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Sedimentation and water quality deterioration problems at Terengganu River Basin, Terengganu, Malaysia

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ABSTRACT

Rivers, which provide 90% of the readily available freshwater, are key components of global water resource system. Terengganu River experienced deterioration in water quality, resulting from the sedimentation, anthropogenic, geomorphology problems and unsustainable development management around the river basin. This study was implemented to prove the sedimentation problem especially the formation of total suspended solid (TSS) and annual sediment load (SL). The technique of analysis of primary data obtained which determine according with the procedure TSS and SL. The results showed that the highest average of TSS (mg/L) is 67.2 (wet season) and 128.2 (dry season) which are class III. While the highest turbidity is 43.57 (wet season) and 21.57 (dry season) which are Class II based on National Water Quality Standard (NWQS). The highest annual average estimation for annual SL flow out from the Terengganu River Basin is 6,846.709 tonnes/km^2/year (Manir River Basin) the lowest in the Pauh River Basin is 2.850 tonnes/km^2/year. The statistical analysis proved the weak regression relationship between TSS, river discharges (Q), SL and area of catchment caused by the anthropogenic factors and uncertain climate changes. Furthermore, the water in the Terengganu River was classified under class III caused by the active land use activities especially industrial and development but it is still suitable for recreational activities and safe for body contact because its water quality index is not less than 65% which early stage of Class II. The contributors of sedimentation problems are from unsustainable land use such as sand mining activities which effectively trap the bed sediments, backflow that carries out high sediments, as well as sedimentation produced due to the river bank erosion. This study suggests the sedimentation management methods including land use settlement, cliff erosion problems, settlement and negotiable of uncontrolled development operations in Terengganu River and the integration of river management methods based on integrated river basin management in Terengganu River Basin is recommended.

Keywords: Sedimentation; Total suspended solid (TSS); Annual sediment load (SL); National water quality standard (NWQS); Terengganu River basin

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1. Introduction

Rivers are among the most vulnerable of water resource systems. Data from around the world indicates that their overall condition continues to deteriorate. Although the source of essential resources necessary for human and ecosystem well-being, river basins are easily impacted by complex land and water relationships [1–6]. As primary freshwater storage system, they receive water, sediments, pollutants, nutrients and biota from inflowing land runoff, groundwater aquifers and from the atmosphere. Being used for a wider range of purpose than any other type of waterbody, they are much more vulnerable to stresses and more difficult to manage than other water systems. The rivers are very important source to humans and other organisms as they are essential resources for living organisms. Any anthropogenic, hydrological, geomorphological factors and climate changes around the catchment can have detrimental effects on both sediment quantity and quality [7–11].

The erosion moves the sediment through by water, ice or wind. Sediments consist of rocks, mud, minerals, and the remains of plants and animals [12,13]. One of the important functions of sediment is to carry of nutrients, pollutants and wastes in the river [14,15]. There is positive relationship between the rate of the side and river bank erosion which proposed to increase the sediment production. The higher rate of speed and volume of water, the stronger the erosion rates that will trigger the sedimentation level production in the river basin [16–18]. The economic development, port maintenance, source control and habitat restoration will typically challenge balancing remediation and degradation material management programs. The water quality level is critical for economic development in urban community areas and can offer significant social benefits [19–22].

The quality aspect of water is ignored, and many reservoirs and rivers became polluted with the introduction of human settlements and activities in water-producing areas [23,24]. For example, a few studies on water quality at some rivers in the world [25] have confirmed that water quality is impaired during periods of peak recreational use and urbanization. These situations also occur in some rivers in Malaysia, and those examples show us that Malaysian rivers are now facing tremendous transformation caused by anthropogenic activities that later contribute to pollution. We are concerned about water quality not only because water is required by cultures and industries but also because it is a fundamental assessment in the environment.

Ecosystem degradation will increase the pollutant inputs and trigger the level of deterioration of the water quality and health status of a river [26–31]. The essential of determining the level equilibrium status of a river is by measuring the water quality of the river according to water quality index (WQI) and (Jabatan Pengaliran dan Saliran (JPS), Malay) river index. Besides that, the calculation of sediment load (SL) is also important in estimating the amount of sediment production in the future as well as the long-term changes in environment and sensitivity to various factors that affect the environment.

These situations also occur in some rivers in Malaysia, and those examples show us that Malaysian rivers are now facing tremendous transformation caused by anthropogenic activities that later contribute to pollution. We are concerned about water quality not only because water is required by cultures and industries but also because it is a fundamental assessment in the environment. Therefore, the study of the quality of this resource called water-quality study has become an important field. It provides basic knowledge and a foundation for water management, a discipline and skill for maintaining land productivity and protecting water resources [32–35].

The management implications of this characteristic in incremental development of degradation problems. This problems are potentially long time for rivers to respond to management interventions including the need for long-term involvement of relevant river basin management institutions and their activities as well as long-term funding. The potential for long-term impacts also suggest a need for precautionary approach in developing and implementing lake management interventions. The wide variations in climate changes and land use impact are much more sensitive to any environmental change [9,36–39]. Natural events can also precipitate sudden changes. Increasingly, however, the anthropogenic effects of human activity such as intensive agriculture, deforestation, urbanization and tourism are causing specialized habitats to change, shrink and become fragmented to the extent that they may no longer be self-sustainable. In addition, the accidental or deliberate introduction of invasive non-native species can also severely impact communities of indigenous species in Terengganu River Basin. Even though protecting the existing fragile natural environment and interactions between humans and the environment is of fundamental significance, this study has identified its key objective to address and promote the sustainable development towards preserving, protecting and enhancing biodiversity in Terengganu River [9,40–42].

The collaborative research to understand the levels of resilience of such specialized environments is critical in protecting them and making informed policy decisions about land use planning and natural resource extraction. This section focuses specifically on the major existing environment in Terengganu River and its basin including the climate characteristics, hydrological characteristics, air quality, topography and geomorphology of the lake and river system. River basin management is a process and not a plan that has to take into account a broad range of management challenges including variable natural conditions and phenomenon, competing interest and concerns and the continuously changing anthropogenic inputs and influences. Integrated River Basin Management (IRBM) is a conceptual framework that supports the process, conveniently regarded as an IRBM platform. The backbone of the platform is composed of the fundamental features of lentic water systems and three basic principles of sustainability for river basin resource use and conservation [5,37,43–45].

