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Evolution of river geomorphology to water quality impact using remote sensing and GIS technique

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ABSTRACT

River plan change is one of the river geomorphology change process. This study focuses on the processes of the river plan change using geographic information system (GIS), remote sensing, and water quality analysis using water quality index (WQI) parameters. Multiple linear regression (MLR) method was used to observe the relationship between river plan change and WQI. Spatial model method was applied along the mainstream of Terengganu River Basin, using GIS to further justify the impact of river plan change on water quality status. The results obtained shows that the Terengganu River Basin has been going through certain river plan changes due to increase and decrease of the river plan criteria. Based on WQI analysis, the classification of water quality is under class III. Based on MLR, there are strong relationships between dissolved oxygen and river plan change which has value of R^2 0.995, total suspended solids (TSS) with R^2 0.764, and WQI with R^2 0.928 during wet season, whereas during dry season, TSS and WQI showed the strong linear relationship with R^2 of 0.997 and 0.985, respectively. This study will appropriately act as an aid of the local enforcement to determine the problems of the river management.

Keywords: River geomorphology; River plan change; Water quality index (WQI); Remote sensing; Spatial model

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1. Introduction

Generally, the river is one of the primary sources of water for many reasons and also provides fertility for lands, which support the development of highly populated residential areas due to its favorable conditions [1,2]. In addition, river is a magnificent and most valuable gift from nature which covers approximately 0.0002% of the total water on earth. It has been sustaining human and organism since the crack of time. Furthermore, it has been playing a fundamental role as the source of living and life itself [3,4].

Moreover, river plan change refers to a morphological movement of water and sediments in relation to available materials at banks and beds of a river, which takes place through time and space determined by different habitats found within a given river channel. Furthermore, river plan change is defined as a variety of ways through which erosion and deposition are affected by catchment characteristics that are of natural (river flow, flood, surface runoff, sedimentation) and human factor (agriculture, industrialization, grazing, deforestation) which are effected to the change of river plan. The changes of river discharge (Q) and sediment load produce an immediate response but rather initiate a change or sequence of changes which may prolong over a long period of time [5–7].

However, water quality is a primary ecological concern all over the world, and it is affected by anthropogenic, climate changes, and natural disturbing influences, such as erosion, surface runoff, sedimentation, overflow effluents, wastewater, land recovery, environmental change, and air testimony, among others [8–11]. Water quality is a state of biological, physical, and chemical characteristics of water in collaboration with anticipated use and a set of standards [12–14]. Additionally, surface waters are vulnerable and helpless to contamination resulting in the consequence of standard techniques, which include, precipitation data, disintegration, weathering of crustal materials, sedimentation, erosion, and anthropogenic exercises such as industrial, urban, horticultural, and agricultural activities [15].

All over the world, there have been incidences of river plan change which brought about tragic results such as the following: In the United States, erosion is at a high rate at the Lower Brule Reservation of the central South Dakota. It has been projected that the reservation shorelines in some locations are losing, approximately 8 feet per year [16]. In Europe, Middle Danubian loess bluff is at risk of river plan change through bank erosion, recently more than ten settlements are in danger, and a great number of municipal and industrial infrastructures have previously been damaged [17]. It is also reported in Africa that river plan change has caused a decrease in agricultural lands which results in a decline in agricultural production especially in areas close to the River Nile [18].

The intensity and quantity of rainfall in Terengganu River Basin are prejudiced by the water level flow and the rates of erosion processes. However, relationship between the rate of side and riverbank erosion is projected to increase in sediment production [19]. The intensity and value of rainfall play a great role in river plan change. The intensity and quantity of rainfall effected to the higher infiltration rates which are resulting in excess runoff and a much greater rate of Total Suspended Solid (TSS) transportation affecting Water Quality Index(WQI) [20]. Subsequently, water quality has been facing more threats from natural phenomenon such as erosion, sedimentation, and flood which are further intensified by river plan change [21].

Terengganu River Basin covered the conditions favorable of river plan change with effects on water quality status, WHICH has been experienced throughout the world [16–18] and also in some parts of Malaysia [6,22,23]. However, this study was identifying the possible changes in river plan change in order to address them and prevent the occurrence of disastrous incident which includes loss of land, infrastructures, and roads. To assess the effect of river plan change to water quality and quantity and evaluate whether the river plan change has a relationship or impact on water quality. Despite this trend, based on scientific knowledge of river plan change, studies have not been conducted on Terengganu River. In addition, this study will not be restricted to river plan change but will also diagnose the effect on water quality which is an aspect that researchers neglect when assessing river plan change despite the fact that they are strongly interrelated [19].

2. Study area and research methodology

2.1. Area of study

Terengganu River is a river basin situated on the East Coast in Peninsular of Malaysia, whose length is as long as 100 km, and approximately 500 km^2 total catchment area of Terengganu River Basin was included along with Berang River, Nerus River, Telemong River, and Tersat River. The upstream of the river originates from Kenyir Lake in Hulu Terengganu flowing through Kuala Terengganu (Fig. 1), state capital, and discharges into South China Sea [24]. The climate of this region is Tropical rainforest climate which is neither cold nor dry as it is consistently moist (all year round). The monthly average temperature is 3°C, and the average annual temperature is 26.7°C. Total average rainfall per year is 2911 mm. Furthermore, there are basically two types of monsoon seasons which are the northwest monsoon season that mostly starts in early November and usually ends in March and then the South West monsoon season usually comes in end of May or early June and ends mainly in September [25]. Terengganu River consists of many tributaries, which are Berang, Pueh, Nerus, Telemong, and others. All of these rivers flow and join into the Terengganu River to lastly reach the South China Sea [23].

