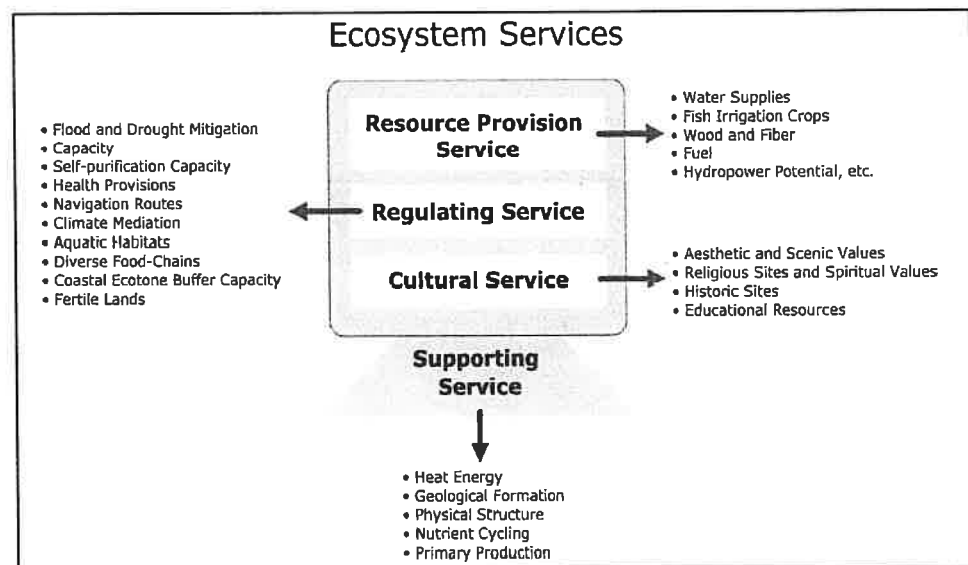


Figure 2. The ecosystem service provided by lakes and reservoir (from [8]).

Some people are significantly more vulnerable to any environmental change than others because of the enormous variations in climate and land use consequences. Natural events may sometimes be the cause of sudden changes. After a while, specialized ecosystems may no longer be self-sustaining due to anthropogenic influences such as intense

deforestation, urbanization, tourism, construction, agriculture, and domestics. Furthermore, the intentional or unintentional introduction of invasive non-native species could have a negative impact on the natural species populations in the Kenyir Lake Basin. To prevent future damage brought on by human activity, the Kenyir Lake Basin and its sub-catchment, which are largely in their original natural state, need to be preserved right now [9–12]. The Kenyir Lake Basin must be properly managed in order to protect the natural environment as well as the activities and interests of many stakeholders. The need for continuing involvement of competent lake basin management organizations and their operations is one of the management impacts of this trait of problem development that gradually worsens over time, as well as the possible extended reaction time of lakes to control measures. Long-term consequences could have a negative impact, which is another reason why lake management methods must be developed and implemented with caution. Joint research is required to assess the levels of resilience of these systems in order to successfully maintain these distinctive ecosystems and make policy choices regarding the zoning of land and the mining of natural resources [12–14]. Figure 3 shows the position of management review in the schematic of the Integrated Lake Basin Management (ILBM) plan's cyclic process, which incorporates a version of the cyclic process to ensure all management measures are properly implemented based on environmental sustainability [15].

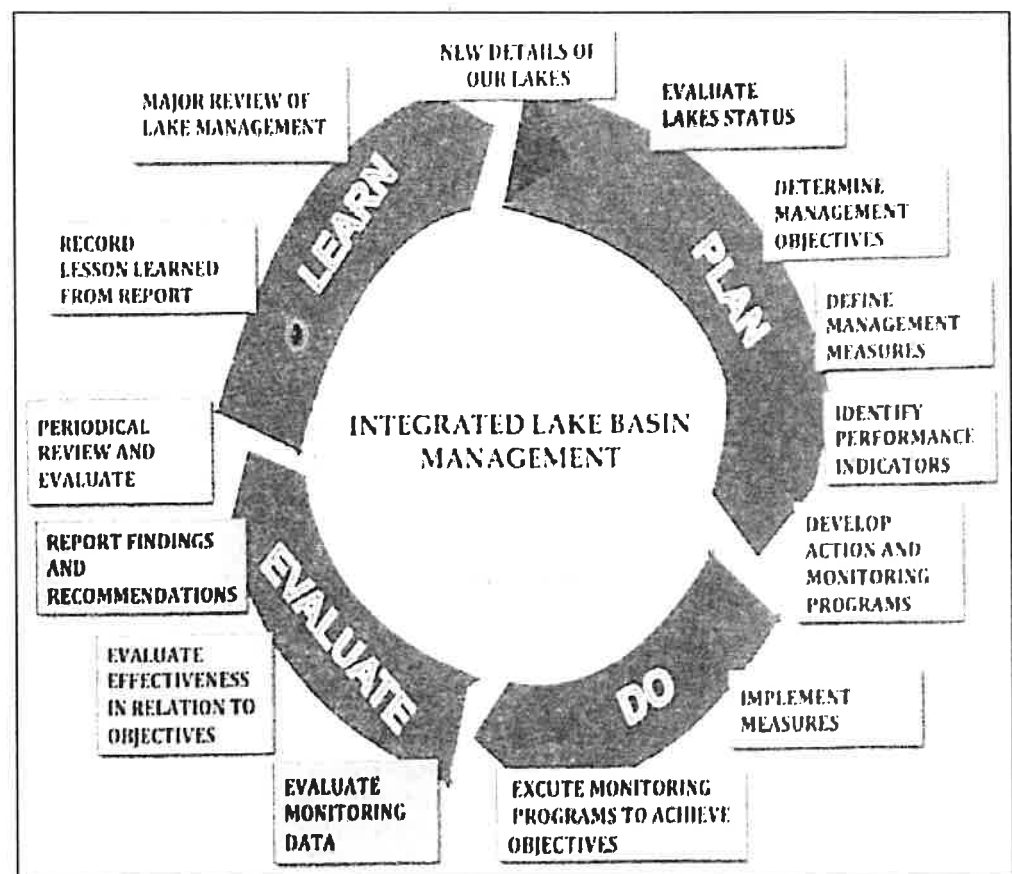


Figure 3. The position of management review in the schematic of the Integrated Lake Basin Management (ILBM) plan's cyclic process (from [15]).

The human, geomorphological, and climate change elements that were present around the basin (which involves basins downstream, middle stream, and upstream) had an impact on the sedimentation processes that took place. Sediment migration is a major cause of the river management issues that have arisen. As a river basin's capacity for maintaining its ecological ecosystem declines, the geometric shape of the riverbed changes, and eventually, floods may arise from the sedimentation process. The river's condition

was influenced by sedimentary content and water quality [16–20]. Then, the rainfall volume and frequency affected the water level, flow, and erosion rates. The increase in sediment production is suggested by the positive association between side and riverbank erosion rates. The production of erosion and sediment is significantly influenced by water velocity, which is influenced by rainfall intensity. In general, the rate of erosion is increased by increased water volume and speed. Sedimentation and deposition are significantly influenced by erosion, transport, and sedimentation, and these processes interact from the river to the estuary. In addition, the ability to carry silt and the mobility of sediment were both impacted by the velocity of water flow. As a direct consequence, sediment deposition processes are affected by river discharge and flow rate [21–24]. Riverbank erosion can occur due to a variety of factors, all of which contribute to the erosion [25–27]. Among the characteristics are the erosion caused by stream flow turbulence, the side erosion that finally causes the bank structure to collapse, landslip caused by a rise in bank slope, and the removal of soil particles on riverbanks as a result of flow regime. Water is a powerful symbol of transportation that may both protract soils and remove and sweep them away, creating an unstable riverbed morphology [28–30]. According to [31], it has been established that the hydrological features, erosion of soil, land use practices, topography and geomorphological elements, dam capacity, and water flow rate are all contributing factors to the sedimentation issue in the Kenyir generating reservoir. These factors also caused the increase in sediment levels. Table 1a,b shows the current and future (100-year ARI) results of sediment load production for each sub-catchment along the Kenyir Lake Basin based on forest coverage reduction percentage [31]. Based on secondary and primary data obtained, the average erosion rate around the research area is assumed to be ‘low’, which is to be expected for a dominantly forested geographical area of medium elevation and slope [11,30–32]. The Kenyir Hydropower Reservoir’s sedimentation issues are not yet critical, but they will become so if more through monitoring programmes and coordinated lake basin management are not recommended to protect and safeguard the catchment, particularly close to the Kenyir Dam, Tembat Dam, and Puah Dam, in order to prevent significant soil erosion.

Furthermore, according to [33], “Reservoir sedimentation management with bypass tunnels in Japan”, sediment bypass tunnel construction for reservoirs was stated as one of the sedimentation management techniques. The bypass tunnel built must have high concrete strength and appropriate tunnel cross-section to facilitate the initial construction process and maintenance. In addition, maintenance and monitoring activities are constantly carried out to ensure that the sediment bypass tunnel system can function smoothly. It is able to reduce the problem of floods in the downstream area near the dam. Although this technique involves high costs due to the construction of the tunnel, the construction of this bypass tunnel provides many advantages that it can be used for existing dams, and it does not involve taking the reservoir level and avoids the problem of reducing water storage capacity. Table 1c shows examples of existing sediment bypass tunnels with the physical characteristics required of sediment bypass tunnels in Japan and Switzerland [33]. Among the factors that significantly relate to these problems are the tunnel’s cross-sectional area and design velocity. Based on these factors, sediment management in reservoirs in Japan and Switzerland is largely classified into three approaches, including reducing the sediment inflow to reservoirs, routing the sediment inflow so as not to accumulate in reservoirs, and removing sediment accumulated in reservoirs.

Table 1. (a) The estimated sediment load production of sub-catchments along the Kenyir Reservoir Catchment. (b) The estimated total sediment load production for the future (100-year ARI) based on forest coverage reduction percentage in Kenyir Reservoir Catchment. (c) The sediment bypass tunnels in Japan and Switzerland.

(a)						
Elements		Specification Catchment Condition				
Return period ARI		2	5	10	50	100
Catchment rainfall		411	582	712	975	1087
Peak flow (m ³ /s)		3718	5277	6466	8880	9899
Total flow		1236	1679	2018	2706	2997
Total sediment load production	tonnes/year	693,238	853,227	998,355	1,437,772	1,682,334
	m ³ /year	450,155	554,043	648,283	933,618	1,092,425
Year required to be fully deposited	Gross storage (m ³)	30,212	24,547	20,978	14,567	12,449
	Live storage (m ³)	16,439	13,356	11,415	7926	6774
	Dead storage (m ³)	13,773	11,190	9564	6641	5675

(b)				
Elements		Present	Future 100-Year ARI	
Percentage reduction in forest from existing coverage		10%	25%	50%
Peak flow (m ³ /s)	9899	10,011	10,132	50%
Total flow	2997	3001	3007	10,267
Peak water elevation (m)	149.94	149.97	150.01	3018
Total sediment load production	tonnes/year	1,682,334	1,850,568	2,102,918
	m ³ /year	1,092,425	1,201,667	1,365,531
Year required to be fully deposited	Gross storage (m ³)	12,449	11,318	9959
	Live storage (m ³)	6774	6158	5419
	Dead storage (m ³)	5675	5159	4540

(c)				
Dam	Tunnel Completion (Year)	Cross-Section of Tunnel (B × H) (m)	Tunnel Length (m)	Design Discharge (m/s)
Nunobiki (Japan)	1908	2.9 × 2.9	258	39
Asahi (Japan)	1998	3.8 × 3.8	2350	140
Miwa (Japan)	2004	2r = 7.8	4300	300
Matsukawa (Japan)	2016	5.2 × 5.2	1417	200
Egshi (Switzerland)	1976	r = 2.8	360	74
Palagnedra (Switzerland)	1974	2r = 6.2	1800	110
Pfaffensprung (Switzerland)	1922	A = 21 m ²	280	220
Rempen (Switzerland)	1983	3.5 × 3.3	450	80
Runcahez (Switzerland)	1961	3.8 × 4.5	572	110

2. Study Area Characteristics

2.1. Study Area

The most extensive artificial lake in Southeast Asia is located in the Kenyir Lake Basin. Nearly 90% of its surroundings are natural, including in excess of 340 islands scattered throughout a 260,000-hectare water catchment basin. In Terengganu and Malaysia's Peninsular, Kenyir Lake is a well-known tourist site with streams, limestone caves, and a lovely tropical forest that is habitat to over 8000 varieties of flowers, 2500 types of tree and plant life, and 300 species of fungi. All the states on Malaysia's peninsula can receive electricity thanks to the hydroelectric power produced by this lake, which was built specifically for that reason. The dam surrounding Kenyir Lake was built beginning in 1978 and finished in 1985. Others are much more susceptible to any potential environmental change due to the huge variances in climate and land use consequences [34–37]. Kenyir Reservoir has hundreds of tributaries that supply water to Kenyir Lake on a daily basis. However, the Terenggan River, Cacing River, Pertang River, Tembat River, Petuang River, and Terengganu Mati River are major tributaries of Kenyir Reservoir. Table 2 states further details about the physical characteristics of Kenyir Dam, and Table 3 shows the parameters of the water body's water level as well as the river systems, which were assessed using hydrological analysis. Figure 4 shows the main river network system and supplier tributaries flowing into the Kenyir Lake Basin. These water resources are dammed by the Kenyir Dam and

continue flowing into the downstream area of the Terengganu River Basin [1]. Nearly 95% of the important channels in the Kenyir Lake Basin were covered during the hydrographic surveying field work that was conducted for this project during the rainy season (August 2018), the dry season (March 2019), and the normal season (July 2019). This study included 21 sampling stations which are Siput River as Station 1 (S1), Petuang River as Station 2 (S2), Tembat River as Station 3 (S3), Terengganu Mati River as Station 4 (S4), Ketiar River as Station 5 (S5), Besar River as Station 6 (S6), Lepar River as Station 7 (S7), Lawit River as Station 8 (S8), Cenana River as Station 9 (S9), Bewah River as Station 10 (S10), Cicir River as Station 11 (S11), Perepek River as Station 12 (S12), Terenggan River as Station 13 (S13), Cacing River as Station 14 (S14), Pertang River as Station 15 (S15), Lasir River as Station 16 (S16), Leban Terengganu River as Station 17 (S17), Sauk River as Station 18 (S18), Mandak River as Station 19 (S19), Kenyir River as Station 20 (S20), and Berangan River as Station 21 (S21).