2. Study area and research methodology

2.1. Area of study

Terengganu River Basin is selected as research location. Terengganu River is the main river in the Terengganu state which is starting from Kenyir Dam (Empangan Tasik Kenyir), Hulu Terengganu (upstream part) and ending in Kuala Terengganu (downstream part). Terengganu River flows from the upper watershed of Kenyir Lake to the South China Sea. This river basin is situated between a latitude of 4°40′N–5°20′N and a longitude of 102°30′E–103°09′E in the North Eastern coastal region of Peninsular Malaysia. The main tributaries of Terengganu River basin are the Nerus River basin, Sekati River basin, Manir River basin, Kepung River basin, Telemung River basin, Cepuh River basin, Pertang River basin, Tersat and Berang River basin, Pur River basin, Pauh River basin, Pueh River basin, Dura River basin and Sala River basin with a total catchment area of about 5,000 km^2 [11,46,47]. These rivers pass through different socio-economical activities organized areas such as sand mining, agricultural practices, tourism, farming, aquacultures, commercial industries, urban and rural settlements, reserves and forests (Taman Negara). This study involves 29 main sampling stations that are located around the basin representing the length of the Terengganu River (from upstream to downstream areas; Table 1 and Fig. 1). The research was performed during wet season (January 2016) and dry season (July 2016).

2.2. Research methodology

Fig. 2(a) shows the distribution of mean monthly temperature recorded at Felda Belara, Hulu Terengganu from 2001 until 2017. The highest mean temperature was recorded during April, May and June every year and the lowest value during the wet season (November until January). In general, relative humidity is slightly high. Relative humidity near 90% can be occurred in the mornings and during the monsoon season, because of an increase in moisture supply rather than a reduction in temperature. Similarly, saturation deficits during the monsoon are significantly smaller than during the pre-monsoon period (August–October), being almost as small as they are during the months of March and April, when air temperature and the amount of water that can be held by air are at their lowest (Fig. 2(b)).

The seasonal distribution is quite variable; monthly means from Kuala Terengganu average was about 1.9 m/s. However, during November, that data increased from 1.8 to 2.6 m/s in December and January, and that data decreased slowly to 2.3 m/s in February and reach normal in April. Whereas, the monthly means along Hulu Terengganu from 2010 until 2017 average was about 0.5 m/s. The maximum distribution recorded was 0.58 m/s (December) and the minimum being 0.45 m/s (June). This trend indicates that annual mean appeared to be more closely related to the monsoon season (Fig. 2(c)).

One of the main causes of sedimentation problems and water deterioration around the Terengganu River basin is the uncontrolled main land use activities such as sand mining project. Since Terengganu River is a major river in the state that is directly connected to Kenyir Lake in Hulu Terengganu, without a strategy to protect the basin, disruption to the river ecosystem may occur in the long term and it will give a negative impact on the environment and society. The increasing sedimentation could lead to increase in turbidity, suspended sediment pH and odors of water. The value of river discharge (Q) at the Terengganu River is the primary factor that affected the sediment mobility [48–50]. The increased rate of water flow triggers the sediment production. The suspended solid was related to the incidence of rainfall that affected the increasing value of river discharge. A study by Wahab et al. [9] proved that the sedimentation problems in the Terengganu River are caused by not only the flow rate of water but also the land use activities such as sand mining, agriculture, industrial operations, farming and tourism. Fig. 3 shows the land use activities covered downstream, middle stream and upstream of Terengganu River.

2.3. Research methodology

2.3.1. Analysis of total suspended solid and annual SL

The gravimetric method (Fig. 4) was used to analyse the TSS measured in mg/L. 250 mL water sample were needed

Table 1
Location of sampling stations at the Terengganu River basin, Terengganu, Malaysia

Sampling stations	Latitude	Longitude	Sampling stations	Latitude	Longitude
Station 1	103°8′21.92″E	5°20′23.93″N	Station 15	102°56′10.96″E	5°3′48.46″N
Station 2	103°6′20.14″E	5°19′26.55″N	Station 16	102°55′46.47″E	5°2′26.86″N
Station 3	103°5′56.80″E	5°19′40.59″N	Station 17	102°55′37.24″E	5°1′55.10″N
Station 4	103°5′12.22″E	5°18′48.53″N	Station 18	102°56′28.08″E	5°3′54.70″N
Station 5	103°5′12.42″E	5°18′32.74″N	Station 19	102°57′4.74″E	5°4′37.88″N
Station 6	103°5′50.67″E	5°17′7.75″N	Station 20	102°58′16.48″E	5°3′43.35″N
Station 7	103°3′3.64″E	5°16′14.99″N	Station 21	103°0′8.50″E	5°4′8.88″N
Station 8	103°1′32.70″E	5°13′9.00″N	Station 22	103°0′25.47″E	5°4′31.96″N
Station 9	103°1′40.09″E	5°12′42.04″N	Station 23	103°2′21.33″E	5°8′2.35″N
Station 10	103°2′9.46″E	5°7′37.61″N	Station 24	103°2′35.85″E	5°11′2.74″N
Station 11	103°0′31.30″E	5°4′8.14″N	Station 25	103°1′50.56″E	5°12′36.82″N
Station 12	102°58′43.16″E	5°3′22.80″N	Station 26	103°2′21.83″E	5°13′26.72″N
Station 13	102°57′58.26″E	5°4′39.67″N	Station 27	103°4′38.05″E	5°16′37.05″N
Station 14	102°56′41.24″E	5°4′37.96″N	Station 28	103°5′29.09″E	5°17′37.90″N
			Station 29	103°5′27.17″E	5°18′57.56″N