2.2. Research methodology

In this study, both primary and secondary data will be used. The secondary data will be collected from two image satellite data of 2010 and 2015 which are sourced from United States Geological Survey (USGS) website, while a primary data of two seasons were gathered from the mainstream of Terengganu River Basin which comprise of biological oxygen demand, TSS, chemical oxygen demand, pH, dissolved oxygen (DO), and ammoniacal nitrogen using standard procedures provided by American Public Health Association and United States Environmental Protection Agency methods

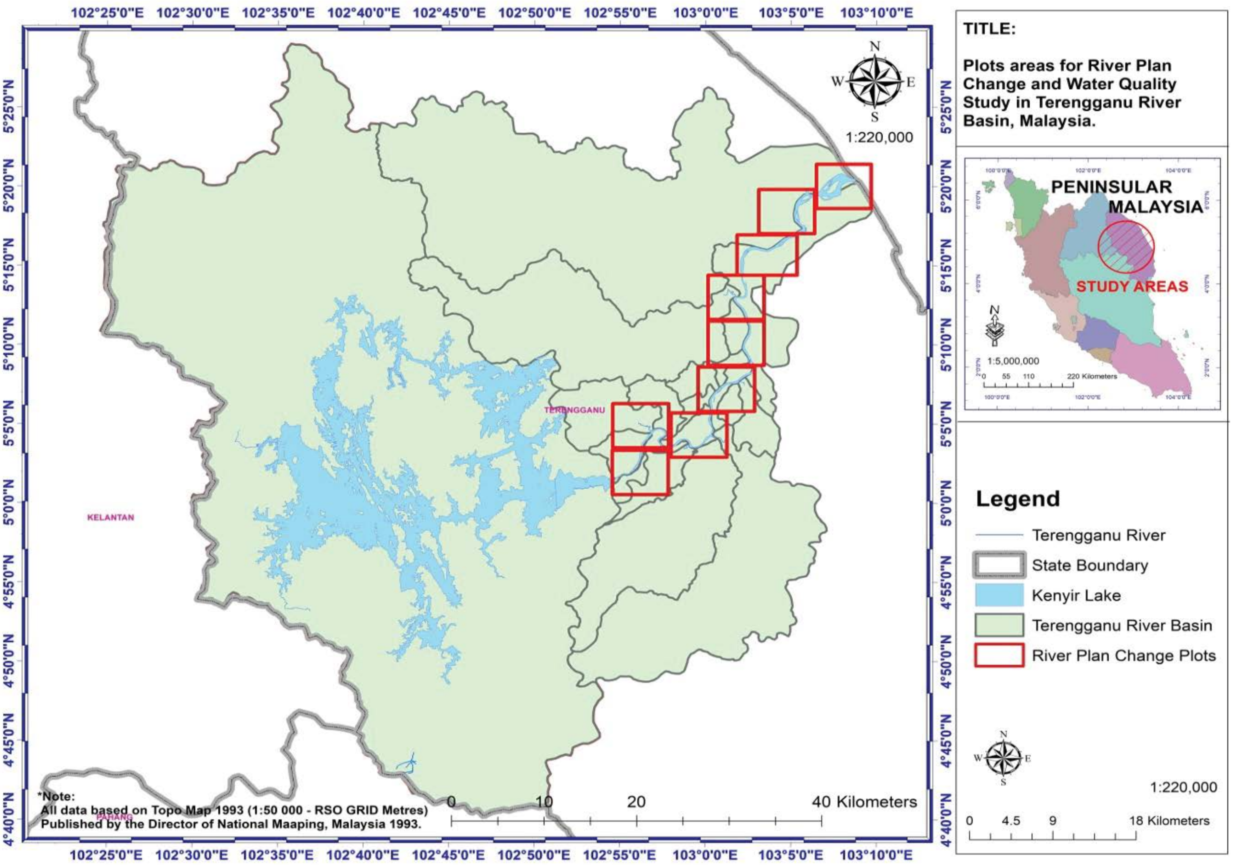

Fig. 1. Plot areas for river plan change and water quality study in Terengganu River Basin, Malaysia.

[26] which are to determine the water quality of Terengganu River Basin. Furthermore, a spatial model is developed based on TSS, DO, and WQI to determine the distribution of water quality status along the river which is affected by river plan change. First, remote sensing technique will be used in processing the satellite images which will be done using ERDAS software. Then, geographic information system (GIS) was used to achieve the original objective of analyzing river plan change using ArcGIS software for geo-referencing and digitization of the satellite image [23]. Errors throughout the digitizing and rectification procedures be momentous, and these can be evaluated by using Eqs. (1) and (2). Eq. (1) delivers the systematic error(s) which is as follows:

$$S = \frac{\sum x}{n} \tag{1}$$

where x = error at n reference point. If $S = 0$, then the errors are random.

Moreover, if s were presented, most probably during map rectification, formerly the value of s designates the degree of channel 'shift' that has been occupied. On the other hand, root mean square error (RMSE) is calculated as:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=0}^{n} x_i^2}{n}} \tag{2}$$

where x_i = error at n reference point, RMSE provides the average error by which coordinates of the same point (or tics) on the two or more maps deviate.

Such errors must be reflected when measuring a change in the channel configuration over the observation period. Using GIS, the accuracy of rectified maps could be calculated against the base map by preserving several geo-reference points [23]. However, the water quality has been analyzed using a standard Malaysian WQI monitored by National Water Quality Standards (NWQS) of six parameters as a laboratory technique for processing the primary data obtained from Terengganu River. To determine the present water quality status of the river and how the changes in river plan impacted to the water quality level [25,27]. Only six parameters of WQI will be used to determine the Malaysian Department of Environment (DOE) WQI results as concluded by a panel of experts in Malaysia (Tables 1 and 2) [25].