Table 2. Further details about the physical characteristics of Kenyir Dam.

Specification	Unit	Value
Length of Dam	[m]	800
Height of Dam	[m]	150
Spillway Length	[m]	140
Dam Crest Elevation	[mRL]	+155
Maximum Flood Level	[mRL]	+153
Full Supply Level	[mRL]	+145
Minimum Operating Level	[mRL]	+120
Lake Area	[km ²]	369
Catchment Area	[km ²]	2612
Gross Storage	[m ³]	13.6 × 10 ⁹
Live Storage	[m ³]	7.4 × 10 ⁹
Name of Power Station	-	Sultan Mahmud
Installed Capacity	MW	4 × 100
Average Annual Energy Output	GWh	1600

Table 3. Hydromorphological characteristics of the river system during wet season, dry season, and normal season at Kenyir Lake Basin.

Station	Location		River Name	Area of Sub-Catchment (km ²)	Datum Elevation M.S.L (m)
	Longitude	Latitude			
Station 1 (S1)	102° 42' 42.602" E	5° 11' 01.064" N	Siput River	14.306	151.26 m
Station 2 (S2)	102° 39' 49.705" E	5° 17' 42.360" N	Petuang River	250.280	155.7 m
Station 3 (S3)	102° 38' 19.879" E	5° 12' 57.393" N	Tembat River	113.261	153.62 m
Station 4 (S4)	102° 37' 46.486" E	5° 11' 24.258" N	Terengganu Mati River	429.811	154.02 m
Station 5 (S5)	102° 33' 17.735" E	5° 03' 30.462" N	Ketiar River	42.070	153.25 m
Station 6 (S6)	102° 34' 15.044" E	4° 58' 03.613" N	Besar River	44.614	152.02 m
Station 7 (S7)	102° 33' 09.379" E	4° 56' 16.506" N	Lepar River	26.786	149.9 m
Station 8 (S8)	102° 35' 13.374" E	4° 54' 38.067" N	Lawit River	34.529	150.6 m
Station 9 (S9)	102° 42' 04.9" E	4° 52' 32.0" N	Cenana River	18.406	153 m
Station 10 (S10)	102° 41' 24.427" E	4° 50' 36.340" N	Bewah River	8.688	155.56 m
Station 11 (S11)	102° 44' 30.707" E	4° 47' 42.302" N	Cicir River	48.593	156.4 m
Station 12 (S12)	102° 44' 31.9" E	4° 47' 16.9" N	Perepek River	49.586	156.48 m
Station 13 (S13)	102° 45' 00.244" E	4° 46' 28.235" N	Terenggan River	126.057	153.12 m
Station 14 (S14)	102° 42' 32.595" E	4° 48' 17.089" N	Cacing River	113.334	152.16 m
Station 15 (S15)	102° 48' 00.5" E	4° 55' 26.2" N	Pertang River	93.332	158 m
Station 16 (S16)	102° 50' 22.510" E	4° 57' 54.633" N	Lasir River	19.961	155.92 m
Station 17 (S17)	102° 45' 03.621" E	5° 02' 21.528" N	Leban Terengganu River	13.119	151.42 m
Station 18 (S18)	102° 46' 42.443" E	5° 04' 58.079" N	Sauk River	9.588	152.85 m
Station 19 (S19)	102° 20' 6.25" E	5° 07' 34.463" N	Mandak River	8.174	153.23 m
Station 20 (S20)	102° 54' 5.18" E	5° 0' 40.01" N	Kenyir River	13.318	145.00 m
Station 21 (S21)	102° 54' 40.34" E	5° 1' 2.36" N	Berangan River	3.983	141.00 m

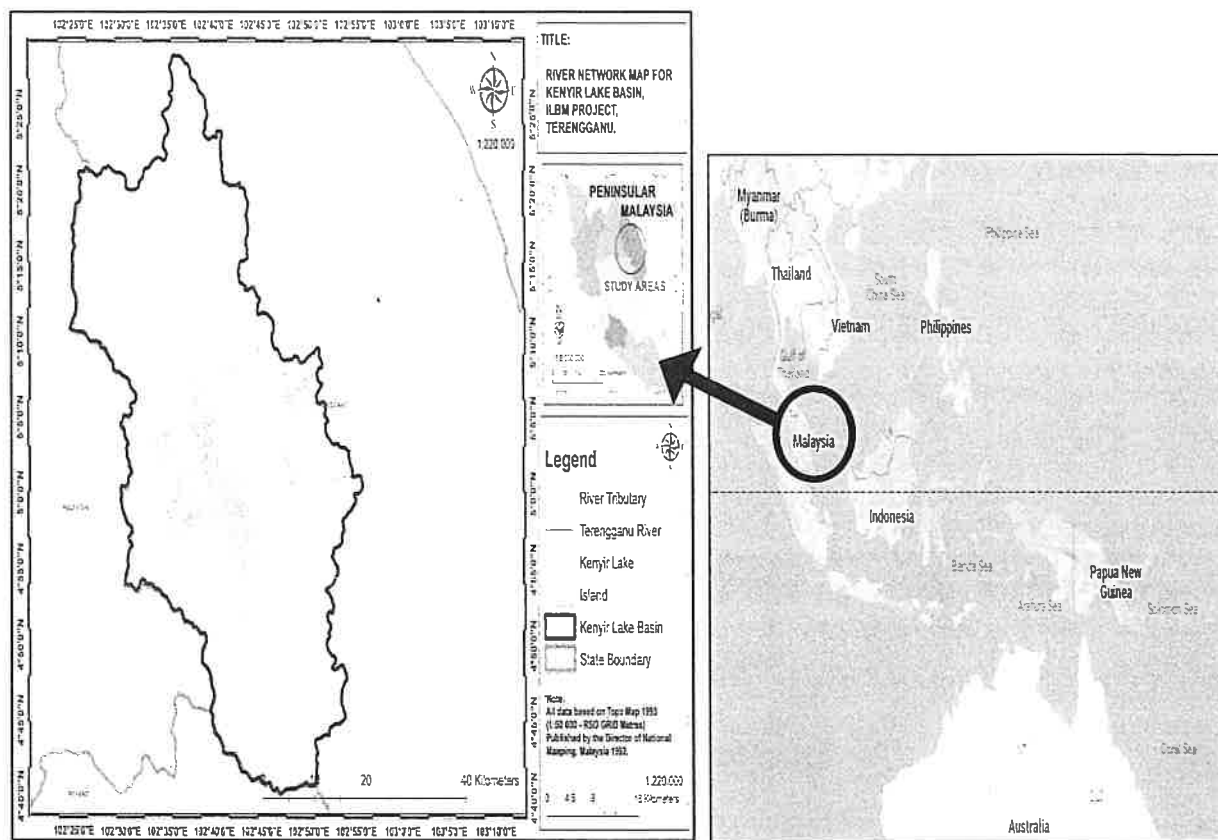
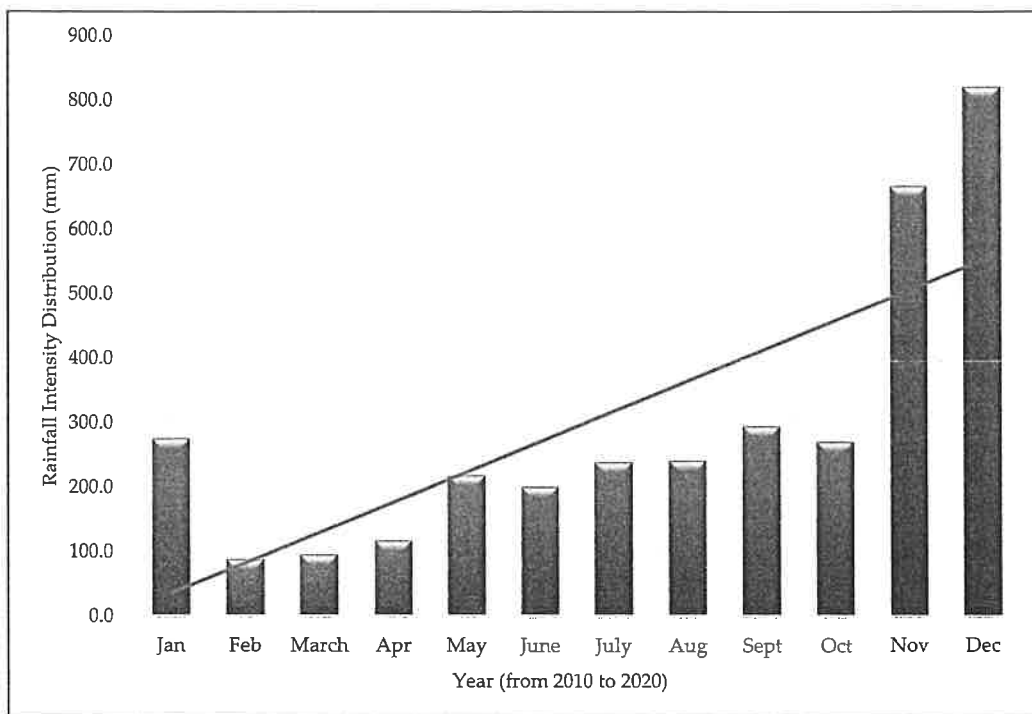


Figure 4. The main river network system and supplier tributaries flowing into Kenyir Lake Basin, Terengganu, Malaysia (drawn by the first author).

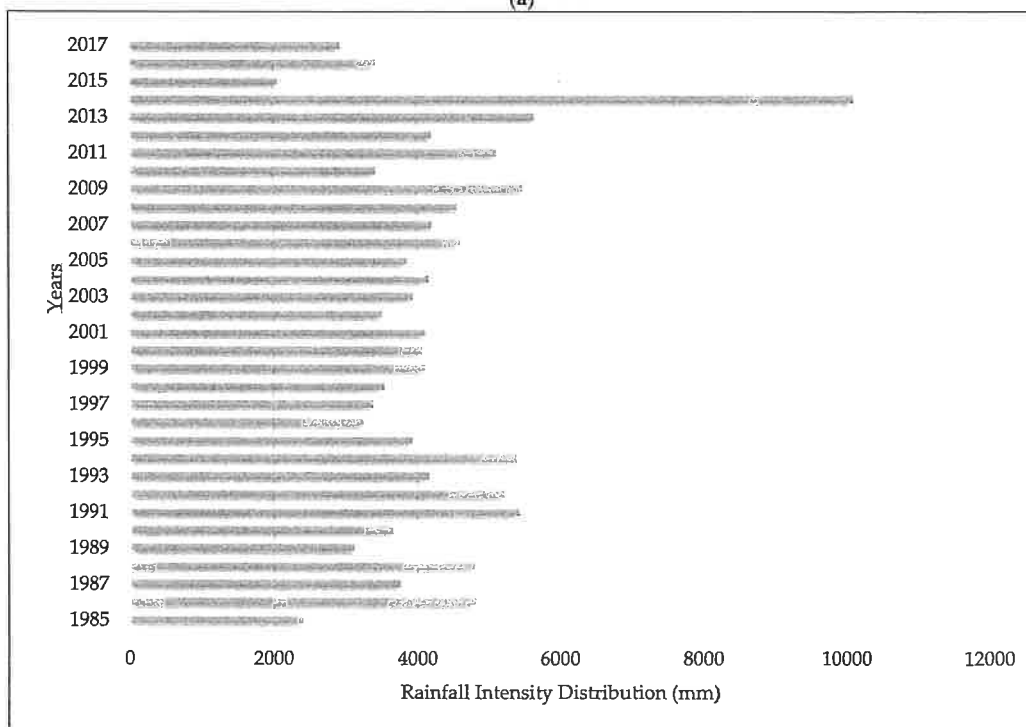
2.1.1. Climatology Status

The characteristic features of the climate in Terengganu State and Kenyir Lake are generally uniform, high intensity rainfall. Climate and precipitation data were obtained from *Jabatan Meteorologi Malaysia* (Malaysia Meteorological Department) (MMD), *Jabatan Pengairan dan Saliran* (Department of Irrigation and Drainage) (DID), and Tenaga Nasional Berhad Research (TNBr). The precipitation distribution is vital when examining the physical environment of natural water bodies such as lakes, rivers, and streams. Extreme regional rainfall, excessive river discharge, and wave energy from the South China Sea are the primary contributors to flooding. Rainfall is the main water source for the river basin. Kenyir Lake Basin, which covers the overall district, experiences an equatorial type of climate characterised by warm and humid weather all year round and is under the influence of the Asian Monsoon system. The two primary types of rainfall are often seasonal variations, with the first occurring from September to February (during the wet Northeast Monsoon Month) and the second occurring from May to October when rainfall is typically less than in the other months (normal season). It has an impact on a river's water storage and outflow, particularly during periods of severe rainfall. To reflect the climate in Hulu Terengganu District (Felda Belara Station), secondary data from 2010 to 2020 were reviewed (Refer to Figure 5a) [1,37]. Figure 5b defines Kenyir Lake from 1985 to 2017 in the upstream areas of Kenyir Lake or border areas of Terengganu and Kelantan, based on the Department of Irrigation and Drainage (DID) Pahang, 2014, the big event that accumulated in 2014, where the amount of rainfall increased in December 2014, particularly from November to mid-December, in several locations such as Jerantut, Maran, Temerloh, Gua Musang, and Nenggiri. According to the created isohyet map, the Terengganu and Kelantan border saw a concentration of high rainfall intensity in December 2014, with rainfall amounts ranging from 2300 mm to 1600 mm. In a few regions that are severely hit by flooding, including National Park, Jerantut, Temerloh, and Cameron

Highlands, particularly in Brinchang and Chini, the aggregate intensity of the rainfall still pours down with a capacity range of roughly 120 mm to 60 m. According to the isohyet map from January 2015, Kuala Rompin saw high-intensity rain in the 800–700 mm range. In other locations, such as Pahang State’s central region and the Pahang River’s upstream region, the intensity of rainfall decreased to a range between 120 mm and 40 mm in the blue area. (Refer to Figure 5c) [1,37–40].