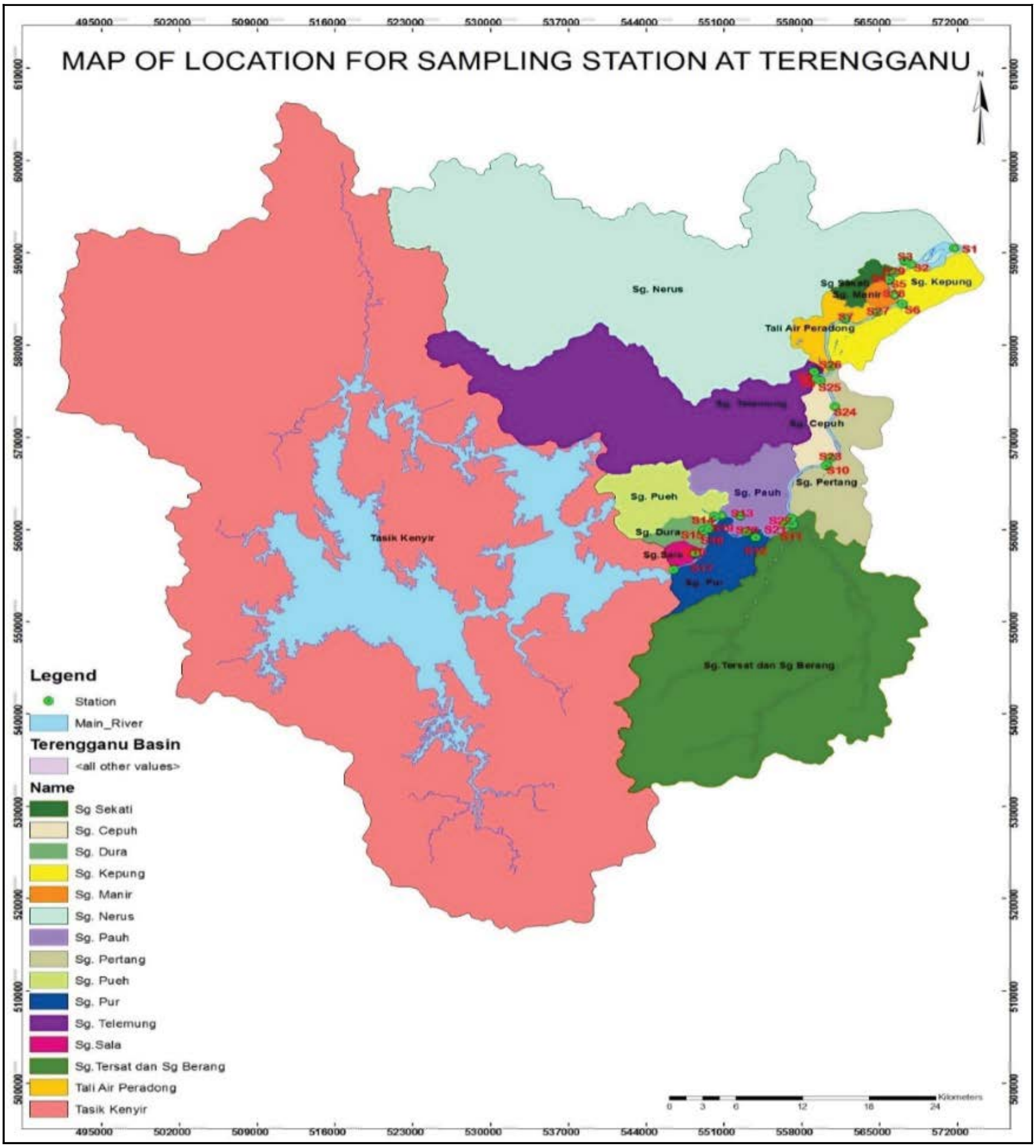


Fig. 1. Map of sampling station at the Terengganu River basin, Terengganu, Malaysia.

for each study area (each station; Fig. 4(a)). First, weighing the membrane filters using electronic weighing machine, then a membrane filter was placed onto a filtration apparatus connected to a vacuum pump and clipped in place (Figs. 4(b) and (c)). The water sample was slowly poured into the filtration jar, the membrane filter was removed and allowed to dry in the drying jar (Figs. 4(d) and (e)).

Next, the membrane filter was weighed. The readings of TSS were taken and calculated using Eq. (1). Besides that, Eq. (2) shows the discharge value (Q) from the product of velocity and cross section area (A). The cross-section area is derived from the product of depth (d) and width (w), the cross-section area. The imprecision of the current meter, variability of the river flow velocity over the cross section and uncertainty used in estimation of the cross-section geometry area.

$$\text{TSS} = \left(\left[\text{WBF} + \text{DR}\right] - \text{WBF}\right)\left(\text{mg}\right) \times \frac{1{,}000}{\text{VFW}}\left(\text{mL}\right) = \frac{\text{mg}}{\text{L}} \tag{1}$$

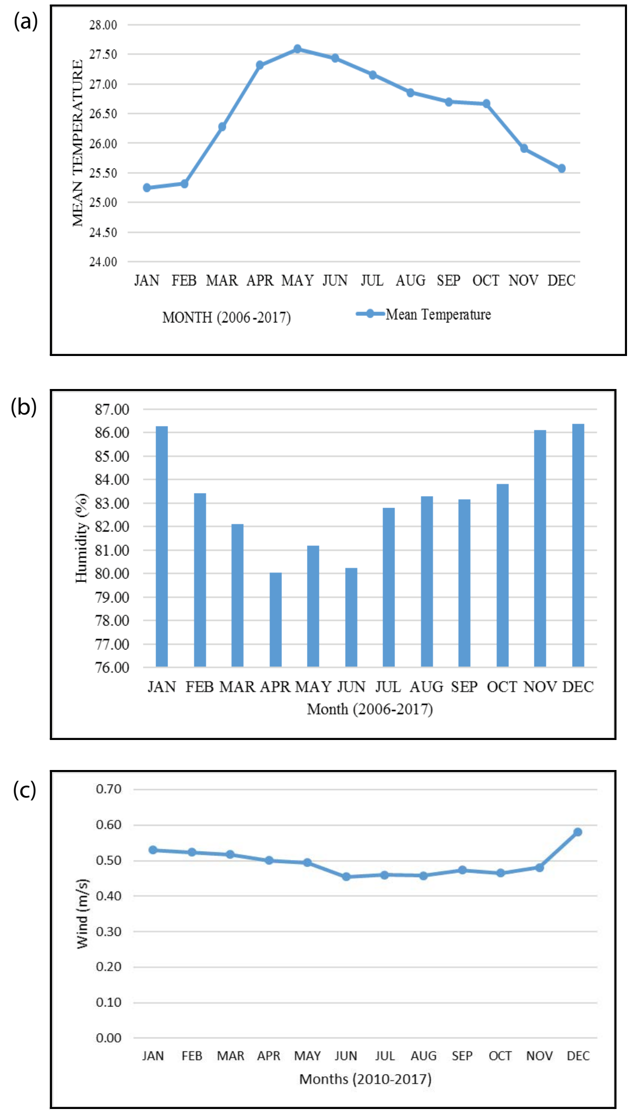


Fig. 2. (a) Mean monthly temperature, (b) mean monthly humidity, (c) monthly wind recorded at Felda Belara, Hulu Terengganu Meteorological Station (2006–2017).
Source: Jabatan Meteorologi Malaysia, Malaysian Meteorological Department (MMD).

Fig. 3. Sand mining activities along the Terengganu River Basin, Terengganu.

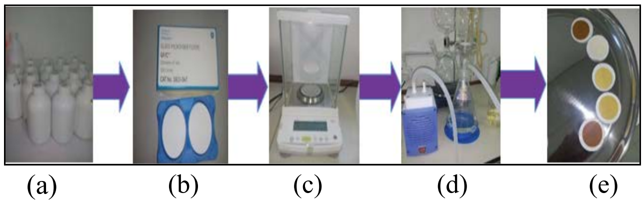


Fig. 4. (a) Water sample, (b) membrane filter paper, (c) electronic weighing machine, (d) filtration apparatus connected to a vacuum pump and (e) dried membrane filter.