Additionally, results obtained from river plan change have been used to assess the relationship and impact of river plan change. The results were found using multiple linear regressions (MLR) to correlate between the WQI and assessment of the river plan change. Linear regression (LR) is referred to as a linear approach for modelling the relationship between one or more explanatory variables (or independent variables) denoted as X and a scalar dependent variable Y. In other words, the term 0 is distinct from multivariate LR, in which multiple correlated dependent variables are anticipated, not a single scalar variable. However,

Table 1
DOE-WQI calculation formula [14,25]

Subindex DO (SIDO) (% saturated)	$x \le 8$	SIDO = 0
	$x \ge 92$	SIDO = 100
	$8 < x < 92$	SIDO = $-0.395 + 0.03x^2 - 0.0002x^3$
Subindex biological oxygen demand (SIBOD) (mg/L)	$x \le 5$	SIBOD = $100.4 - 4.23x$
	$x > 5$	SIBOD = $108e^{-0.055x} - 0.1x$
Subindex chemical oxygen demand (SICOD) (mg/L)	$x \le 20$	SICOD = $-1.33x + 99.1$
	$x > 20$	SICOD = $103e^{-0.0157x} - 0.04x$
Subindex ammoniacal nitrogen (SIAN) (mg/L)	$x \le 0.3$	SIAN = $100.5 - 105x$
	$0.3 < x < 4$	SIAN = $94e^{-0.573x} - 5^* \mid x - 2 \mid$
	$x \ge 4$	SIAN = 0
Subindex TSS (SITSS) (mg/L)	$x \le 100$	SITSS = $97.5e^{-0.00676x} + 0.05x$
	$100 < x < 1{,}000$	SITSS = $71e^{-0.0016x} - 0.015x$
	$x \ge 1{,}000$	SITSS = 0
Subindex pH (SIpH)	$x < 5.5$	SIpH = $17.2 - 17.2x + 5.02x^2$
	$x \le x < 7$	SIpH = $-242 + 95.5x - 6.67x^2$
	$7 \le x < 8.75$	SIpH = $-181 + 82.4x - 6.05x^2$
	$x \ge 8.75$	SIpH = $536 - 77x + 2.76x^2$

Table 2
National Water Quality Standards (NWQS)

Parameter	Class					
	I	IIA	IIB	III	IV	V
pH	6.5–8.5	6–9	6–9	5–9	5–9	–
DO, mg/L	7	5–7	5–7	3–5	<3	<1
Biological oxygen demand, mg/L	1	3	3	6	12	>12
Chemical oxygen demand, mg/L	10	25	25	50	100	>100
TSS, mg/L	25	50	50	150	300	300
Ammoniacal nitrogen, mg/L N	0.1	0.3	0.3	0.9	2.7	>2.7

*Class I: Conservation of natural environment.
Water supply I – Practically no treatment necessary
Fishery I – Very sensitive aquatic species
Class IIA: Water Supply II – Conventional treatment required
Fishery II – Sensitive aquatic species
Class IIB: Recreational use with body contact
Class III: Water supply III – Extensive treatment required
Fishery III – Common of economic value and tolerant species; livestock drinking
Class IV: Irrigation
Class V: None of the above

MLRs are a statistical method that is used to forecast the variability that occurs among dependent and independent variables [28,29].

GIS is a geographical tool for mounting solutions to the complications of water resources through determining water availability, deterioration of water quality status, preventing flooding, the management of water resources, and understanding the natural environmental regional scale or on a local [30]. The development of the spatial model has been done using a standard deterministic spatial interpolation model known as inverse distance weighting (IDW). It is a commonly used method by geographers and geoscientists. IDW is of GIS procedure which has been successfully implemented in several GIS studies. IDW approach has been used in the current study to designate the locational distribution of water constituents or pollutants [31]. Furthermore, GIS enables us to appearance into the effect and determine the relationship with a visual presentation [30]. We construct a piece-wise constant function $f_k(r)$ that takes the value f_i whenever $q_k(r) = r_i$. With this notation, IDW interpolation formula is as follows:

$$\check{v}_1 = \frac{\sum_{i=1}^{n} \frac{1}{d_i^p} v_i}{\sum_{i=1}^{n} \frac{1}{d_i^p}} \qquad (3)$$

where $p > 0$ is an input parameter. The f_k has cusps on the data sites r_k for $p \le 1$ while it is smooth for $p > 1$. Typically, the value $p = 2$ is chosen.

Fig. 2 shows a flow chart of methods used in assessing the impact of river plan change to water quality status. The results obtained using GIS were further analyzed by mode of meander movement (MOME) and types of lateral activity (TYLAT) methods. However, WQI parameters were used to evaluate the water quality level in Terengganu River Basin. MLR was used to measure the impact and relationship of river plan change and water quality level. Lastly, a spatial model was used to show the impact visually on map based on locations, showing areas of high impact and those with low impact.

3. Result and discussion

3.1. River geomorphology change or river plan change

Based on this study, Terengganu River Basin was classified into 9 plots from the downstream until upstream with 5 km length and width on each plot to accurately detect the changes found in each plot and to curtail the possibility of overseeing certain changes [6,32]. Nonetheless, the downstream, middle stream, and upstream are subdivided into three plots each having a sum of 9 plots all together. The evolution of the changes in Upstream of Terengganu River Basin includes subplots P1, P2, and P3 as presented in Fig. 3. The Upstream River changes in Table 3 which shows 9 cases of Progression and cut-offs manage an analysis based on TYLAT caused as a result of water flow in the river. In contrast, meander progression types have been located in 5 cases, braiding in 6 cases, and 3 in different types of creasing amplitude that occurred from 2010 to 2015. The river plan on the upstream of Terengganu River has undergone several changes and also have an adverse impact on, from so many factors such as plain flood, discharge and so on [1,6].

Table 4 shows the analysis of MOME based on the six different types which are used to assess the upstream of Terengganu River which is ranging from 2010 to 2015. Based on the MOME type assessments, extension has been found in 3 cases while translation in one single case and rotation has been found in 2 cases. Additionally, the lateral movement has been found in only 1 case. However, enlargement and complex change have no situations in the upstream. Based on the types of changes in river plan, the river middle stream of 2010–2015 showed the highest changes is progression and cut-offs where 9 cases of change were followed by meander progression in 4 cases and increasing amplitude and braiding in 3 cases as shown in Fig. 4. Thus, meandering turns of the river are because of the meander bend erosion which is the combination of both hydraulic and geotechnical

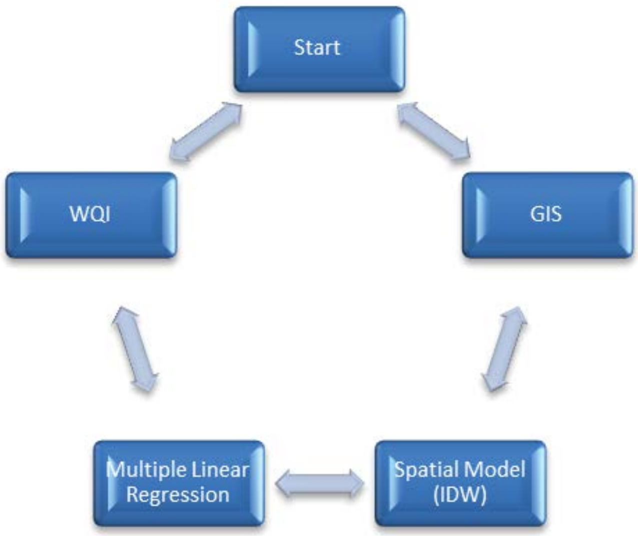

Fig. 2. Impact of river plan change on water quality.