(a)



(b)

Figure 5. Cont.

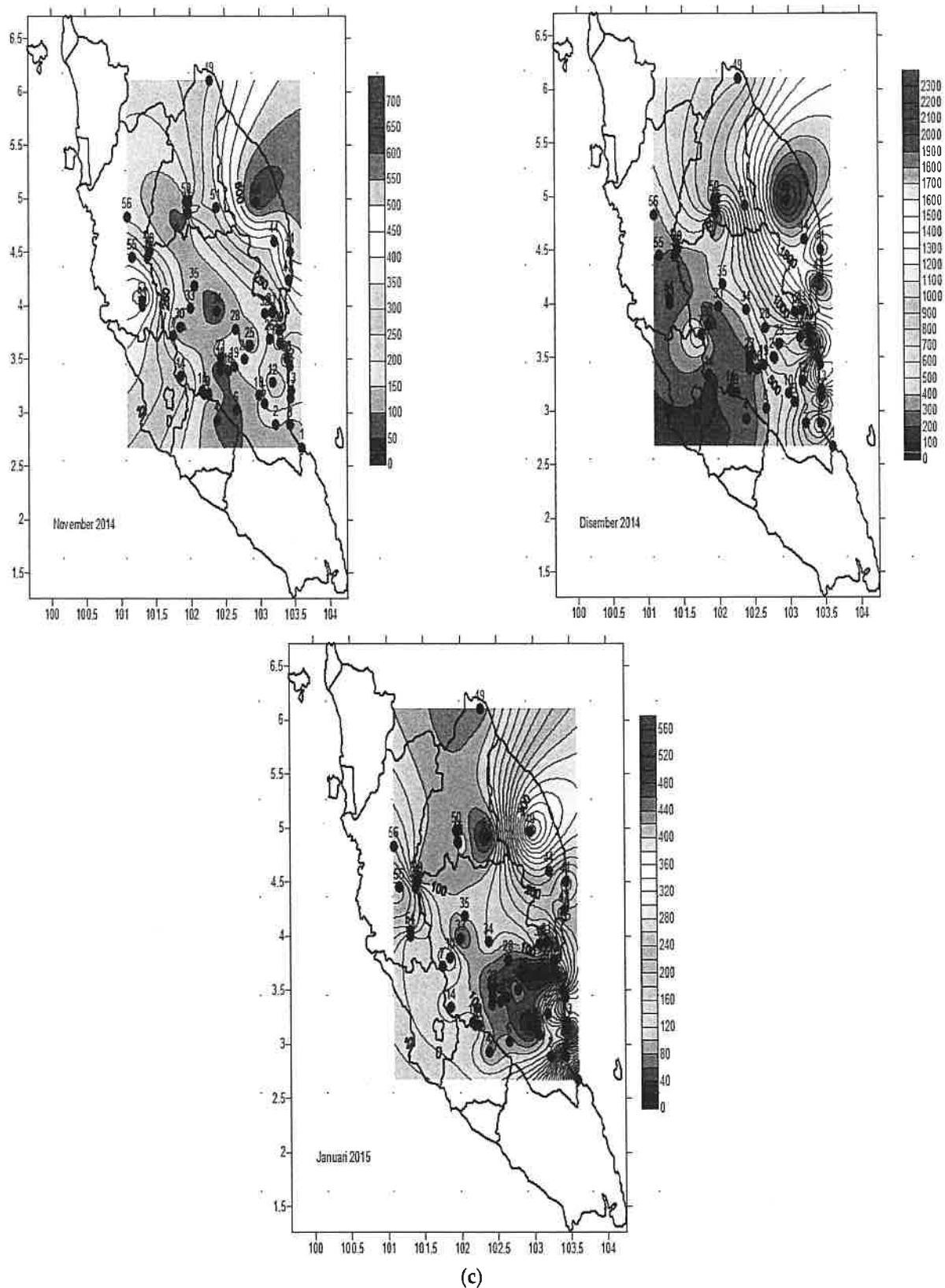
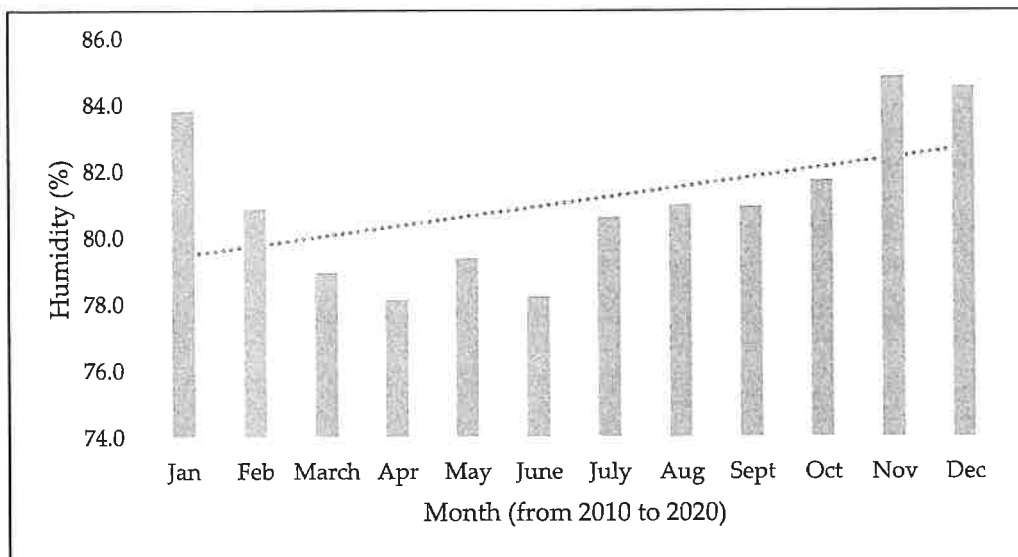


Figure 5. Cont.



(d)

Figure 5. (a) The level of rainfall intensity distribution at Hulu Terengganu District (Felda Belara Station) from 2010 to 2020 (from [1,37]). (b) The aggregate level of rainfall intensity distribution at Kenyir Lake Basin from 1985 to 2017 (from [1]). (c) Cumulative rainfall distribution of the Terengganu border from (a) November 2014, (b) December 2014, and (c) January 2015 (from [1,40]). (d) The mean monthly humidity recorded at Felda Belara, Hulu Terengganu, Meteorological Station (2001–2017) (from [1,37]).

In relation to the maximum (highest point) for that temperature, relative humidity gauges the current absolute humidity. Although humidity is a climate variable in and of itself, it also has a significant impact on other climate factors. Wind and rainfall have an impact on the humidity. At the same time, humidity has a significant impact on both the energy budget and temperatures. First, atmospheric water vapour includes “latent” energy. This latent heat is taken from the surface liquid via transpiration or evaporation, cooling the earth’s surface. The largest non-radiative cooling effect is currently occurring at the surface. Approximately 70% of the mean net radiant heating at the surface is made up of it. The relative humidity has not significantly changed over the course of the year in the Terengganu River Basin. For instance, lower down, Kuala Terengganu’s monthly mean relative humidity is 83%, with a minor seasonal variation from 80% in March to 85% in October. Figure 5d for the Hulu Terengganu climatological station from 2001 to 2017 shows detailed relative humidity data. The relative humidity is generally a little high. In the early hours of the day as well as during the monsoon season, relative humidity may reach close to 90% due to a rise in the supply of moisture rather than a drop in temperature. Similar to this, during the monsoon, saturation deficits are substantially lower than they are during the pre-monsoon season (August to October) and are virtually as low as they are in March and April when the temperature of the air and the volume of water that the air can hold are at their lowest points [1,37–40].

2.1.2. Land Use Distribution

Act 172’s Sections 16B(1), 16B(2), and 16B(3) specify that *Rancangan Kawasan Khas* (RKK) is the location of Kenyir Lake. The study locations are in both Level 1 and Level 2 Environmentally Sensitive Areas (ESA) and are close to forest reserves. Various categories, including business, transportation, public, residential, and recreational infrastructure, and water bodies, are separated into proportions of developing structures that are utilised. The forest covers the majority of the Kenyir Lake Basin at 476.55 hectares, or 52.83% of the total area. The water body, which makes up around 308.80 hectares, or 34.23% of the entire basin’s surface, is the second-largest element. Only a minor section of the total 902 hectares

authorised for development is located in the Kenyir Lake Basin (Refer to Table 4a). *Rancangan Kawasan Khas* (RKK) for Kenyir Lake Basin has a development action plan that is divided into eight zones of land use classification, as stated in Table 4b below [41]. Based on remote sensing satellite image information provided by the U.S. Geological Survey (USGS) and the Malaysian Remote Sensing Agency (ARSM), an analytical study of changes in land use distribution scenarios in the Kenyir Lake Basin from 1976 to 2017 was conducted using Remote Sensing (RS) software and Geographic Information Systems (GIS). The results are shown in Figure 6a. Three stages of land use changes were identified: 1976 (before the construction of the Kenyir Dam), 1989 (after the Kenyir Dam’s full operational status in 1985), and 2001–2020 (the most recent data available during the study). For some regions that have undergone considerable land use changes, the job of “site validation” using DGPS and drone technologies is employed to verify and validate these data. The proposed scenario of change in land use in the Kenyir Lake Basin from 1976 to 2020 is based on Figure 6a. Based on the changes that have taken place for approximately 40 years, the Puah Dam and Tembat Dam building activities are more focused on the arrangement of water bodies than on the percentage of rising urbanisation developments in the Kenyir Lake Basin [41]. Modelling and simulation of land cover change are crucial for the assessment of the effects on the environment that will follow. Remote sensing and geographic information systems (GIS) offer key methods that might be used in research at both the local and municipal levels. In the years 2001, 2009, and 2016, as well as in the anticipated year 2030, the Kenyir Basin had constant urban growth from 5.04 km² to 79.51 km², 117.03 km², and 220 km², with a stimulation value of 0.6934 K-standard. Location maps of land use and cover simulations from 2030 reveal a significant increase in the area covered by buildings. A total of 220 km², or 8.42% of the Kenyir Lake River Basin’s total area, will be occupied by built-up regions, according to data on land use and vegetation change detection. With the use of the data, we may more effectively create and implement land use and environmental management strategies that more effectively integrate urban growth with environmental preservation (Refer to Figure 6b,c) [32,42].

Table 4. (a) The percentage of land use distribution in Kenyir Lake Basin during 2018. (b) *Rancangan Kawasan Khas* (RKK) of Kenyir Lake Basin based on the eight zones of land use classification.