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

$$Q = \frac{m^3}{s} \times 86,400 \frac{s}{d} \times 1,000 \frac{L}{m^3} = \frac{L}{d} \tag{2}$$

The calculation of annual SL production is based on the discharge value (Q) (m^3/s), TSS value (mg/L) and area of sampling basin (km^2). The data to be analyzed would be used to determine the changes in the concentration of suspended sediment and its relationship with hydrological and geomorphological factors and other variables. Eq. (3) below shows the following formula used in the measurement of SL ($tonnes/km^2/year$).

$$\begin{aligned} \text{Annual SL production}(\text{SL}) &= (Q \times \text{TSS}) / \text{area of sampling basin} \\ &= (\text{L/d} \times \text{tonnes /d}) / \text{km}^2 \\ &= \text{tonnes /km}^2 / 365 \text{ d} \\ &= \text{tonnes /km}^2 / \text{d} \end{aligned} \tag{3}$$

2.3.2. *Analysis of water quality status using WQI and JPS river index*

This analysis has been developed to assess the suitability of water for a variety of uses. The index reflects the status of water quality in lakes, streams, rivers and reservoirs. The concept of WQI is based on the comparison of the water quality parameter with respective regulatory standards. Water quality index combines several important water quality parameters that give an overall index of the water quality for a specific use. Different pollutants and factors are required for the development of an index. National Water Quality Standard (NWQS) is used as a guideline in maintaining Malaysia's river water quality. The objective of NWQS is to create a benchmark of water quality for the protection and management of the surface water. All of the parameters were multiplied with their specific index Eq. (4):

$$\begin{aligned} \text{WQI} = &(0.22 \times \text{SIDO}) + (0.19 \times \text{SIBOD 5}) + (0.16 \times \text{SICOD}) + \\ &(0.16 \times \text{SISS}) + (0.12 \times \text{SIpH}) + (0.15 \times \text{SIAN}) \end{aligned} \tag{4}$$

3. Result and discussion

3.1. *Sedimentation problems around Terengganu River basin*

The density of water at forest canopy is the main role towards reducing the surface erosion which contributes to SL production in Terengganu River basin. This situation proved the land use development in construction (residential, factory and tourism structure) around Terengganu River which increases the chances for runoff and erosion. This leads to an increase in runoff rates, causing cliff erosion and increased turbidity in river basin. When the water flow in a basin increased, the TSS will also increase because the higher flow contains the stronger energy to move the higher concentrated suspended SL compared with the lower flow level and higher water flow also increased the rate of erosion. This will increase the amount of suspended solid, water turbidity and the river becomes more shallow, giving negative impact on the benthic ecosystem, flora and fauna in the area around the river and reduces the water quality level. TSS is one of the water quality indicators to determine whether the status of water quality is clean, moderately polluted or contaminated, and to estimate the suspended SL production in the Terengganu River Basin, TSS classified the river in Class I, II, III, IV or V, based on NWQS. Fig. 5 showed the highest amount of TSS at Station 6 and Station 7, 61.8 and 67.2 mg/L, respectively. The minimum amount of TSS at Station 17 and Station 19 is 0.4 mg/L during wet season. The value of TSS during dry season showed higher range compared with wet season effected by El Nino phenomenon on January 2016, the ocean surface warming gives impacts on the atmospheric conditions affected by dry weather changes in certain areas [51]. The TSS amount at Station 1, Station 2, Station 3, Station 4, Station 5, Station 6, Station 7, Station 8 and Station 9 were recorded to be 66.8 ± 128.2 mg/L. From the result, the difference amount level of TSS at Terengganu River caused by the anthropogenic and geomorphology factors, climate changes and hydrological cycle. The value of TSS at downstream and mid-stream of Terengganu River Basin is higher than upstream. This study proved that wet season (higher density of rainfall) caused the higher level of soil loss and TSS concentration production at the downstream and mid-stream areas (Station 1 to Station 8; between classes II and III) that needs to be treated for water supply purpose (Fig. 6). Department of Environment (DOE) 2008 stated the WQI class for TSS in class II, the river water needs to be treated and still suitable to protect aquatic species and can be used for recreational activities [52]. TSS in class III, the river water requires intensive treatment for the purpose of supply but for the aquatic species it is still appropriate.

The highest annual suspended SL during wet season is 1,079.539 tonnes/km^2/year (Station 6) (Kepung River Basin) and the lowest of SL value at Station 8 (Telemung River Basin) is 3.419 tonnes/km^2/year. Meanwhile, the highest SL during dry season was recorded at Station 5 (Manir River Basin) is 12,691.461 tonnes/km^2/year and the lowest at Station 15 (Dura River Basin) is 1.866 tonnes/km^2/year. Overall, the annual average estimation for annual SL production flow out from the Terengganu River is 673.464 tonnes/km^2/year (Manir River Basin) the lowest in the sub catchment Sungai Dura River is 3.265 tonnes/km^2/year (Figs. 7 and 8). The sedimentation that occurs in the river basin in Malaysia is majorly caused by the geomorphology, anthropogenic factors, climate changes and bank erosion. The value of SL at downstream and mid-stream of Sungai Terengganu is higher than upstream. This study proved the impact of the El Nino phenomenon in January 2016 affects the SL concentration production in Terengganu River. Therefore, the next step towards to control and prevention by the authorities and the communities' responsibility to cover the environmental issues. The negative correlation of both seasons on the parameters of the areas catchment for 13 sub catchments along Terengganu River Basin and annual SL production proved that there is a correlation between the two variables that are related to the opposite directions, when the area catchment increases, the annual SL production decreases (Tables 2(a) and (b)). Sediment production was closely related to the incidence of rainfall intensity which is affected by the increasing values of river discharge and not