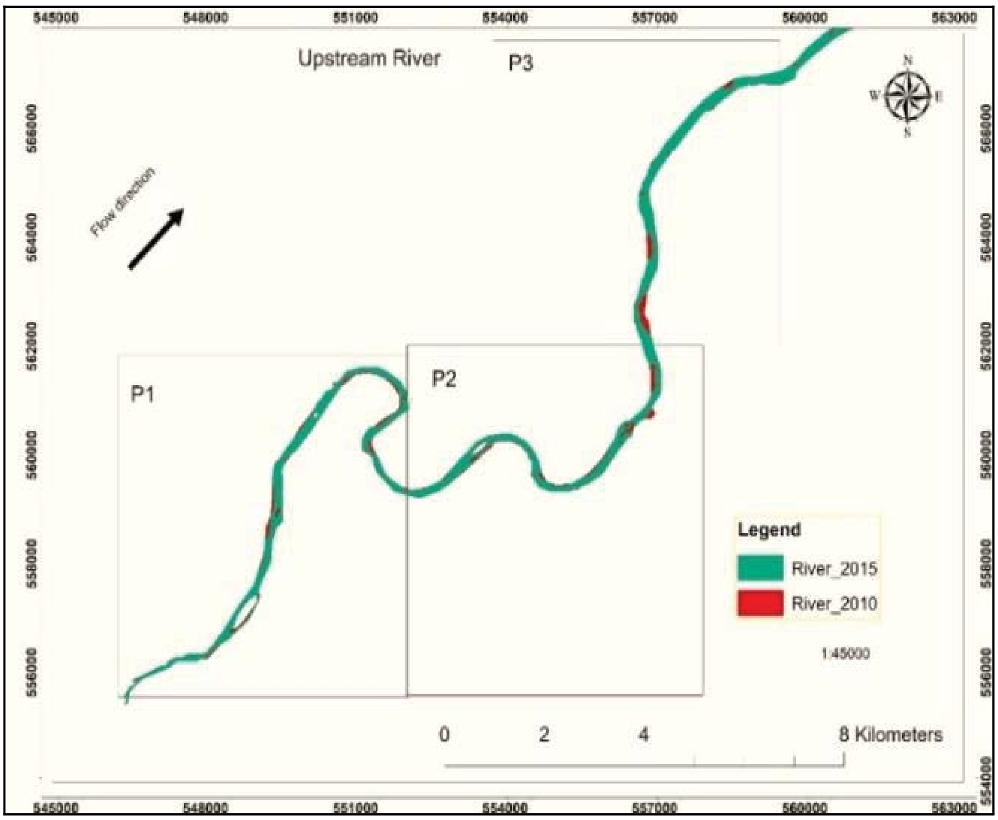

Fig. 3. Upstream of Terengganu River.

Table 3
Types of river plan change based on the TYLAT for Upstream of Terengganu River

Subplot	Meander progression	Increasing amplitude	Progression and cut-offs	Irregular erosion	Avulsion	Braiding
P1	2	1	3	0	0	0
P2	2	1	3	0	0	4
P3	1	1	3	0	0	2
∑	5	3	9	0	0	6

Table 4
Types of river plan change based on the MOME for upstream Terengganu River

Subplot	Extension	Translation	Rotation	Enlargement	Lateral movement	Complex change
P1	1	1	1	0	0	0
P2	1	0	1	0	1	0
P3	1	0	0	0	0	0
∑	3	1	2	0	1	0

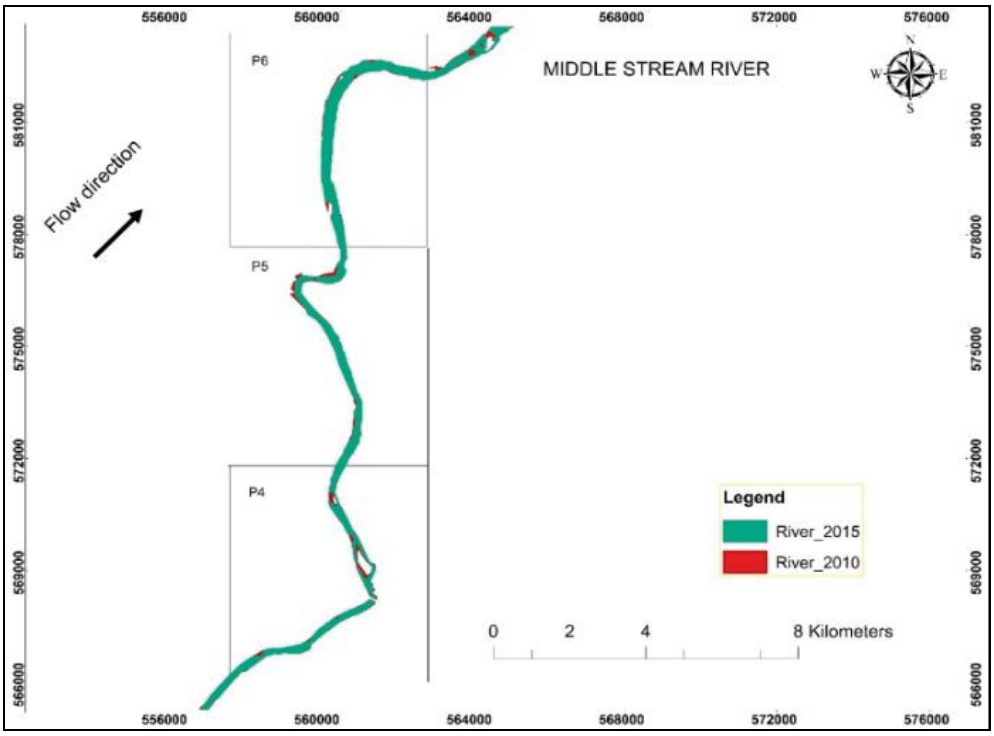

Fig. 4. Middle stream of Terengganu River Basin.

processes [33]. It also has shown the evolution of the changes in river plan at the middle stream river for P4, P5, and P6 on 2010–2015.