(a)		
Land Use	Area (Hectare)	Percentage (%)
Forest	476.55	52.83
Water Body	308.80	34.23
Transportation	46.81	5.19
Public Infrastructure	45.14	5.00
Residential	2.95	0.46
Recreation	1.84	0.33
Utility and Infrastructure	15.66	0.20
Industry	0.17	1.74
Total	902.00	100.00

(b)	
Zone of Land Use Classification	Area (Hectare)
Tourism Centre Pengkalan Gawi	111.3
Service Centre Kenyir One	86.2
Institution Centre Kenyir One	35.4
Pusat Desa Kg Basong	22.4
Forest	289.0
Agriculture	255.9
Public Infrastructure	25.4
Transportation	76.2
Total	902.0

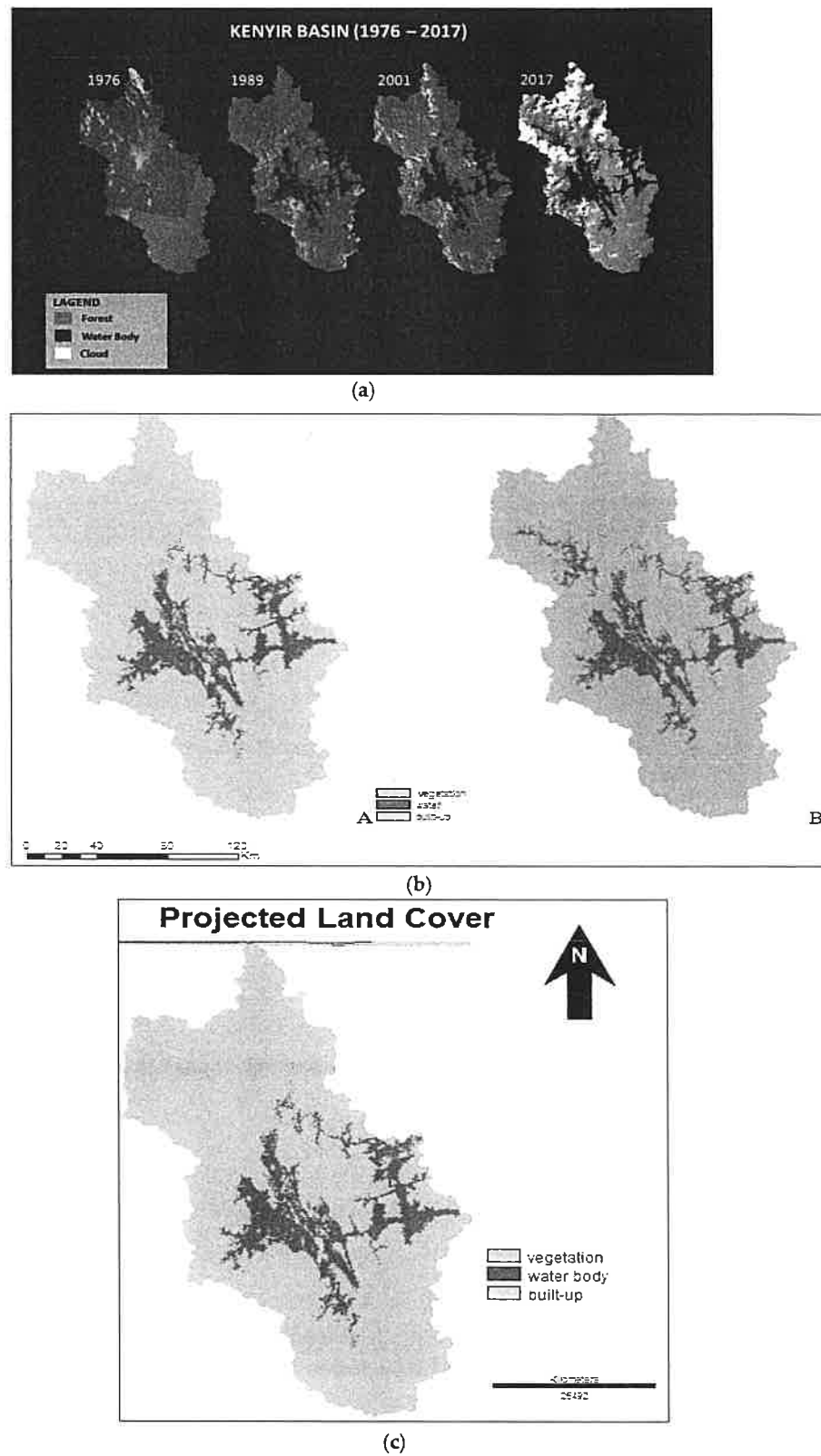


Figure 6. (a) Satellite image of land use distribution scenario changes in Kenyir Lake Basin from 1976 to 2017 (from [1]). (b) The illustration of images of Kenyir Lake Basin based on the analysis of the CA–Markov model (A and B) (where A is the projected image and B is the real or classified image) (from [32,42]). (c) The illustration of stimulated land use on the land cover map of Kenyir Lake Basin in 2030 (from [32,42]).

3. Research Methodology

Using the Fundamental Georeferencing of ArcGIS analysis, the annual Sediment Load (SL) production is calculated based on a few other key parameters, including measurements of Total Suspended Solid (TSS), river discharge (Q), and sub-catchment areas. In addition, in identifying the level of sedimentation problems along the Kenyir Lake Basin, this study also includes an analysis to determine the particle size distribution of the underlying sediment (ϕ). In this regard, primary and secondary data identified are discussed to determine the direct relationship to the sediment production process along Lake Kenyir Basin. By analysing the data, it is possible to ascertain how the concentration of suspended sediment has changed over time and how it relates to other variables, including hydrological and geomorphological ones. The simplified hydrological framework for the Kenyir Lake Basin sedimentation problem study is shown in Figure 7, along with a few key factors used to calculate the generation of yearly sediment loads.

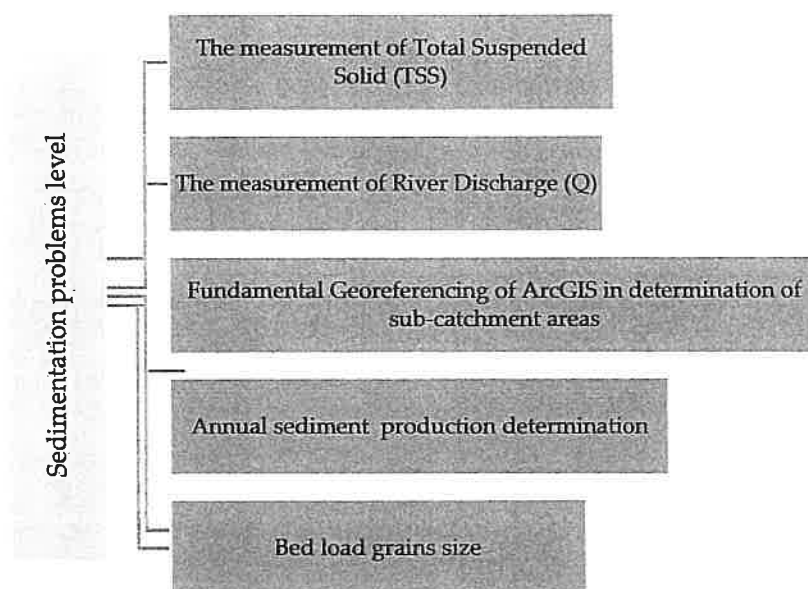


Figure 7. The important parameters applied in this study.

3.1. The Measurement of Total Suspended Solid (TSS)

The Total Suspended Solid is evaluated using the gravimetric method. For each station, a 250 mL sample of water is required. TSS is measured by weighing each piece of 0.45-mm membrane filter paper and recording the results. In the next stage, water samples are filtered using a membrane-based filtering set and a weighted membrane filter. Later, the dried membranes are allowed to air-condition in the drying jar. The dried membrane is weighed to determine its standard weight. TSS is quantified by (Refer to Equation (1)) in mg/L. Be cautious that safety precautions must be taken when collecting a river water sample. In order to minimize the accumulation of the identified suspended silt, the amount that causes disturbances affecting the flow of water in the river needs to be maintained at a minimum. The American Public Health Association (APHA) [42–45].

$$\text{TSS} = \{(\text{WBF} + \text{DR}) - \text{WBF}\} (\text{mg}) \times 1000 / \text{VFW} (\text{mL}) = \text{mg/L} / 1000 / 1000 / 1000 = \text{tonne/L} \quad (1)$$

WBF = weight of membrane filter; DR = dry residue; VFW = volume of filtered water.

3.2. The Measurement of River Discharge (Q)

There are many different aspects of rivers that can be evaluated in situ, including river stream flow, river breadth, depth, and river datum view according to Mean Sea Level (MSL). In order to classify a river, evaluate its planform, and survey its geometry, the cross-section must be calculated and measured. Rivers are measured using GPS and many

types of measuring tools, including levelling metres, depth metres, range finders, and tiny divers that calculate water level increases automatically. The primary factor influencing a sediment's capability for transport and its capacity to move is the speed of flow. River flow rate (V) and river discharge level (Q) both have an impact on the sediment deposition process. Generally speaking, the downstream regions experience higher flowing water rates and discharge values than the upstream regions, which causes a larger silt deposit. The discharge value (Q) is obtained by multiplying the cross-sectional area (A) by the velocity. Details can be found in Equations (2) and (3) [46–50].

$$\begin{aligned}
 Q &= vA, \text{ or } Q = \frac{1}{2} vA \\
 Q &= \text{m}^3\text{s}^{-2} \\
 A1 &= 1/2 (L1 \times D1) \\
 A2 &= L2 [(D1 + D2)/2] \\
 A3 &= L3 [(D2 + D3)/2] \\
 A4 &= 1/2 [L4 \times D3] \\
 A &= dw \text{ (m)} \quad A = \frac{1}{2} dw \text{ (m)} \\
 \Sigma &A1 + A2 + A3 + A4
 \end{aligned} \tag{2}$$

To obtain the unit L day^{-1} , the following formula is used:

$$Q = \text{m}^3 \text{ s}^{-1} \times 86,400 \text{ s day}^{-1} \times 1000 \text{ L m}^{-3} = \text{L day}^{-1} \tag{3}$$

3.3. Fundamental Georeferencing of ArcGIS in the Determination of Catchment Areas

The size of each sub-catchment (area sampling basin) is calculated using the Fundamentals of Georeferencing in ArcGIS approach, as shown in Figure 8a,b. The yearly sediment load production (SL) is computed as a function of the sub-catchment regions using the discharge value (Q) (m^3/s) and TSS value (mg/L) as inputs. Additionally, using the Inverse Distance Weighting (IDW) interpolation approach, this parameter is used to calculate the graphical trends of level sediment load generation by sub-catchment [42,50–52].

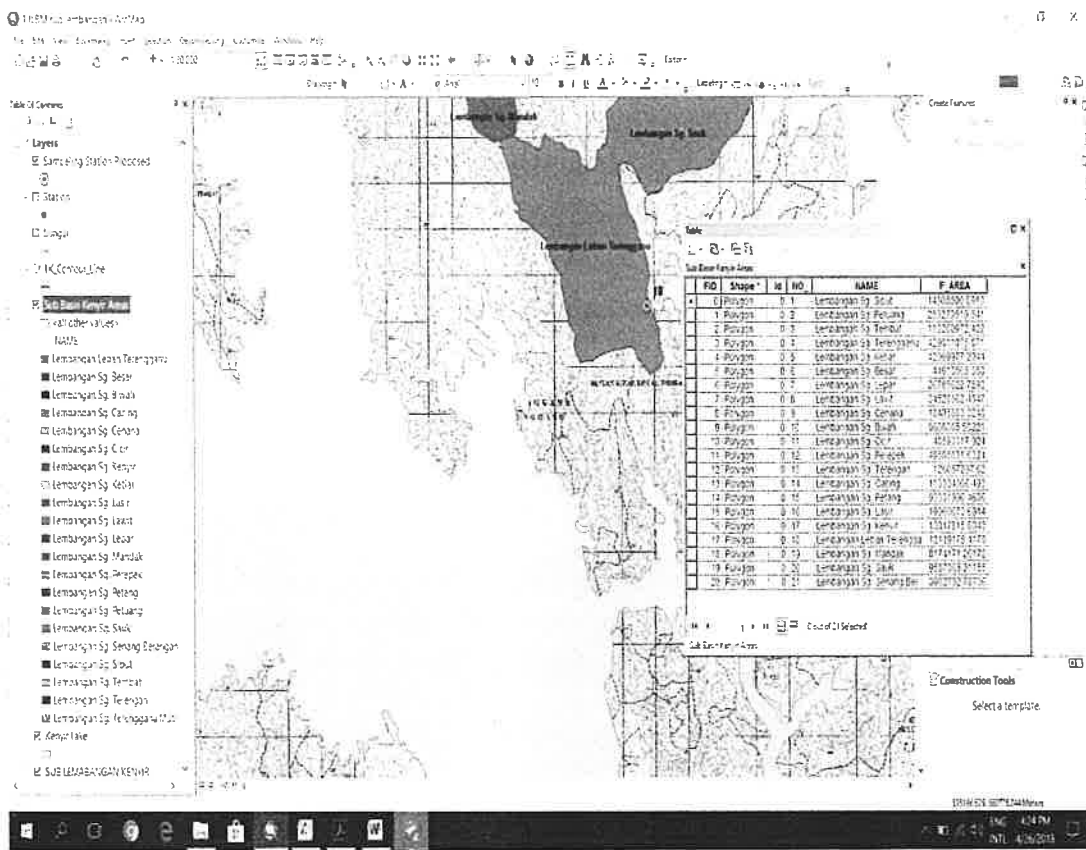
3.4. Annual Sediment Production Determination Areas

The annual output of sediment load (SL) is calculated based on the sub-catchment area (km^2), TSS value (mg/L), and discharge value (Q) (m^3/s). The data analysis would show alterations in the suspended sediment concentration and how these components are connected to hydrological, geomorphological, and other variables. The method used to measure SL ($\text{tonnes}/\text{km}^2/\text{year}$) is shown in Equation (4) below [11,27,45].