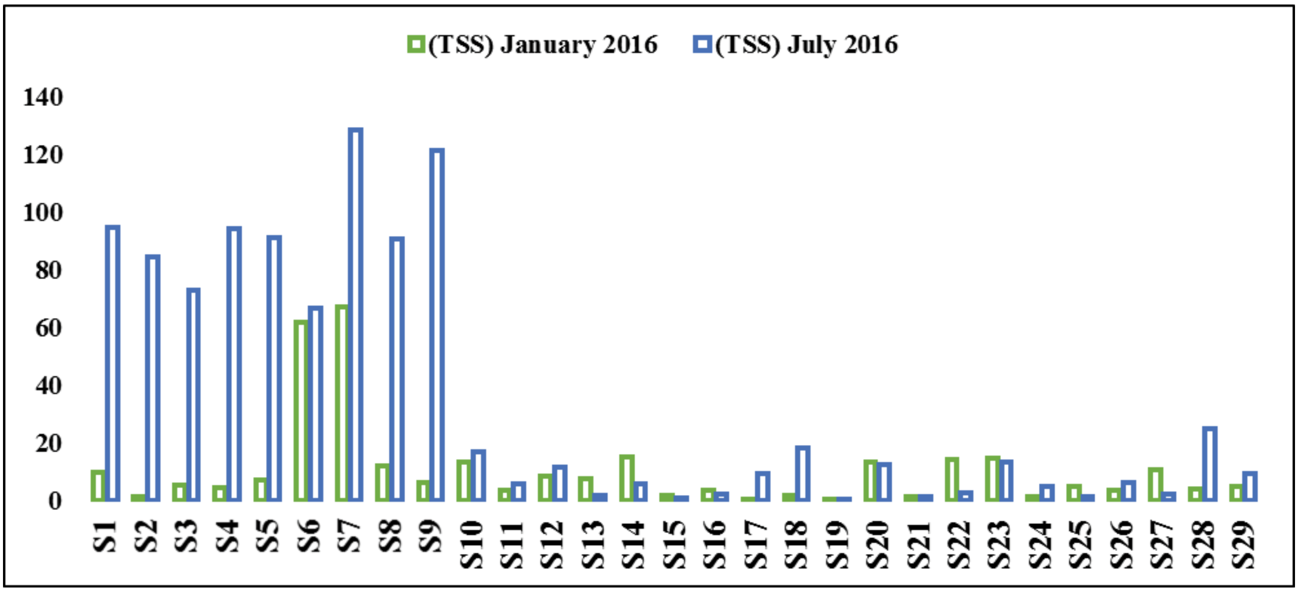


Fig. 5. Distribution of total suspended solid (TSS) (mg/L) during wet season (January 2016) and dry season (July 2016) at Terengganu River Basin, Terengganu, Malaysia.

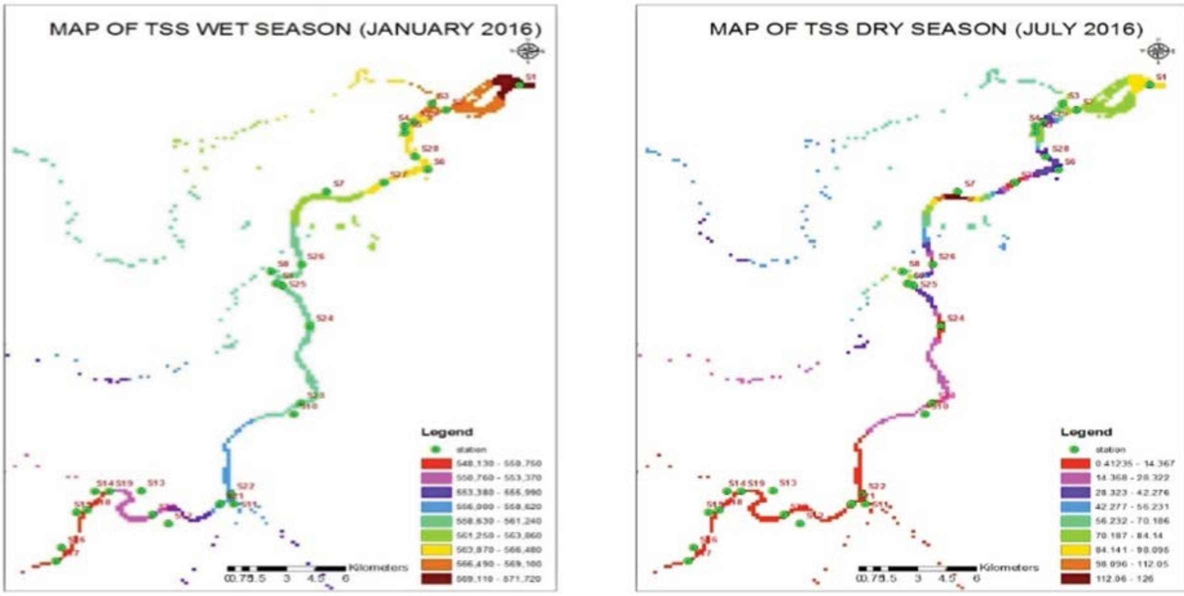


Fig. 6. Distribution interpolation map of total suspended solid (TSS) on wet season and dry season at Terengganu River, Terengganu, Malaysia, 2016.

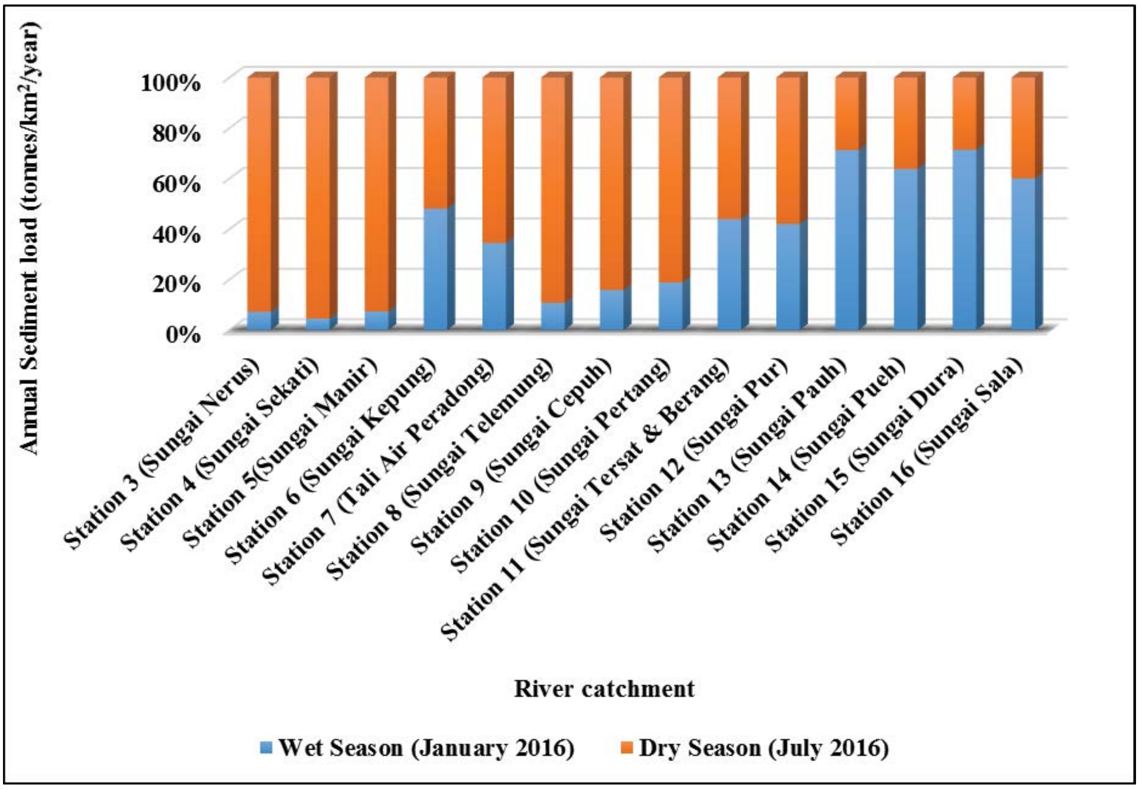


Fig. 7. Distribution of annual sediment load production (tonnes/km^2/year) at Terengganu.

only impacted by the areas catchment. However, the reason for increased sedimentation in the Terengganu River basin was not water flow alone. Activities within the vicinity of the basin such as industrial operations, agriculture and sand mining also contributed to the increasing levels of sediment. The environmental factors such as flooding were also one of the contributing factors. Based on observations during the sampling period and data obtained from local inhabitants, these basin areas faced frequent flooding and overflow from the Terengganu River during the monsoon season. Besides