Referring to the results in Table 5, the lowest cases of the middle stream based on TYLAT have 3 cases of braiding, 3 cases of increasing amplitude, and 4 cases of meander progression. This is, however, as a result of a river water continuous flow which is related to the homogeneity and resistance from erosion. Arch of meander has two parts which can pile sediments until the cause moves which is called undercut. Furthermore, faster flow of the river water beyond the boundaries of the river causes the side to curve which leads to the curvature as a result of erosion deposited on the inner side [33]. The middle stream of Terengganu River also has no cases of Irregular erosion and Avulsion, all shown in Fig. 4.

Table 6 shows that the MOME highest situations in the middle stream is rotation which is in 7 different cases throughout the middle stream. The rotation has been caused because of faster or slower river flow. Enlargement also has

Table 5
Types of river plan change based on TYLAT for middle stream Terengganu River

Subplot	Meander progression	Increasing amplitude	Progression and cut-offs	Irregular erosion	Avulsion	Braiding
P4	1	2	4	0	0	1
P5	3	1	3	0	0	
P6	1	0	2	0	0	2
∑	4	3	9	0	0	3

Table 6
Types of river plan change based on the MOME for middle stream Terengganu River

Subplot	Extension	Translation	Rotation	Enlargement	Lateral movement	Complex change
P4	2	0	4	0	1	0
P5	2	2	1	0	1	0
P6	2	2	2	1	0	0
∑	6	4	7	1	2	0

a single case in the middle stream; the occurrence of such change is mostly due to land and case of soil erosion in the area. Besides that, extension has 6 cases which have no error subject in this field, followed by translation with 4 cases and lateral movement with 2 cases. From the analysis, only complex change has no case found in the middle stream (Fig. 4).

The river changes at downstream of Terengganu River are subplot into P7, P8, and P9 (Fig. 5). The changes in the river plan are dominantly meander progression and cut-offs because cut-off shortens the length of the river, causing a disturbance in the regime of upstream and downstream till readjustment is made. Erosion in meander bends is a conventional process responsible for local bank retreat and for initiating a bank stabilization program [34].

Table 7 showed the types of river plan changes based on the TYLAT method index for downstream of the Terengganu River. The highest number of cases found based on Table 7 in the middle stream is progression and cut-offs with 10 cases within the five-year period which is from 2010 to 2015. Changes in the river caused by types of progression and cut-offs were little change at the coast of the river and caused by soil erosion that often occurs in that region or maybe because of human activities which are uncontrollable such as forestry, agriculture, urban, and so on. Braiding has 4 cases; meander progression and irregular erosion are both having 3 cases each while increasing amplitude with only 2 cases. Based on the assessments of downstream by TYLAT, Avulsion has no situations of change as seen visually in Fig. 5.

Table 8 shows a result based on the six types of MOME from the downstream of Terengganu River. According to the results, Extension has 6 cases of change, Translation with 3 cases of change, and Enlargement with 2 cases. However, no changes were found in rotation, lateral movement, and complex change in the downstream of Terengganu River. Additionally, by using satellite image data as shown on Fig. 5 of years 2010 and 2015, it is easy to get an analysis with more accuracy. Whereas braiding is found in 4 cases and 13 cases are meander progression, cut–offs and irregular erosion are changes based on 2010–2015.

Figs. 3–5 show river changes which can be seen decreasing compared with the middle reaches of the river. The value of areas and changes in river plan from 2010 to 2015 are shown. First, the largest area (hectare) that increases in 2010 and 2015 is 154.67 which are in P2, and the percentage of the changes in river plan of the river upstream is 5%. According to the results, a change in river braiding is 10%. Braiding happens when there is a high flow stage, significant changes take place due to rapid rates of stream migration aided by high stream power and unstable banks [35]. Furthermore, there can be extensive changes in flow situation like subdivided streams which are abandoned or earlier stream reactivation. Even in braided reaches, a single dominant stream in some cases will be distinguishable from the surroundings of Terengganu River from early years of 2010–2015 as illustrated in pie chart in Fig. 6.

There is also an improvement in the town, city, and village in this field which has well caused changes in the river. Nevertheless, the second highest increase in river plan is 129.51 ha which is in P4 for middle stream evolution and the percentage of the P4 is increasing in width of the river of about 8%. The lowest area values decreased by –5.06 ha which is P1 for upstream stream river, and the changes based on percentage in river plan is 10% which is the width area of the river getting smaller and have been cut-off. Area of the upstream river has changed because of activities in the river such as town center, Recreational Park, and Kenyir Lake Dam (Fig. 3).