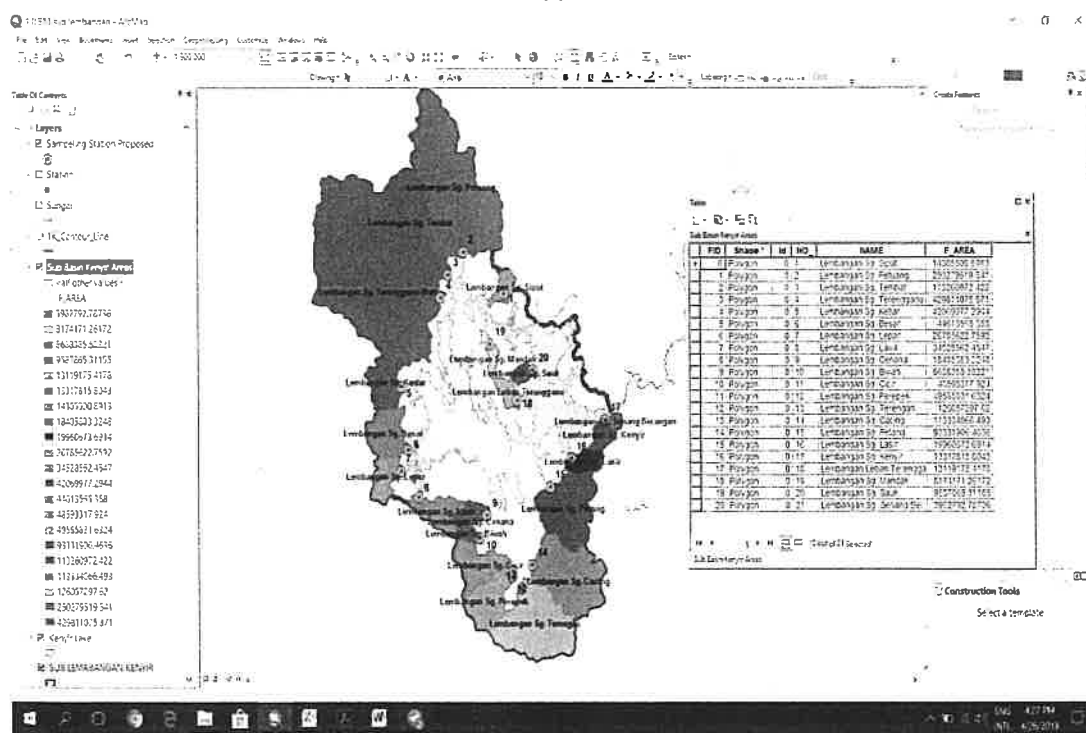
$$\begin{aligned}
 \text{Annual sediment load production (SL)} &= (Q \times \text{TSS}) / \text{Area of sampling basin} \\
 &= (\text{L/day} \times \text{tonnes/day}) / \text{km}^2 \\
 &= \text{tonnes}/\text{km}^2 / 365 \text{ days} \\
 &= \text{tonnes}/\text{km}^2 / \text{days}
 \end{aligned} \tag{4}$$

3.5. Size Measurement of Bed Load Grains

Bed load grain size analysis regarding the size of sediment grains is one of the primary data requirements in this research and is obtained from the results of fieldwork and analysis in the laboratory. ASTM D 422: Standard Test Method for Particle-Size Analysis of Soils (Sieve Grain Size Analysis) is the method applied in this research to determine the classification of different grain sizes that influence and have a significant effect on putting pressure on sedimentation problems. The method of analyzing the size and texture of bed load grains deposited on the bottom and banks of the river aims to classify the size of the sediment grains found in the river along the Kenyir Lake Basin. Furthermore, GRADISTAT software (A Grain Size Distribution and Statistics Package) was used as the main tool in the analysis of determining the size of these sediment grains [11,39].



(a)



(b)

Figure 8. (a) The illustration process of the Fundamentals of Georeferencing of ArcGIS in the determination of river sub-catchment areas in Kenyir Lake Basin. (b) The illustration of each river sub-catchment area in Kenyir Lake Basin (drawn by the first author).

4. Results and Discussion

The topography of the Kenyir Lake catchment area varies from 50' to a spot height of 1210' above mean sea level (MSL), but for about 80% of the area, the topography is well below 250' MSL. Areas above the 250-foot contour area are mainly constrained to the southwest, where Taman Negara National Park is located. The main water sources contributing to the main lake body comprise, firstly, the natural tributaries of the Terengganu River and a few rivers along the Kenyir Lake Basin. Historical and current-day changes in land uses and plant cover explain the complex interactions assessed in the Kenyir Lake River Basin between geomorphic processes in hill slopes and calculated from the topography map of Kenyir Lake. Figure 9 shows the length slope characteristics for Kenyir Lake Catchment Areas, Hulu Terengganu. Technically, riverbank erosion can occur due to several factors that contribute to the erosion occurring. Among the factors are the loss of soil particles on the riverbank due to stream flow, landslide due to the increment of bank slope, erosion due to the turbulence of the stream flow, and finally, side erosion that caused the structure of the bank to collapse. River geometry includes a cross-section for minimum geometry (width, depth, cross-section, and meander length), and hydraulic variables include riverbank slope, minimum friction, and minimum stream flow that affect bed erosion and sedimentation. In the end, the shape of the river geometry profile can be elaborated as a physical shape of a river, whether it is plain or grooved, due to the pressure of the bed surface transverse flow that led to erosion and sedimentation [1,31,41,51–55].

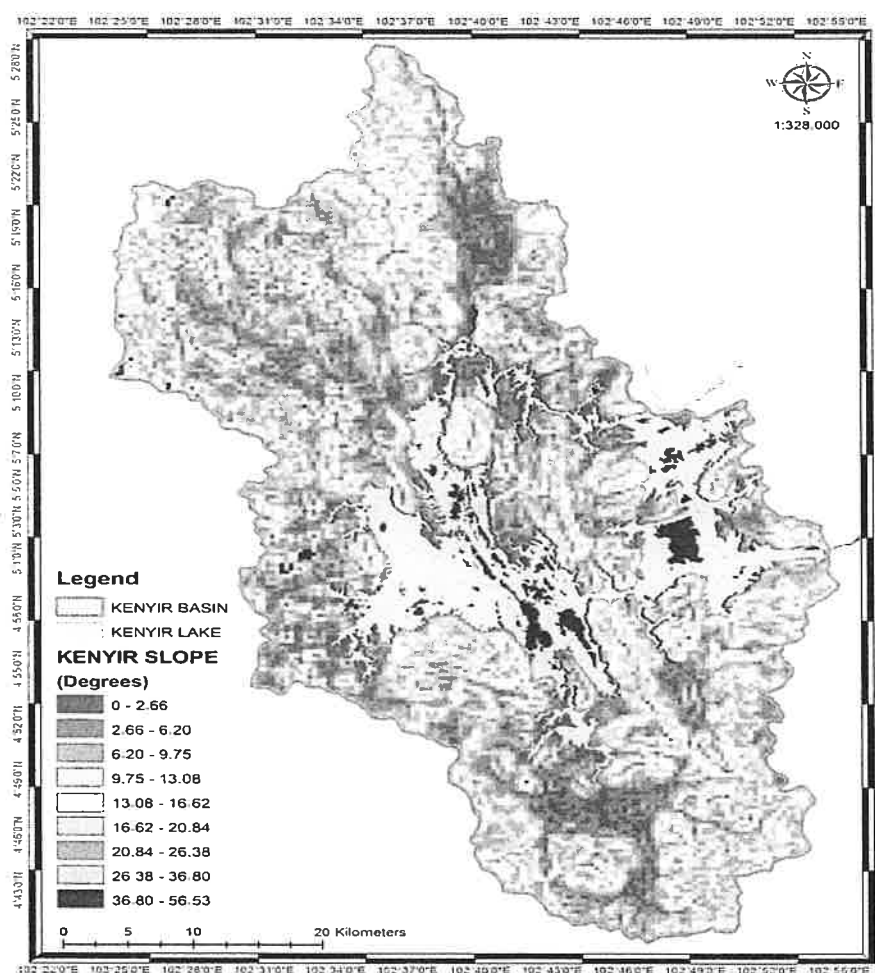
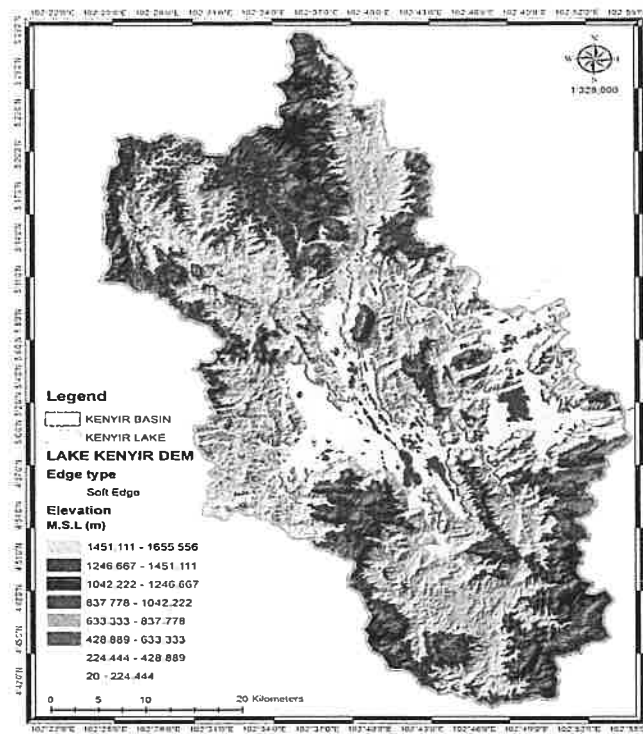


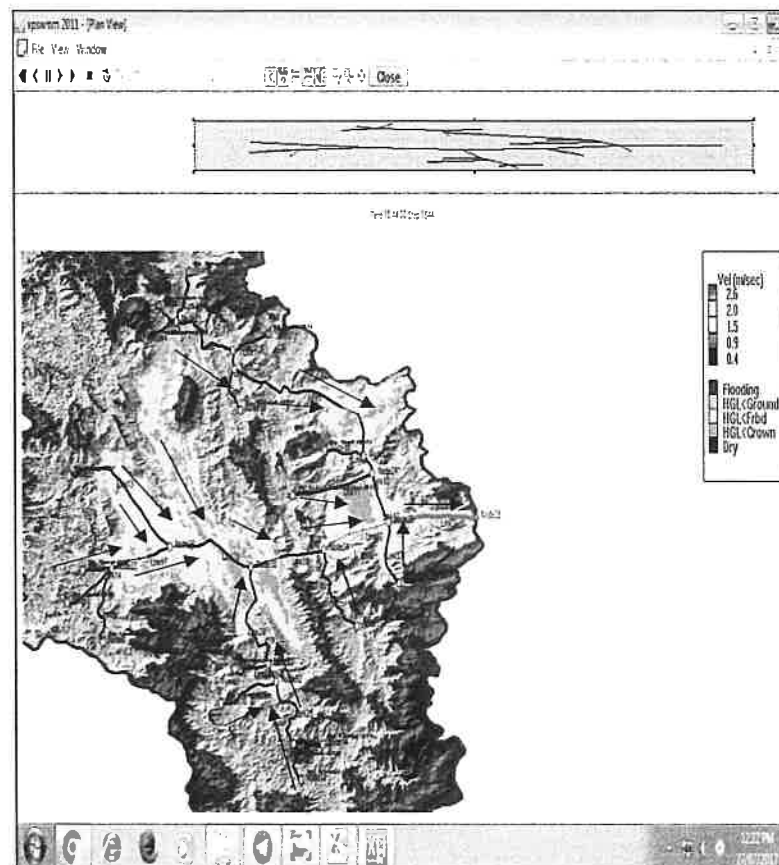
Figure 9. Length slope characteristics for Kenyir Lake catchment areas, Hulu Terengganu, Terengganu, Malaysia (drawn by the first author).

As the flood water receded, the lake level dried out, reaching its lowest level from March to June. During this period, the water stays shallow with sedge-covered mud banks for up to six months until the rain comes again. The climate of Kenyir Lake is typical of the equatorial climate of Peninsular Malaysia, which is characterised by moderate average annual rainfall, temperature, and humidity. Topographically, about 90 per cent of Kenyir Lake is hilly, with elevations over 224 m, and the highest is up to 1655 m from sea level (M.S.L.) (Refer Figure 10a,b). The mountainous areas are under virgin jungles, and some placement areas are in the lowlands. Present anthropogenic activities within the site catchment that may have contributed to river regimes are tourism and agriculture activities. The role of lakes within the global hydrologic cycle or hydrological system for their very existence depends on a balance between their many sources of water and the losses that they experience. This so-called water budget of lakes is important enough to have warranted considerable study throughout the world, with each lake or lake system possessing its own hydrologic system. These may include restrictions on water utilisation, especially during the wet and dry seasons, to enhance water quantity and quality management activities. To predict imbalances in the hydrologic budget, it is usually difficult to influence the basic natural factors that cause the imbalances. Precipitation and evaporation, for the most part, are uncontrollable, although some advances have been made in evaporation suppression in small lakes through the use of monomolecular surface films. Groundwater flow is not controllable, except where highly restricted flow can be tapped. Rivers and streams, however, can be subjected to regulation by well-established practices through the use of dams, storage reservoirs, and diversions. It is mainly through these controls that efforts are made to make the most efficient use of water as a resource [24,27,36,51].