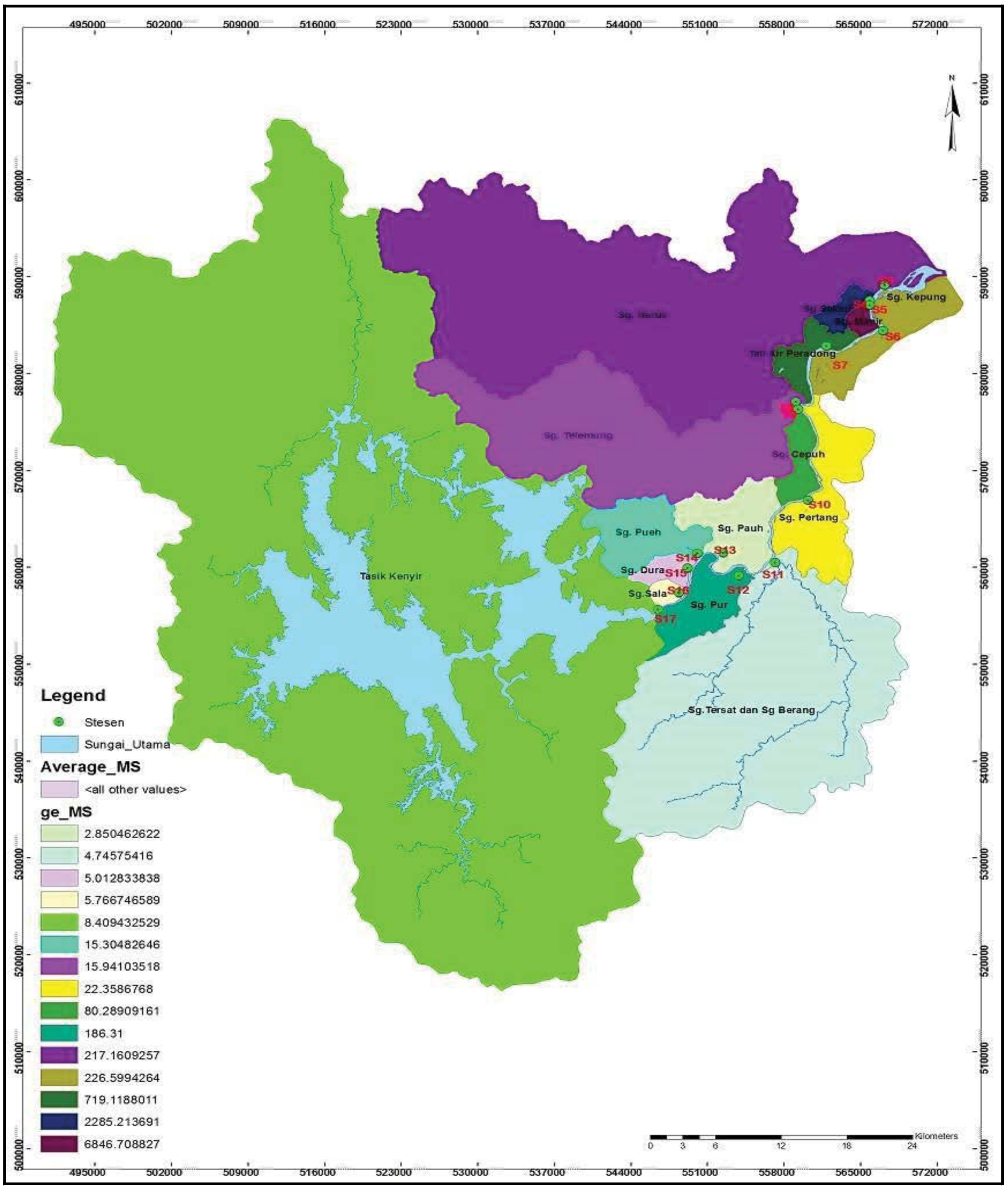


Fig. 8. Map of distribution of annual sediment load production (tonnes/km^2/year) at Terengganu River Basin, Terengganu, Malaysia, 2016.

Table 2
Correlation analysis of the area of catchment and annual sediment load production (SL) in wet season (a) and dry season (b), Terengganu River Basin, Terengganu
(a)

Variables	Area Catchment (km^2)	Annual sediment load production (SL) (tonnes/km^2/year)
Area Catchment (km^2)	1	−0.301
SL (tonnes/km^2/year)	−0.301	1

(b)

Variables	Area Catchment (km^2)	Annual sediment load production (SL) (tonnes/km^2/year)
Area Catchment (km^2)	1	−0.237
SL (tonnes/km^2/year)	−0.237	1

that, the regression analysis showed that the coefficient relationship was not significant, R^2 = 0.091 (wet season) and R^2 = 0.056 (dry season; Figs. 9(a) and (b)) [53,54]. The results of this study showed that the area of the river catchment is not a major factor in the production of SLs. The abundance of sediment production will certainly have many impacts on the surrounding basin.

3.2. Water quality status around Terengganu River basin

WQI is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water. It is calculated from the point of view of human consumption. A few preliminary water quality level studies in Terengganu River proved that there are high values of BOD, COD, TSS and AN at middle and downstream areas as compared with the upstream of the river basin. The reverse was true for the pH and DO values. This study adopted the DOE-WQI tool to evaluate the water quality of the Terengganu River Basin affected by hydrological characteristic and possible sources from anthropogenic activities. In addition, the beneficial use of the water was also compared with the classification based on the NWQS. Low water quality was found at the downstream and middle stream stations which are located around industrial, farming, sand mining and residential area (WQ1 until WQ14). In contrast, high water quality was recorded at the upstream stations of the basin which are nearest to the Kenyir Dam (Fig. 10). Fig. 11 showed the comparison between the predicted WQI and actual WQI for two seasons at Terengganu River Basin in 2016; the result proved that there are higher predicted values of WQI at downstream and middle stream than actual level of WQI. The value of WQI at Terengganu River Basin from 2009 until 2013 was 82% ± 88% (upstream), 79% ± 85% (middle stream) and 84% ± 90% (downstream). According to the NWQS classification, the Terengganu River Basin from 2009 until 2013 is categorized under Class II that is considered slightly contaminated (Fig. 12).

The main sources of pollutants were possibly waste products (both organic and inorganic) and effluents which were from development activities in the residential, sand mining, farming and agricultural areas that ultimately contaminate the river basin [55,56]. Based on the NWQS, most of the parameters measured remained in Class I from the upstream to the downstream stations. Various anthropogenic activities have caused significant changes in the water quality of the basin. The results presented here provide a baseline reference on the future monitoring of the Terengganu River basin.