3.2. Water quality

The application of WQI has been used to assess the water quality of Terengganu River for which results have been shown in Fig. 7. The statistical analysis of TSS, DO, and WQI will help determine the relationship and impact of river plan change on the water quality. However, the results are of

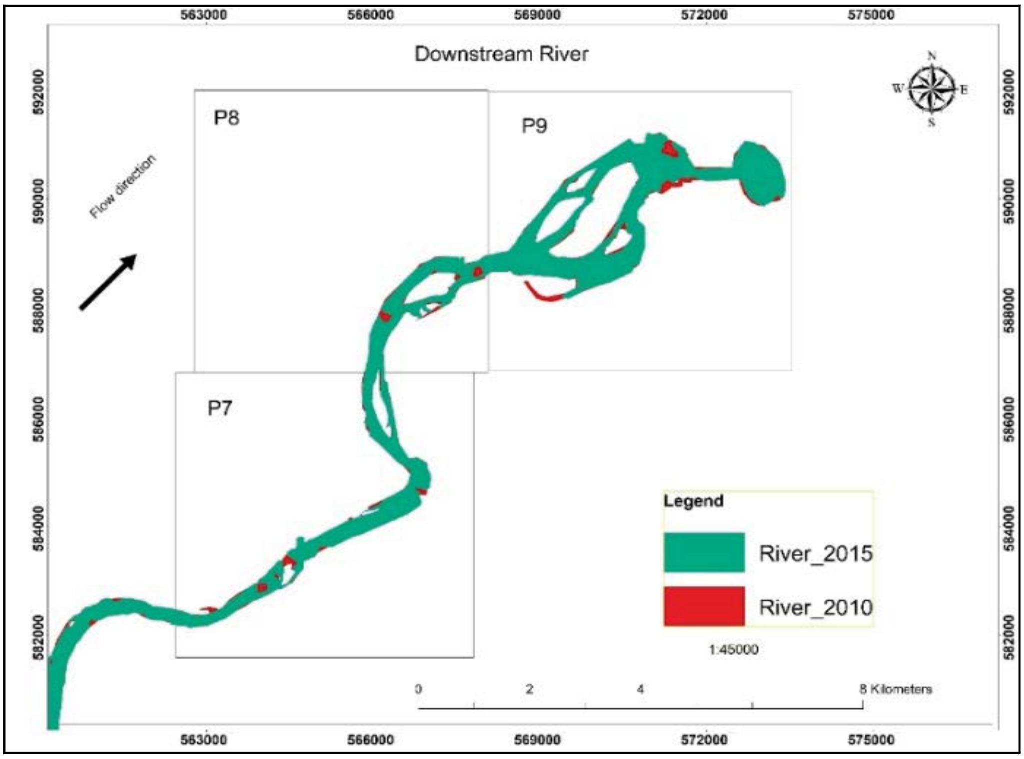

Fig. 5. Downstream of Terengganu River.

Table 7
Types of river plan change based on the TYLAT for downstream Terengganu

Subplot	Meander progression	Increasing amplitude	Progression and cut-offs	Irregular erosion	Avulsion	Braiding
P7	1	1	5	1	0	1
P8	1	0	4	1	0	2
P9	1	1	1	1	0	1
∑	3	2	10	3	0	4

Table 8
Types of river plan change based on the MOME for downstream Terengganu River

Subplot	Extension	Translation	Rotation	Enlargement	Lateral movement	Complex change
P7	0	0	0	0	0	0
P8	3	1	0	2	0	0
P9	3	2	0	0	0	0
∑	6	3	0	2	0	0

both wet and dry seasons, respectively. Results from Fig. 7 have been carefully calculated to determine the water quality of Terengganu River. Nevertheless, more attention has been turned to TSS because significant river plan changes are through erosion and weather. Furthermore, the higher the suspended solids, the higher the temperature which in turn decreases the DO. It is because suspended particles literarily captivate more heat from solar radiation than water molecules [36].

Results from Fig. 7 have been carefully calculated to determine the water quality of Terengganu River. Based on the analysis from Fig. 7, TSS data for wet season vary from 0.40 to 67.20 mg/L with a mean value of 10.52 mg/L while for the dry season data range from 0.40 to 128.20 mg/L and an average of 34.36 mg/L. Classifying TSS stations according to NWQS for the wet season is as follows: class III having just stations WQ 6 and WQ 7, while the remaining 27 positions all fall into class I. Nevertheless, dry season have WQ 1, WQ 2,

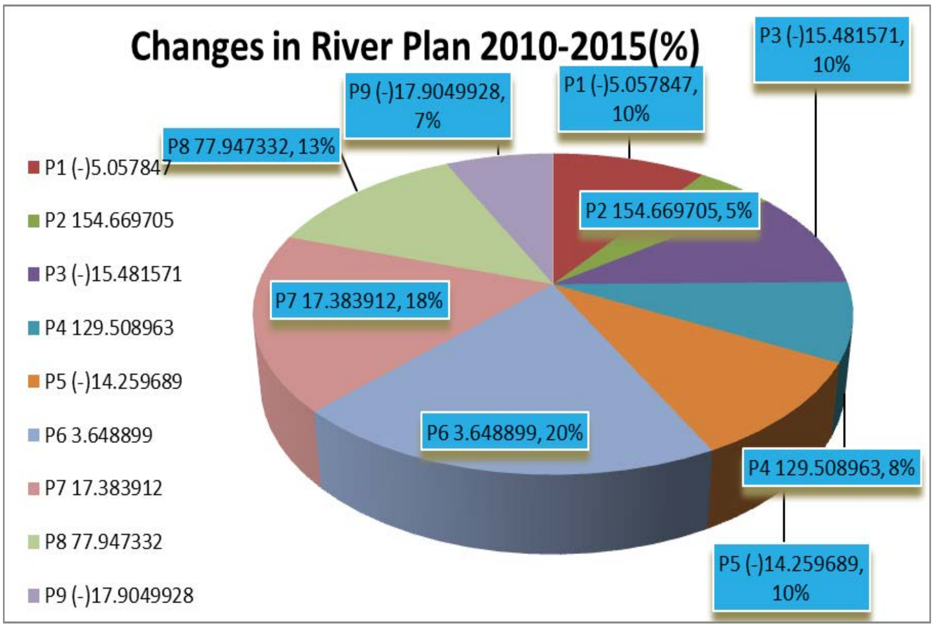

Fig. 6. The changes of the river plan in 2010 until 2015.