In the typical interpretation of the hydrological theory, the higher flow contains more powerful energy to move the higher concentrated suspended sediment load compared to the lower flow, and the TSS production is higher during the water flow in a basin. This is because the higher flow has a higher discharge value (Q), or the water velocity in the elevated downstream is higher than upstream [54–56]. The key factor in minimising surface erosion, which increases the generation of sediment load in river basins, is the density of water at the forest canopy. Since a greater flow contains more powerful energy to carry a concentrated load of heavier suspended sediment than a lower flow level, and a high flow also enhances the rate of erosion, the total suspended solids (TSS) will rise as the water flow in a basin rises. TSS is an indicator to classify the river in Class I, II, III, IV, or V based on the National Water Quality Standard (NWQS). TSS is also used to determine whether the status of water quality is clean, moderately polluted, or contaminated and to estimate the suspended sediment load production in the Kenyir Lake Basin [37,57–59]. Figure 11 shows the highest amount of TSS at Lepar River, recorded at 18 mg/L (wet season) and 15 mg/L (dry season), respectively. During the normal season, the Ketiar River recorded the highest value of 14.5 mg/L. The minimum level of TSS at Cacing River was 5.20 mg/L (wet season) and 4.1 mg/L (normal season). The value of TSS in the dry season showed a higher range compared to the wet season, affected by climate changes and anthropogenic factors. The TSS amount for all sampling stations was recorded at 5.20 mg/L 18.00 mg/L during the wet season, 1.20 mg/L \pm 15.00 mg/L during the dry season, and 4.1 mg/L \pm 14.50 mg/L during the normal season. According to the findings, the hydrological cycle, anthropogenic and geomorphological issues, and climate variability all had an impact on the difference in TSS levels at the Kenyir Lake Basin. This study established that the increased amount of soil loss was driven by the rainy season (higher density of rainfall) [60–65].



(a)



(b)

Figure 10. (a) Digital Elevation Model (DEM) characteristics for Kenyir Lake catchment areas, Hulu Terengganu, Terengganu, Malaysia (drawn by the first author). (b) The Digital Elevation Model (DEM) map of Kenyir Lake, Hulu Terengganu, Terengganu, Malaysia (drawn by the first author).

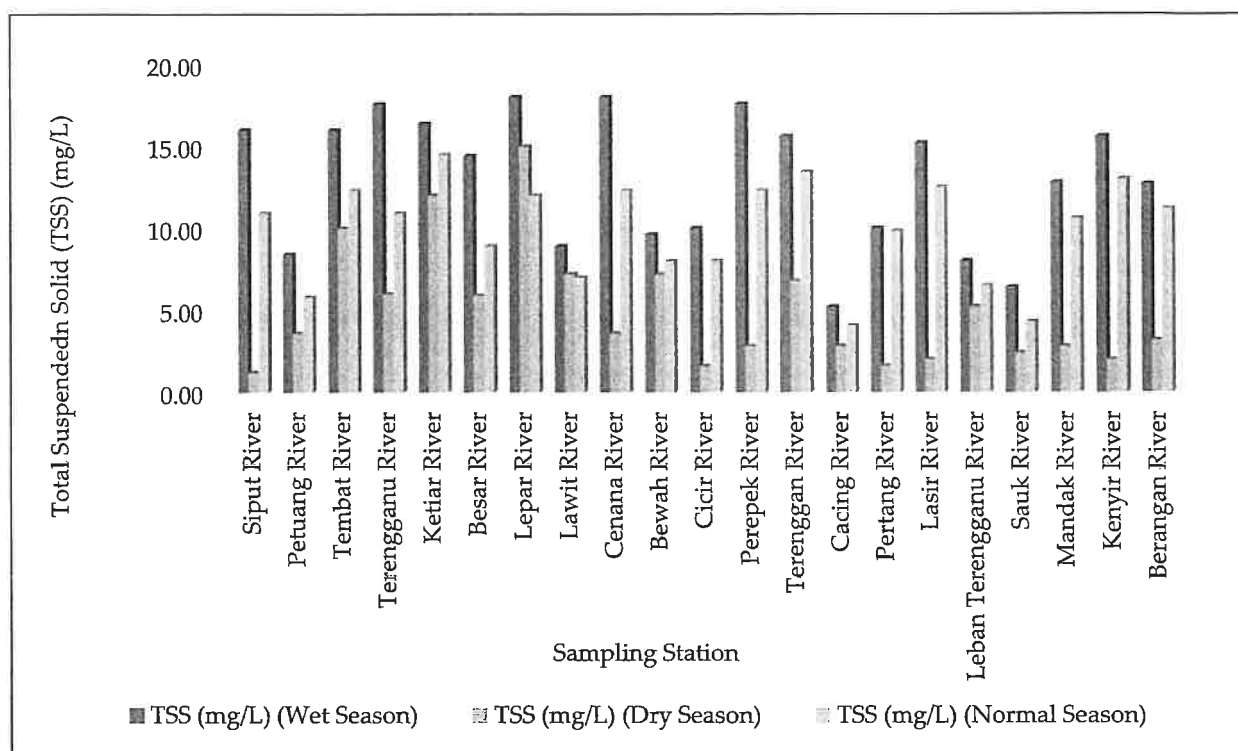


Figure 11. The distribution of TSS (mg/L) at Kenyir Lake Basin, Terengganu, during wet season (August 2018), dry season (March 2019), and normal season (July 2019).

This study also aims to determine the factors influencing the dynamic variation of Q and sediment yield production. The sedimentary content and the flow of water were influencing the condition of the river. Based on the hydrological facts, the frequency and intensity of rainfall influenced the water level flow and the rates of the erosion process. The positive relationship between the rate of side and riverbank erosion is proposed to increase sediment production. The velocity of water plays an important role in erosion activity and sediment production; the velocity depends on the intensity of rainfall. Generally, the higher the rate of speed and volume of water, the stronger the erosion rates. However, the anthropogenic factors along the river basin also influences the variation of river discharge and sediment production. Figure 12 shows the regression relationship between TSS and Q during wet season ($R^2 = 0.0048$), dry season ($R^2 = 0.0078$), and normal season ($R^2 = 0.0085$). There are low significant relations between two important parameters shown in Figure 12. The increase in Q caused an increase in TSS, but this result demonstrated that Q was not the primary factor in the increasing amount of TSS because the R^2 values for three seasons were <0.5 . According to the statistical values, the production of TSS in the Kenyir Lake Basin is dependent not only on Q but also on other factors such as anthropogenic, geomorphology, and climate factors. Other factors will influence TSS and sediment load production because the hydrological process in a lake basin is just not static and always adapts because of numerous environmental factors [65–67].

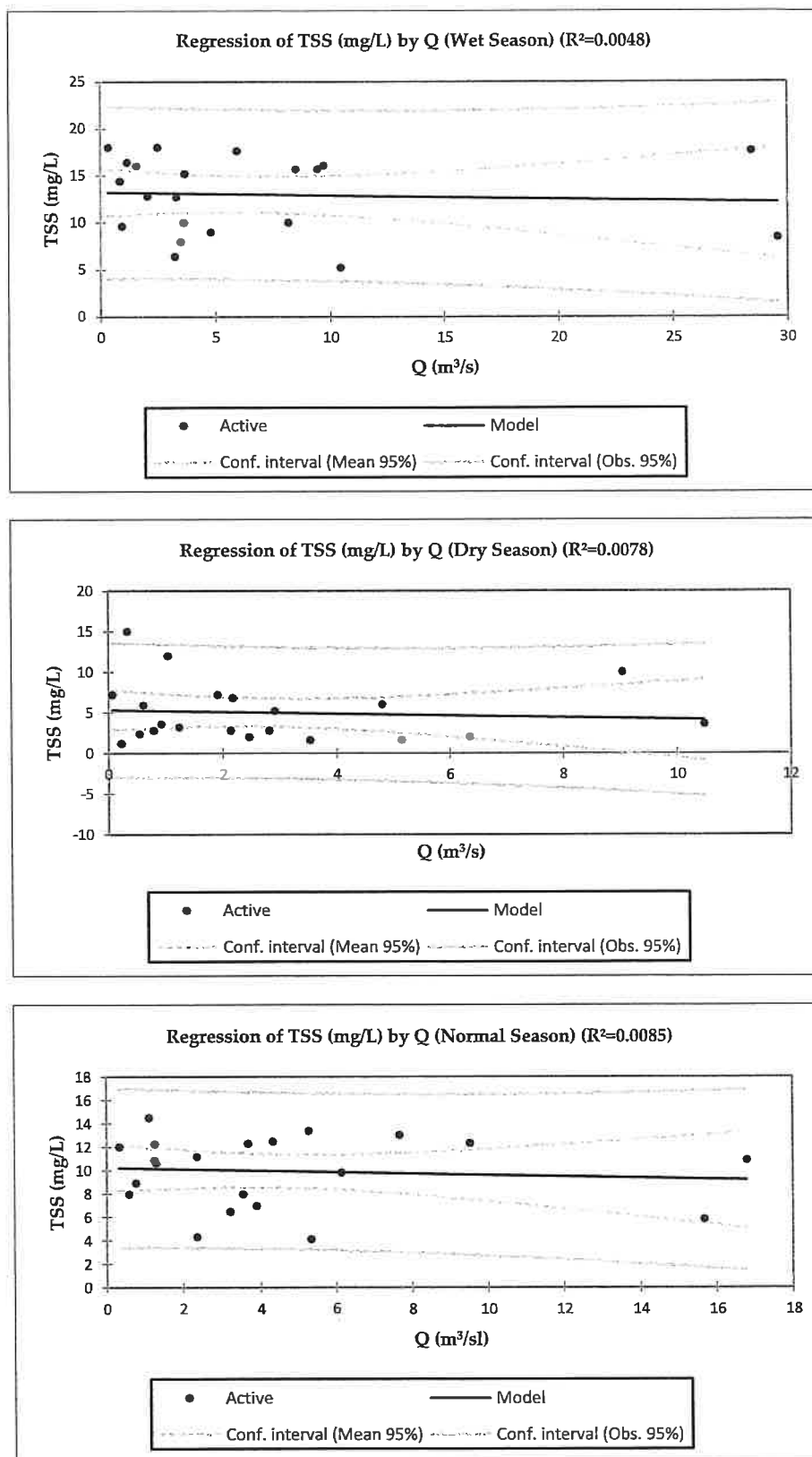


Figure 12. The regression relationship between Total Suspended Solid (TSS) and river discharge (Q) during wet season (August 2018), dry season (March 2019), and normal season (July 2019) at Kenyir Lake Basin.

Based on Figure 13 and Appendix A, the estimate annual sediment load production from Station 1 to Station 21 representing 21 sub-catchments around Kenyir Lake is shown, including sub-catchment of Siput River, sub-catchment of Petuang River, sub-catchment of Tembat River, sub-catchment of Terengganu Mati River, sub-catchment of Ketiar River, sub-catchment of Besar River, sub-catchment of Lepar River, sub-catchment of Lawit River, sub-catchment of Cenana River, sub-catchment of Bewah River, sub-catchment of Cicir River, sub-catchment of Perepek River, sub-catchment of Terenggan River, sub-catchment of Cacing River, sub-catchment of Pertang River, sub-catchment of Lasir River, sub-catchment of Leban Terengganu River, sub-catchment of Sauk River, sub-catchment of Mandak River, sub-catchment of Kenyir River, and sub-catchment of Berangan River. During the wet season, the annual suspended sediment load is the highest recorded at 348,968.41 kg/km²/year at Station 20 (sub-catchment of Kenyir River), and the lowest SL value at Station 7 (sub-catchment of Lepar River) is 6993.35 kg/km²/year. Besides that, the highest SL during the dry season was recorded at Station 17 (sub-catchment of the Leban Terengganu River) at 36,249.93 kg/km²/year and the lowest at Station 1 (sub-catchment of the Siput River) was 581.96 kg/km²/year. Meanwhile, the highest SL during the normal season was recorded at Station 20 (sub-catchment of Kenyir River) at 23,641.34 kg/km²/year and the lowest at Station 7 (sub-catchment of Lepar River) was 466.22 kg/km²/year. The highest sediment load rate was recorded in August 2019 (the start of the wet season) because the fieldwork was conducted after the rain period when the accumulated river flow had strong energy to transport sediment in large quantities. The density of water in the forest canopy plays a major role in reducing surface erosion, which contributes to sediment load production in river basins. When the water flow in a basin increases, the TSS will also increase because the higher flow contains more energy to move the more concentrated suspended sediment load compared to the low flow level, and the high water flow also increases the rate of erosion. The comparison of the sediment load production values of the sub-catchment of Kenyir River to those of other sub-catchment river basins with similar areas is very high [50–56].