3.3. Management strategies of Terengganu River Basin

Sedimentation occurs when flowing water slows down enough to allow suspended soil particles to settle. Heavier sands and silts settle out sooner than do finer clay particles. Sedimentation destroys fish-spawning beds, reduces the useful storage volume of reservoirs, clogs streams and increases filtration costs for municipal water supplies [13,51]. Suspended sediment, as measured by turbidity and TSSs, can reduce in-stream photosynthesis and alter the ecology of a stream. Based on the study carried out, the cause of high sedimentation in Terengganu River Basin was identified. There are several management, control, mitigation and conservation methods suggested to reduce this problem.

3.3.1. Solution to land use changes

The significant change of land use such as agriculture, industry, tourism and sand mining until creating an open area is the cause of sedimentation problems in the Terengganu River Basin. When the land is disturbed at construction sites, the soil erosion rate accelerates dramatically. The major problem associated with erosion at a construction site is the movement of soil from the site and the impact of the soil on water quality in streams, rivers and wildlife habitat. The erosion begins when water or wind detaches soil and rock particles from the land's surface. After detachment, soil particles are transported by air or water movement. Factors affecting erosion rates include climate, soil type, slope length, slope steepness and vegetative cover. Anytime if the land is disturbed, the potential for soil erosion increases. Eroded soil particles carried by water often move

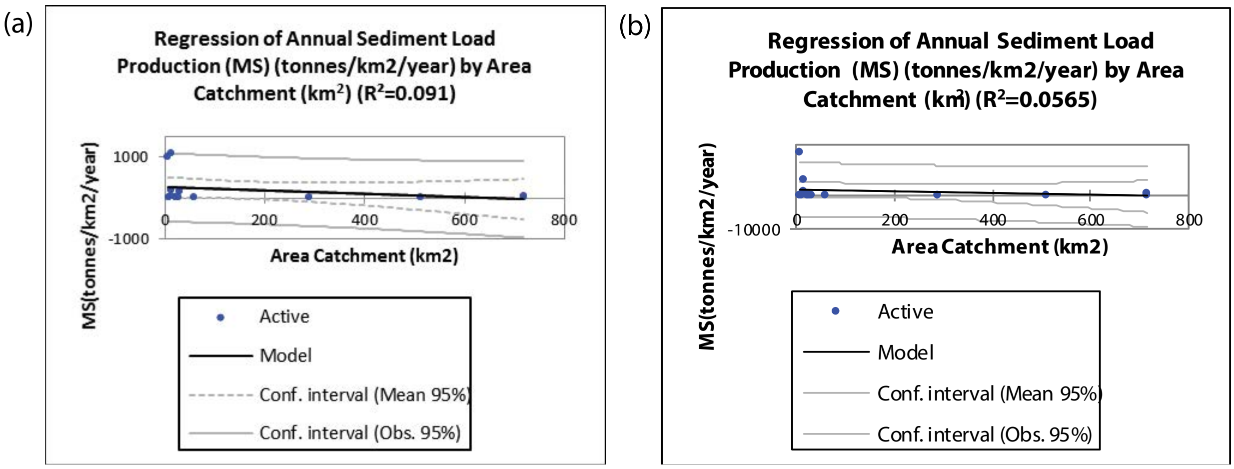


Fig. 9. (a), (b) Regression of Annual Sediment Load (SL) and area catchment (km^2) during wet season and dry season.

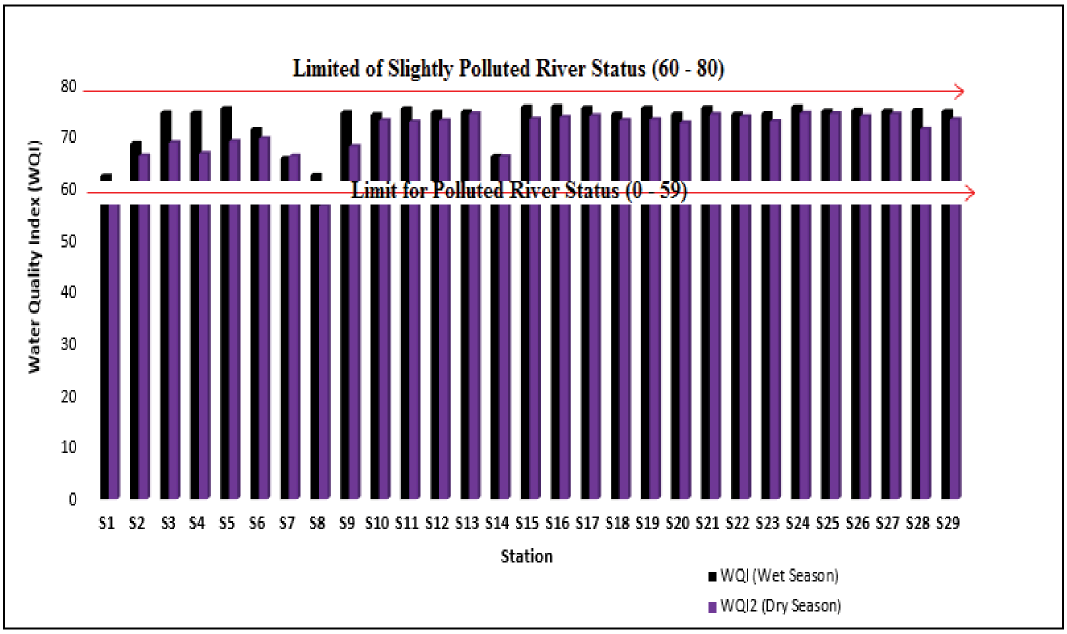


Fig. 10. Distribution of WQI at Terengganu River on January 2016 (wet season) July 2016 (dry season).

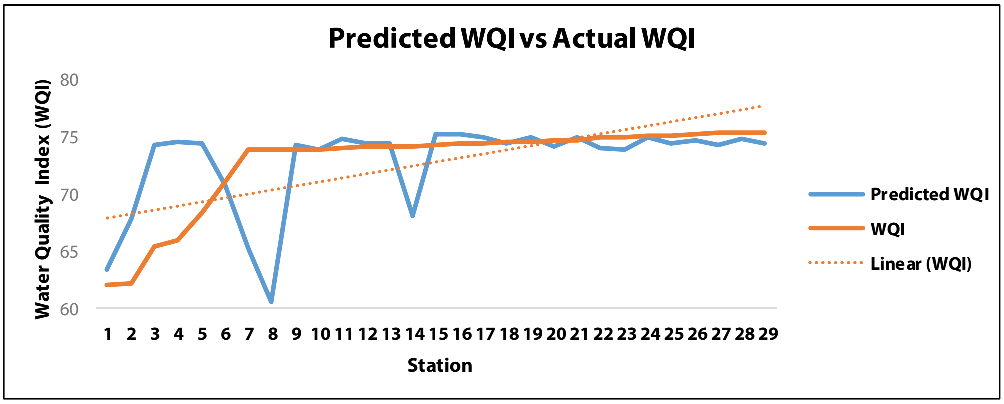


Fig. 11. Predicted WQI vs. actual WQI at Terengganu River basin.