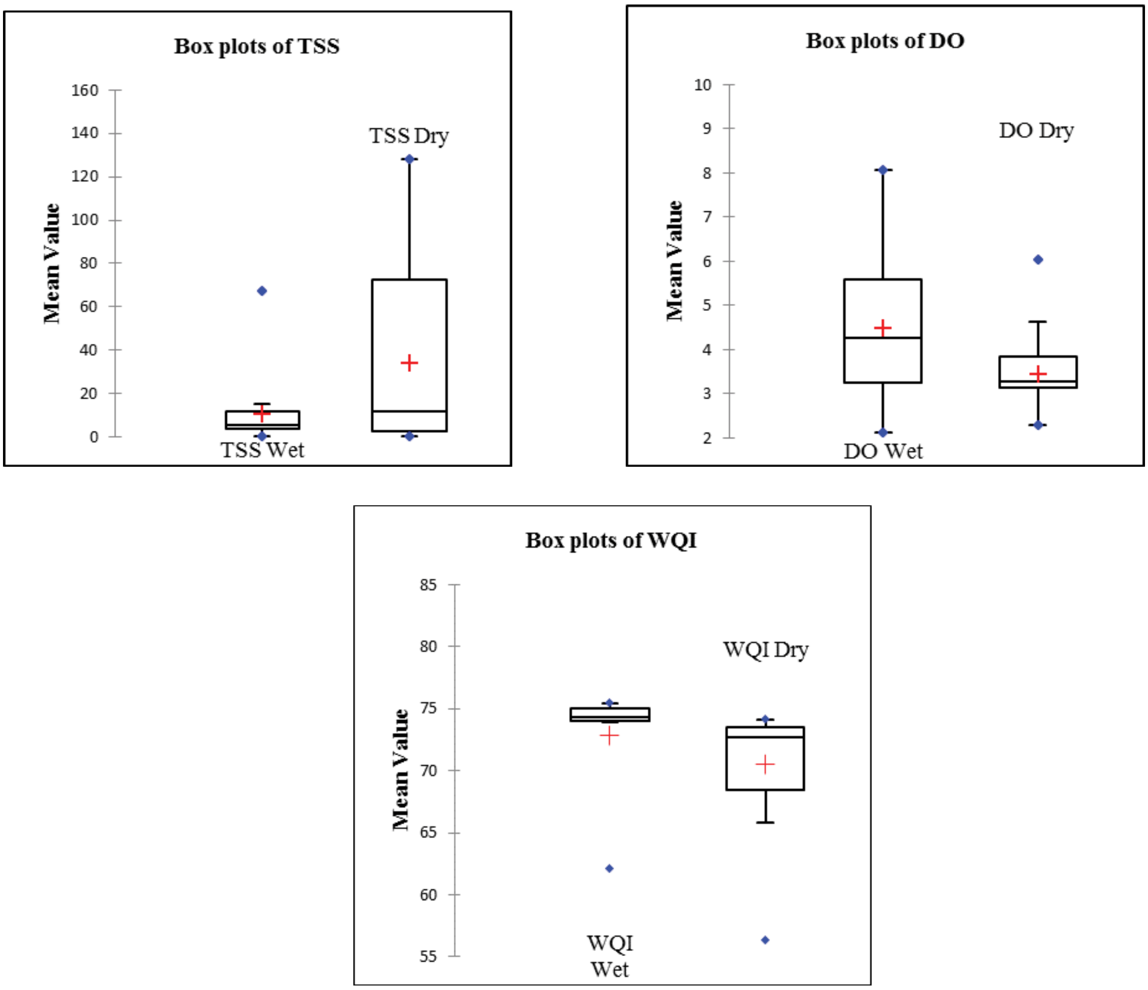

Fig. 7. Statistical analysis of TSS, DO, and WQI for dry and wet seasons in Terengganu River.

WQ 3, WQ 4, WQ 5, WQ 6, WQ 7, WQ 8, and WQ 9 while the remaining of 20 stations fall under class I. Narrowing down to conclude wet season based on the mean value to be in class I and dry season to be in class II.

The DO values according to NWQS is classified as follows: the wet season includes class IV with WQ 8, class II having WQ 6, WQ 12, WQ 15, WQ 19, WQ 24, WQ 26, and WQ 29, while class I contains the remaining 21 stations, and dry season includes class V having WQ 2, class IV having WQ 1, class III with WQ 7, WQ 11, WQ 12, WQ 15, WQ 16, WQ 19, WQ 20, WQ 22, WQ 23, and WQ 28, and class II having the majority of the remaining 17 stations. Based on mean average, wet season is classified to be in class II and the dry season is set to be in class III. Moreover, results of WQI shows wet season ranging from 62.10 to 75.46 mg/L with a mean value of 72.81 mg/L and dry season ranging from 56.33 to 74.14 mg/L with a mean value of 70.47 mg/L. Based on the mean values, both wet and dry seasons fall into class III of the DOE WQI class.

3.3. Multiple linear regressions

In this study, to correctly and accurately find the MLR, an average of both river plan change and water quality data was found based on three main categories which are upstream, middle stream, and downstream. Fig. 7 shows a standardized coefficient of DO, TSS, and WQI for the wet season, while Fig. 8 indicates a regression plot for the dry season, illustrating the strength and significance of the R^2. Based on the analysis, all three variables are robust and confident because they were high and significant at p-value < 0.5. With DO having an R^2 value of 0.995, it strongly signifies that the river plan change is having a significant impact on DO. Thus, note that the atmospheric pressure during wet season is suitable for high desolation of oxygen with other factors such as flood and wave movement that traps oxygen around the water surface. Literarily, the absorption rate of heat by suspended solid increases or decreases the amount of DO in any water body [14,37]. River plan change also has a substantial impact on TSS with evidence to Figs. 7 and 8 with a positive R^2 value of 0.764. While WQI with an R^2 of 0.928 is also having a positive influence too. Based on the results, river plan change has a tremendous impact on DO, TSS, and WQI in the dry season.

In addition, Fig. 9 shows regression plots assessing another three parameters which are DO, TSS, and WQI for the dry season. Concerning these analyses, DO is having an R^2 value of 0.451 which is 0.544 less than R^2 result in the wet season. This is because during the dry season recorded low amount of rainfall intensity than the wet season and high temperature level which is effected the variety level of TSS in the river basin. While, during wet season recorded the lower temperature level and higher amount of water with abandoned DO than dry season. It showed that the DO for the dry season does not have a strong relationship with river plan change which is as a result of river flow rate, velocity of water, and others. However, the TSS R^2 value is strongly positive with a value of 0.997 which is 0.233 higher than wet season TSS result. This results from the rate of erosion, sedimentation, among others during the dry season. Also, there is high amount of rainfall during wet season that always results in flood which washes back to the river with solid particles, which concentrate during dry season due to the reduction in the amount of surface water by evaporation. This result shows a higher rate of river plan change during wet season than dry season and a higher effect of river plan change on water quality, while WQI is likewise having an active R^2 value of 0.985. Additionally, the results signify all variables are having a strong relationship with the river plan change which may result in rate of rainfall, velocity, water flow, run off, erosion, sedimentation, and flood among others.