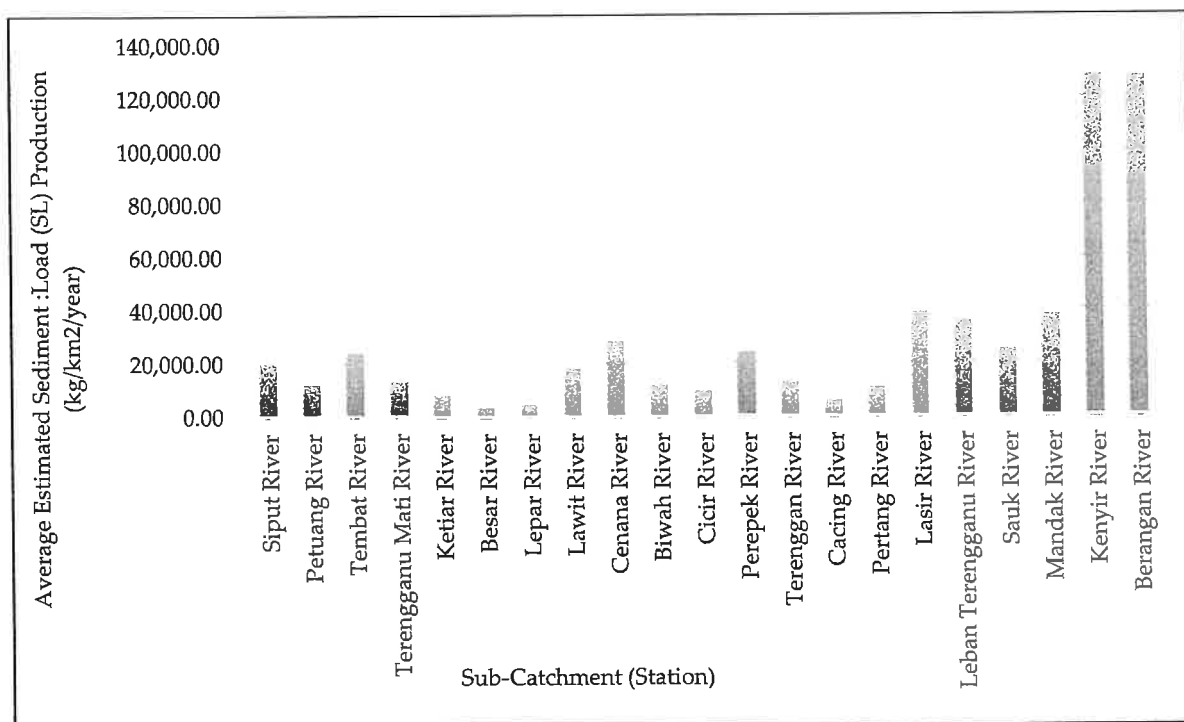


Figure 13. The distribution of average estimated Sediment Load (SL) production (tonnes/km²/year) at Kenyir Lake Basin, Hulu Terengganu, Terengganu, Malaysia.

There are distributions of SL, such as the recorded values for the sub-catchment of Siput River (14.306 km²) which are 55,409.54 kg/km²/year (wet season), 581.96 kg/km²/year (dry season), and 2999.36 kg/km²/year (normal season), while the sub-catchment of Kenyir River recorded sediment load production values more than 10 times, with an area of 13.318 km². This indicates that the amount of sediment production in this basin area is high compared to other sub-catchment basins in Kenyir Lake Basin. Based on the trend of sediment load production in Kenyir Lake Basin, the hydrological theory that the larger the sub-catchment area, the higher the amount of sediment load production, cannot be fully applied without relating external environmental factors such as anthropogenic factors around the basin and climate change factors [51–54,68–71]. Figure 14a–c shows the interpolation distribution of sediment load production during the wet season, dry season, and normal season in Kenyir Lake Basin. The average estimation by season for sediment load production flow out from the tributary rivers into Kenyir Lake is 72,016.40 kg/km²/year or 72.02 tonnes/km²/year (wet season), 9458.81 kg/km²/year or 9.46 tonnes/km²/year (dry season), and 4449.49 kg/km²/year or 4.45 tonnes/km²/year (normal season). Overall, the annual average estimation for annual sediment load production flow out from the tributary rivers into Kenyir Lake is 128,070.86 kg/km²/year (sub-catchment of Kenyir River); the lowest in the sub-catchment of Besar River is 3833.70 kg/km²/year. The rapid development around lake areas has produced great amounts of human waste, including domestic, industrial, commercial, transportation, residential, and tourism waste, in water bodies. Proper lake management depends on the purpose for which the lake is being built. A lake, which was designed for recreational and tourism activities, requires good quality water and an ecosystem [42,54–56].

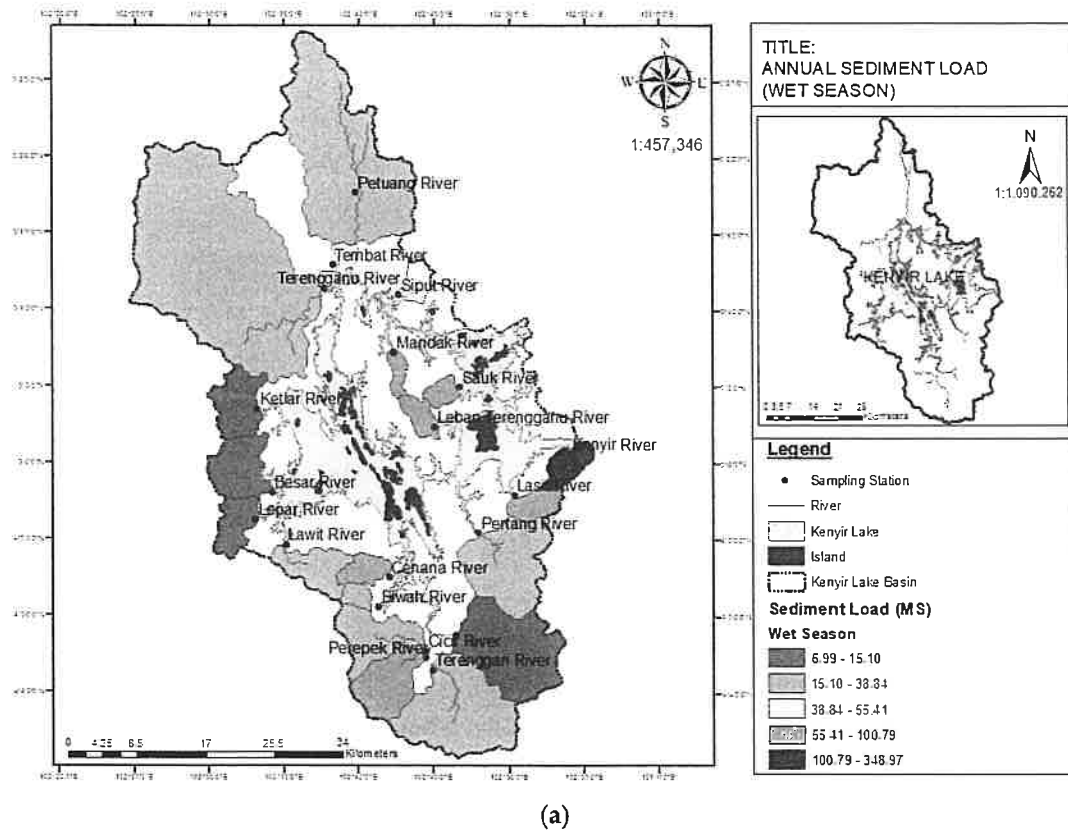
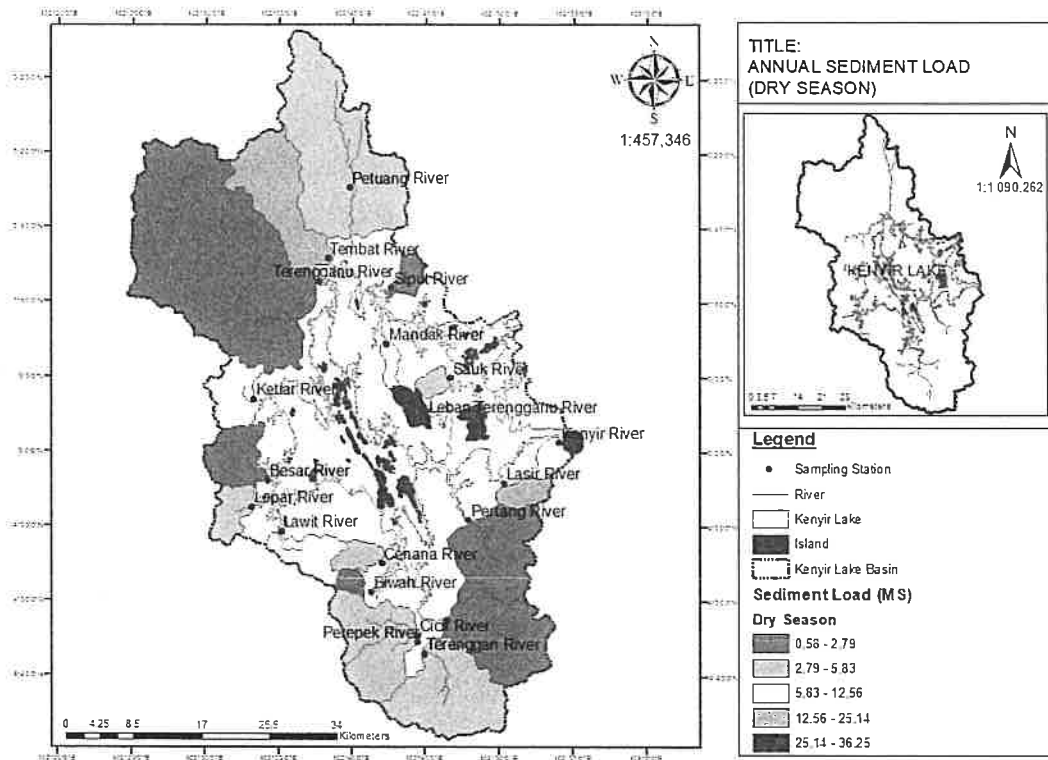
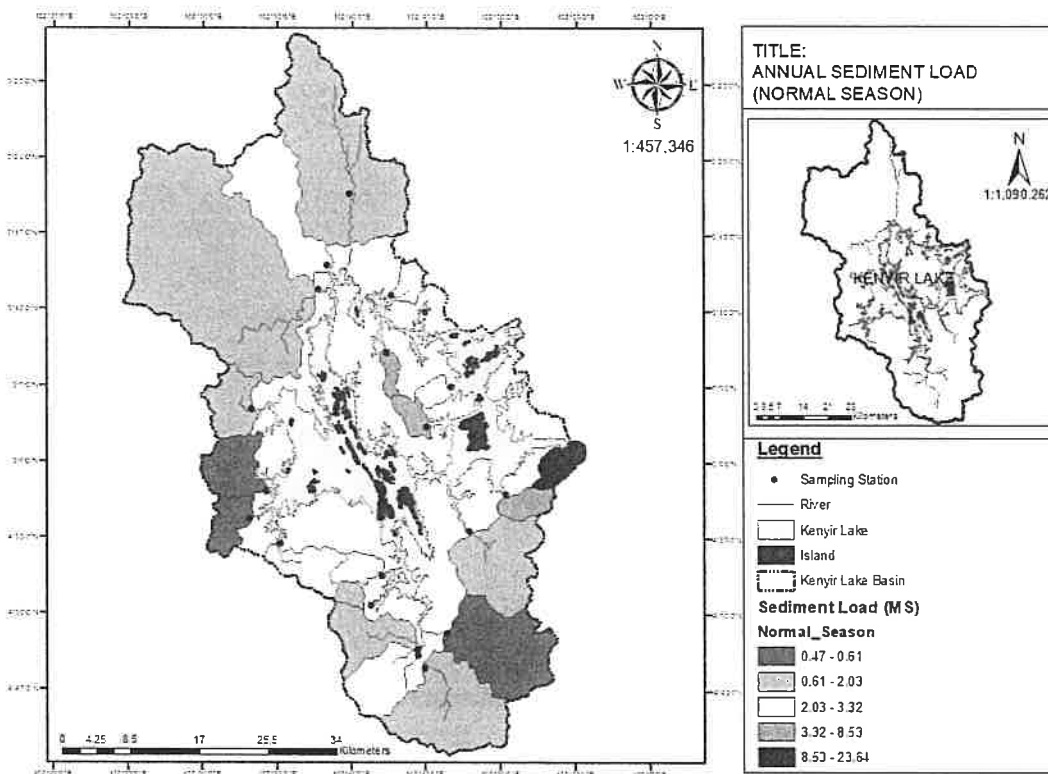


Figure 14. Cont.



(b)



(c)

Figure 14. (a). Interpolation distribution of sediment load production during wet season (November 2017) in Kenyir Lake Basin. (b). Interpolation distribution of sediment load production during dry season (August 2018) in Kenyir Lake Basin. (c). Interpolation distribution of sediment load production during normal season (July 2019) in Kenyir Lake Basin.

Figure 15 shows the dendrogram for classes in Kenyir Lake Basin based on the size distribution of sediment grains using median, mean, standard deviation, skewness, and kurtosis. Based on the dendrogram, Kenyir Lake Basin can be classified into only one main class of dominant land use activities based on the distribution of measured sediment grains. Based on the kurtosis parameters recorded in the study, it shows that throughout the Kenyir Lake Basin, there is a level of regularity that is dominated by grain size that is very platykurtic, with a value of $< \phi 0.67$ that has the characteristics of a moderately rough distribution as well as a moderate level of uniformity, showing properties that lead to tourism, both domestic and international. This area is also located in the upper part of the Terengganu River near the Kenyir Dam. The sub-rivers in the Kenyir Lake Basin have medium-sized sediment particles. These simple details show that the area is at risk of erosion, transport, and sedimentation. In addition, the moderate level of uniformity also shows that the size of the grains that are not too small is likely to be at risk of being easily eroded and transported by erosion agents to become sediment. Based on the sediment analysis in this study, medium-sized coarse sediments are produced along the Kenyir Lake Basin, especially in the middle and upper reaches. This shows that the Kenyir Lake Basin has a soil structure that is sandy and easily changes due to natural and anthropogenic factors. The Kenyir Lake Basin will also become increasingly dynamic, especially in the bed and banks of the river, which can cause various problems such as flood disasters and water quality problems that ultimately affect the health of the environment in the basin in general [39,44–46].