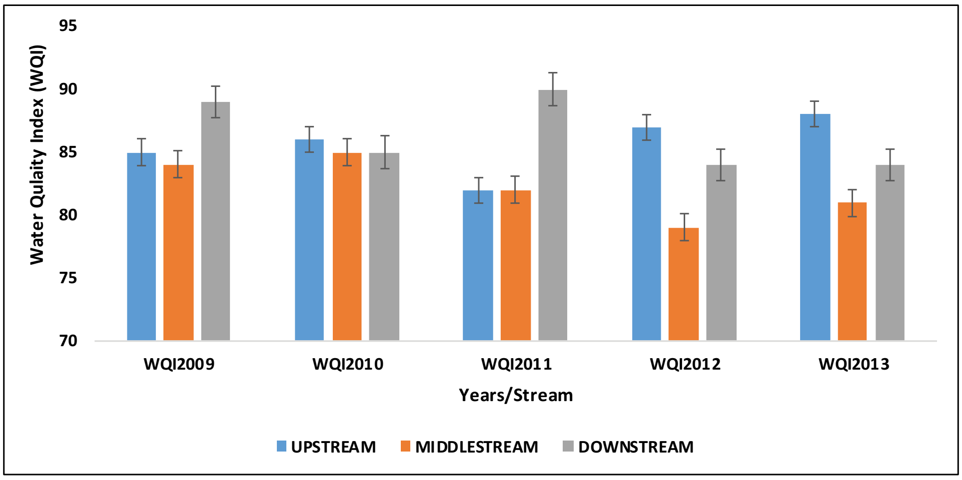


Fig. 12. Distribution of WQI at Terengganu River Basin from 2003 to 2009.

into streams where sedimentation and suspended solids can lead to a number of problems. However, this study suggests the existence of control laws to control the unplanned land use activity in this basin. The suggestion to create a buffer zone of the rivers in the basin area of Terengganu River including the main river is the smart way to overcome this problem (Fig. 13 and Table 3). The existence of the conserved zones not only reduces the sediment entry from the direct surface flow of the main rivers but also creates and sustains the natural habitat of the flora and fauna in the surrounding area [57–59].

3.3.2. Solution to riverbank erosion

In the Terengganu River basin, the riverbank erosion is one of the contributors for the formation of sediment production. The control structure for the riverbank erosion is usually done by building an erosion wall. The wall that is commonly used as barriers for the erosion is "gabion" structure or stone nest. The study suggests the construction of riverbank erosion control in the Terengganu River by using a more natural substance such as "fibre roll". Besides that, the flex slab and rock revetments were also suggested to overcome the riverbank erosion problem and one short as a natural sediment filter for the river (Fig. 14) [45,61,62].

3.3.3. Integrated river basin management at Terengganu River Basin

The IRBM is a process of coordinating conservation, management and development of water, land and related resources across sectors within a given river basin, in order

Fig. 13. Proposed map of buffer zone surrounding the Terengganu River basin and Kenyir Lake basin, Terengganu.

Table 3
Minimum width of river reserve to control the construction nearby the river basin area

Width of water flow and river cliff	Buffer zone
More than 40 m	50 m
Between 20 and 40 m	40 m
Between 10 and 20 m	20 m
Between 5 and 10 m	10 m
Less than 5 m	5 m

Source: Garis Panduan Konsep Pembangunan Berhadapan Sungai prepared by Drainage Irrigation Department (DID), Akta Perairan (Waters Act) 1920 [60].

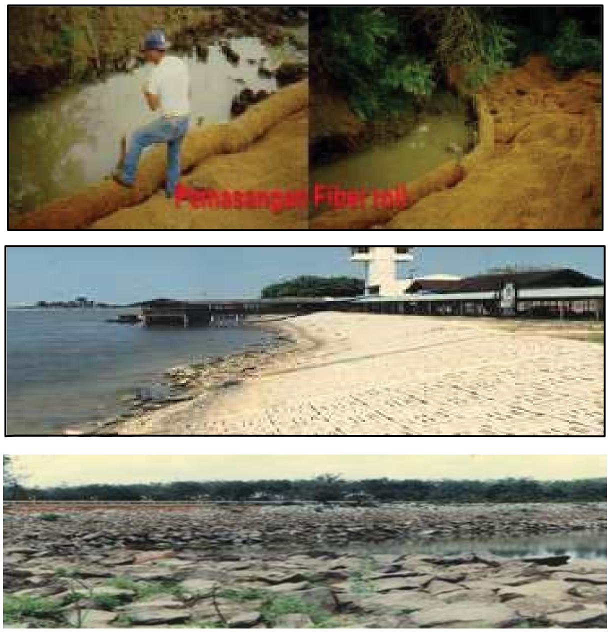
(a)
(b)
(c)


Fig. 14. Example of the proposed riverbank erosion control using (a) fibre roll, (b) flex slab and (c) rock revetments.

to maximize the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems. IRBM aims to establish a framework for coordination whereby all administrations and stakeholders involved in river basin planning and management can come together to develop an agreed set of policies and strategies such that a balanced and acceptable approach to land, water and natural resource management can be achieved. IRBM program was run by Department of Irrigation and Drainage (DID) which collaborated with the Danish International Development Agency (DANIDA) representing the Denmark government used in the development of the Selangor River Basin and Kedah River including the aspects of legislative institutions, the provision of legislation on water resources, human resource, river basin management and planning and improving environmental management practices [21–24,63–65].

This concept can be proposed and applied as a conservation of Terengganu River Basin. One of the IRBM practices in Terengganu River basin such as Rancangan Struktur Negeri Terengganu (RSN) from 2005 to 2020, Kawasan Sensitif Alam Sekitar (KSAS) Negeri Terengganu used GIS method. The KSAS Region of Terengganu is concentrated in the west of the state and in the coastal areas as well as the islands. Based on the land-use trend from 1990 to 2005, Rancangan Struktur Negeri Terengganu (RSN) targeted a total of 15,666 hectares of land needed to accommodate new developments until 2020 with an average of 920 hectares a year. Areas that are ready for unrestricted development are concentrated in the Koridor Pantai Negeri Terengganu.

4. Conclusion

This study showed that the water quality status of the 29 stations in the Terengganu River basin was at an unstable level but not very critical. The rapid urbanization and growth of the population triggered the increasing demand of water consumption levels thereby increasing water pollution at rivers basin in Malaysia. The river is polluted by domestic and municipal waste, agricultural activities, run-off, industrial activities and sand mining. In general, it is contaminated by point source pollution and non-point source pollution. Besides, it is compulsory to control and prevent these problems through determining the variations in water quality. The next step towards control and prevention by the authorities and the communities is the responsibility to cover the environmental issues.

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