Figure 15. Dendrogram for various classes in Kenyir Lake Basin based on bed load grain size distribution.

5. Conclusions

The Kenyir Lake Basin's condition deteriorated after a small dam was constructed in 1989 to retain the lake's water for tourism purposes. The dam had made water movement less dynamic. As a side effect, a better understanding of Kenyir Lake's hydrology will allow for more sustainable lake development and management. The analysis was performed to investigate the hydrological and water quality status of Kenyir Lake through several physicochemical criteria and to identify the variables contributing to the pollutant levels in the lotic watersheds within and surrounding Kenyir Lake. The construction of a hydroelectric power dam upstream has altered the hydrogeochemical compartments of Kenyir Lake and the Terengganu River's main tributary. As a consequence, domestic and municipal waste,

intensive agriculture, runoff, and industrial activities pollute the river. It is commonly contaminated by both point-source and non-point-source pollution. The management implications of this characteristic of incremental development of degradation problems and the potentially long time for lakes to respond to management interventions include the need for long-term involvement of relevant lake basin management institutions and their activities. The potential for long-term impacts also suggests a need for a precautionary approach in developing and implementing lake management interventions. Collaboration in research to understand the levels of resilience of such specialised environments is critical to protecting them and making informed policy decisions about land use planning and natural resource extraction. In addition, it is required to endanger these issues by evaluating the different variants of environmental sustainability through the conservation and preservation phases.

Author Contributions: Conceptualisation, methodology, writing—original draft preparation, writing—review and editing, formal analysis, validation, N.A.W.; conceptualisation, methodology, writing—review and editing, M.K.A.K.; supervision, resources, funding acquisition, project administration, M.E.T.; supervision, resources, project administration, H.J.; methodology, formal analysis, validation, M.A.A.S.; supervision, resources, validation, M.A.; validation, software, formal analysis, A.S.M.S.; supervision, resources, L.I.H.; formal analysis, validation, writing—review and editing, M.H.M.S.; supervision, resources, S.S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Annual sediment load production (SL) during wet season (August 2018), dry season (March 2019), and normal season (July 2019) at Kenyir Lake Basin.

Sampling Station	Sub-Catchment Area (km ²)	Parameter	Wet Season (August 2018)	Dry Season (March 2019)	Normal Season (July 2019)	Average
Station 1 Sub-Catchment Siput River	14.306	TSS (mg/L)	16.00	1.20	10.92	9.37
		Total Sediment (kg/km ² /day)	151.81	1.59	8.22	53.87
		Total Sediment (kg/km ² /year)	55,409.54	581.96	2999.36	19,663.62
		Total Sediment (tonnes/km ² /day)	0.15	0.0016	0.008	0.05
		Total Sediment (tonnes/km ² /year)	55.41	0.58	3.00	19.66

Table A1. Cont.

Sampling Station	Sub-Catchment Area (km ²)	Parameter	Wet Season (August 2018)	Dry Season (March 2019)	Normal Season (July 2019)	Average
Station 2 Sub-Catchment Petuang River	250.28	TSS (mg/L)	8.40	3.60	5.8	5.93
		Total Sediment (kg/km ² /day)	85.80	13.02	3.14	33.99
		Total Sediment (kg/km ² /year)	31,318.77	4753.84	1145.92	12,406.18
		Total Sediment (tonnes/km ² /day)	0.09	0.01	0.003	0.03
		Total Sediment (tonnes/km ² /year)	31.32	4.75	1.15	12.41
		TSS (mg/L)	16.00	10.00	12.3	12.77
Station 3 Sub-Catchment Tembat River	113.261	Total Sediment (kg/km ² /day)	118.64	68.88	8.94	65.49
		Total Sediment (kg/km ² /year)	43,302.45	25,142.82	3263.81	23,903.02
		Total Sediment (tonnes/km ² /day)	0.12	0.07	0.009	0.07
		Total Sediment (tonnes/km ² /year)	43.30	25.14	3.26	23.90
		TSS (mg/L)	17.60	6.00	10.9	11.50
		Total Sediment (kg/km ² /day)	100.60	5.79	3.68	36.69
Station 4 Sub-Catchment Terengganu River	429.811	Total Sediment (kg/km ² /year)	36,720.64	2113.11	1341.98	13,391.91
		Total Sediment (tonnes/km ² /day)	0.10	0.01	0.004	0.04
		Total Sediment (tonnes/km ² /year)	36.72	2.11	1.34	13.39
		TSS (mg/L)	16.40	12.00	14.5	14.30
		Total Sediment (kg/km ² /day)	38.56	25.63	3.31	22.50
		Total Sediment (kg/km ² /year)	14,076.14	9355.11	1206.49	8212.58
Station 5 Sub-Catchment Ketiar River	42.07	Total Sediment (tonnes/km ² /day)	0.04	0.03	0.003	0.02
		Total Sediment (tonnes/km ² /year)	14.08	9.36	1.21	8.21
		TSS (mg/L)	14.40	5.90	8.9	9.73
		Total Sediment (kg/km ² /day)	23.23	6.97	1.31	10.50
		Total Sediment (kg/km ² /year)	8478.97	2544.00	478.12	3833.70
		Total Sediment (tonnes/km ² /day)	0.02	0.01	0.001	0.01
Station 6 Sub-Catchment Besar River	44.614	Total Sediment (tonnes/km ² /year)	8.48	2.54	0.48	3.83
		TSS (mg/L)	18.00	15.00	12	15.00
		Total Sediment (kg/km ² /day)	19.16	15.97	1.28	12.13
		Total Sediment (kg/km ² /year)	6993.35	5827.79	466.22	4429.12
		Total Sediment (tonnes/km ² /day)	0.02	0.02	0.001	0.01
		Total Sediment (tonnes/km ² /year)	6.99	5.83	0.47	4.43
Station 7 Sub-Catchment Lepar River	26.786	TSS (mg/L)	8.90	7.20	7	7.70
		Total Sediment (kg/km ² /day)	106.41	34.41	6.81	49.21
		Total Sediment (kg/km ² /year)	38,838.17	12,559.97	2486.97	17,961.70
		Total Sediment (tonnes/km ² /day)	0.11	0.03	0.007	0.05
		Total Sediment (tonnes/km ² /year)	38.84	12.56	2.49	17.96
		TSS (mg/L)	8.90	7.20	7	7.70
Station 8 Sub-Catchment Lawit River	34.529	Total Sediment (kg/km ² /year)	38,838.17	12,559.97	2486.97	17,961.70
		Total Sediment (tonnes/km ² /day)	0.11	0.03	0.007	0.05
		Total Sediment (tonnes/km ² /year)	38.84	12.56	2.49	17.96
		TSS (mg/L)	8.90	7.20	7	7.70
		Total Sediment (kg/km ² /day)	106.41	34.41	6.81	49.21
		Total Sediment (kg/km ² /year)	38,838.17	12,559.97	2486.97	17,961.70

Table A1. Cont.

Sampling Station	Sub-Catchment Area (km ²)	Parameter	Wet Season (August 2018)	Dry Season (March 2019)	Normal Season (July 2019)	Average
Station 9 Sub-Catchment Cenana River	18.406	TSS (mg/L)	18.00	3.60	12.3	11.30
		Total Sediment (kg/km ² /day)	209.12	15.55	7.22	77.30
		Total Sediment (kg/km ² /year)	76,329.94	5674.63	2634.28	28,212.95
		Total Sediment (tonnes/km ² /day)	0.21	0.02	0.007	0.08
		Total Sediment (tonnes/km ² /year)	76.33	5.67	2.63	28.21
		TSS (mg/L)	9.60	7.20	8	8.27
Station 10 Sub-Catchment Bewah River	8.688	Total Sediment (kg/km ² /day)	87.55	5.01	4.53	32.36
		Total Sediment (kg/km ² /year)	31,954.16	1829.44	1655.20	11,812.93
		Total Sediment (tonnes/km ² /day)	0.09	0.01	0.005	0.03
		Total Sediment (tonnes/km ² /year)	31.95	1.83	1.66	11.81
		TSS (mg/L)	10.00	1.60	8	6.53
		Total Sediment (kg/km ² /day)	64.08	10.04	5.05	26.39
Station 11 Sub-Catchment Cicir River	48.593	Total Sediment (kg/km ² /year)	23,389.32	3665.45	1843.11	9632.63
		Total Sediment (tonnes/km ² /day)	0.06	0.01	0.005	0.03
		Total Sediment (tonnes/km ² /year)	23.39	3.67	1.84	9.63
		TSS (mg/L)	17.60	2.80	12.3	10.90
		Total Sediment (kg/km ² /day)	181.64	10.39	7.89	66.64
		Total Sediment (kg/km ² /year)	66,298.23	3793.02	2878.73	24,323.33
Station 12 Sub-Catchment Perepek River	49.586	Total Sediment (tonnes/km ² /day)	0.18	0.01	0.008	0.07
		Total Sediment (tonnes/km ² /year)	66.30	3.79	2.88	24.32
		TSS (mg/L)	15.60	6.80	13.4	11.93
		Total Sediment (kg/km ² /day)	90.72	10.11	4.85	35.23
		Total Sediment (kg/km ² /year)	33,114.34	3691.55	1770.02	12,858.64
		Total Sediment (tonnes/km ² /day)	0.09	0.01	0.005	0.04
Station 13 Sub-Catchment Terenggan River	126.057	Total Sediment (tonnes/km ² /year)	33.11	3.69	1.77	12.86
		TSS (mg/L)	5.20	2.80	4.1	4.03
		Total Sediment (kg/km ² /day)	41.37	5.98	1.67	16.34
		Total Sediment (kg/km ² /year)	15,100.24	2181.54	609.22	5963.66
		Total Sediment (tonnes/km ² /day)	0.04	0.01	0.002	0.02
		Total Sediment (tonnes/km ² /year)	15.10	2.18	0.61	5.96
Station 14 Sub-Catchment Cacing River	113.334	TSS (mg/L)	10.00	1.60	9.8	7.13
		Total Sediment (kg/km ² /day)	75.44	7.64	5.57	29.55
		Total Sediment (kg/km ² /year)	27,534.70	2789.62	2033.15	10,785.83
		Total Sediment (tonnes/km ² /day)	0.08	0.01	0.006	0.03
		Total Sediment (tonnes/km ² /year)	27.53	2.79	2.03	10.79
		Station 15 Sub-Catchment Pertang River	93.332			

Table A1. Cont.

Sampling Station	Sub-Catchment Area (km ²)	Parameter	Wet Season (August 2018)	Dry Season (March 2019)	Normal Season (July 2019)	Average
Station 16 Sub-Catchment Lasir River	19.961	TSS (mg/L)	15.20	2.00	12.5	9.90
		Total Sediment (kg/km ² /day)	240.80	54.97	23.37	106.38
		Total Sediment (kg/km ² /year)	87,891.93	20,064.49	8531.36	38,829.26
		Total Sediment (tonnes/km ² /day)	0.24	0.05	0.023	0.11
		Total Sediment (tonnes/km ² /year)	87.89	20.06	8.53	38.83
		TSS (mg/L)	8.00	5.20	6.5	6.57
Station 17 Sub-Catchment Leban Terengganu River	13.119	Total Sediment (kg/km ² /day)	183.25	99.31	13.74	98.77
		Total Sediment (kg/km ² /year)	66,884.49	36,249.93	5015.62	36,050.01
		Total Sediment (tonnes/km ² /day)	0.18	0.10	0.014	0.10
		Total Sediment (tonnes/km ² /year)	66.88	36.25	5.02	36.05
		TSS (mg/L)	6.40	2.40	4.3	4.37
		Total Sediment (kg/km ² /day)	185.82	11.68	9.11	68.87
Station 18 Sub-Catchment Sauk River	9.588	Total Sediment (kg/km ² /year)	67,824.11	4262.69	3323.65	25,136.81
		Total Sediment (tonnes/km ² /day)	0.19	0.01	0.009	0.07
		Total Sediment (tonnes/km ² /year)	67.82	4.26	3.32	25.14
		TSS (mg/L)	12.80	2.80	10.6	8.73
		Total Sediment (kg/km ² /day)	276.14	23.38	14.45	104.66
		Total Sediment (kg/km ² /year)	100,791.74	8534.09	5275.55	38,200.46
Station 19 Sub-Catchment Mandak River	8.174	Total Sediment (tonnes/km ² /day)	0.28	0.02	0.014	0.10
		Total Sediment (tonnes/km ² /year)	100.79	8.53	5.28	38.20
		TSS (mg/L)	15.60	2	13	10.20
		Total Sediment (kg/km ² /day)	956.08	31.79	64.77	350.88
		Total Sediment (kg/km ² /year)	348,968.41	11,602.82	23,641.34	128,070.86
		Total Sediment (tonnes/km ² /day)	0.96	0.03	0.065	0.35
Station 20 Sub-Catchment Kenyir River	13.318	Total Sediment (tonnes/km ² /year)	348.97	11.60	23.64	128.07
		TSS (mg/L)	12.70	3.2	11.2	9.03
		Total Sediment (kg/km ² /day)	907.19	86.07	57.09	350.12
		Total Sediment (kg/km ² /year)	331,124.83	31,417.24	20,839.25	127,793.77
		Total Sediment (tonnes/km ² /day)	0.91	0.09	0.057	0.35
		Total Sediment (tonnes/km ² /year)	331.12	31.42	20.84	127.79

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