3.4. Spatial model

This section is visually explaining the water quality of Terengganu River using an IDW interpolation tool to describe the spatial model of DO, TSS, and WQI, relating it with river plan change. The analysis will be based on the two seasons of Terengganu which are the wet and dry seasons in accordance with the locations or stations. Through the application of GIS (spatial interpolation method), pollution zone classification in the river can easily be done, for better management of the river. Fig. 10 shows a spatial distribution model of DO for wet season for which water quality value ranges from 2.11 to 8.03. Starting with 2.12–2.78 and 2.78–3.34 categories colored dark green and light green, respectivey, which are found in the downstream and middle stream of the river, these are classified as class IV of the NWQS, while 3.34–4.09 colored yellowish brown, 4.09–4.75 colored with a darker shade of yellowish brown, and 4.75–5.41 colored light brown are classified as class III which are mostly found in the middle stream and few locations of the upstream. However, class 5.41–6.07 colored brown, 6.07–6.72 colored dark brown, and 6.72–7.38 colored purple are classified as class II which are dominantly found in the upstream of the river. The spatial model proves and elaborates the impact of river plan change on water quality with a spatial distribution showing upstream to be less polluted than middle and downstream. The higher rate of pollution around downstream areas has increases the deterioration water quality level which is having up to class IV of DO concentration. Showing how after all activities of changes and DO reducing, the water flows to the downstream of the river having the worst DO quality as shown in Fig. 10.

The IDW interpolation plot in Fig. 11 shows a range of TSS across Terengganu River based on water quality. The class I TSS value is found in most parts of the river which are classified into 0.40–7.65 colored dark green, 7.65–14.90 colored green, 14.90–22.15 colored yellowish brown, and 22.15–29.40 colored light brown, while class II is found in the middle stream and downstream of the river which is categorized as 29.40–36.65 colored brown, 36.65–43.90 colored dark brown, and 43.90–51.15 colored dark purple. Thus, the worst TSS quality during the wet season is class III ranging from 51.15–58.40 colored purple and 58.40–65.65 colored pink; these ranges are mainly found in the downstream and a small portion of the middle stream. The TSS value is higher at the downstream because the sediments flow to the downstream along with the water. According to the analysis and evidence to Fig. 12, the WQI for the wet season has a single water quality class. The upstream, middle stream, and downstream have all fallen under class III with a slight difference in terms of the values. Moreover, some values range from 62.11

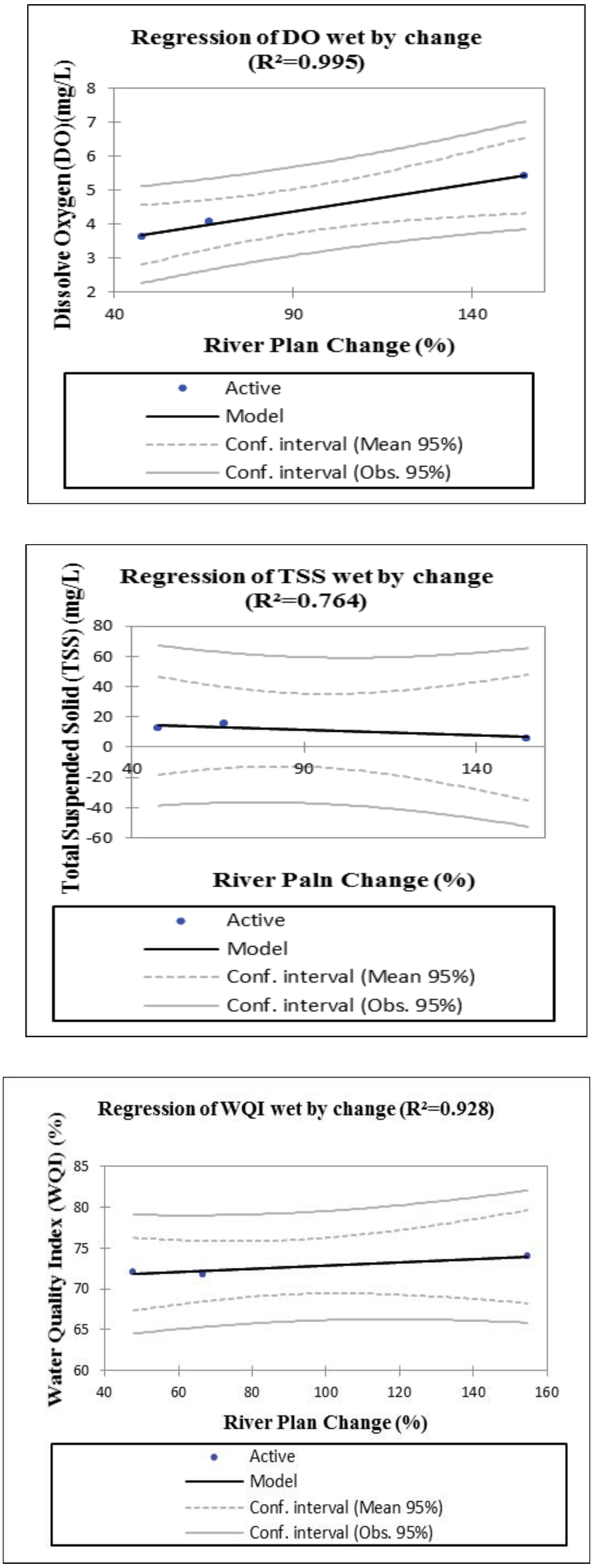

Fig. 8. Regression plots for wet season in Terengganu River.

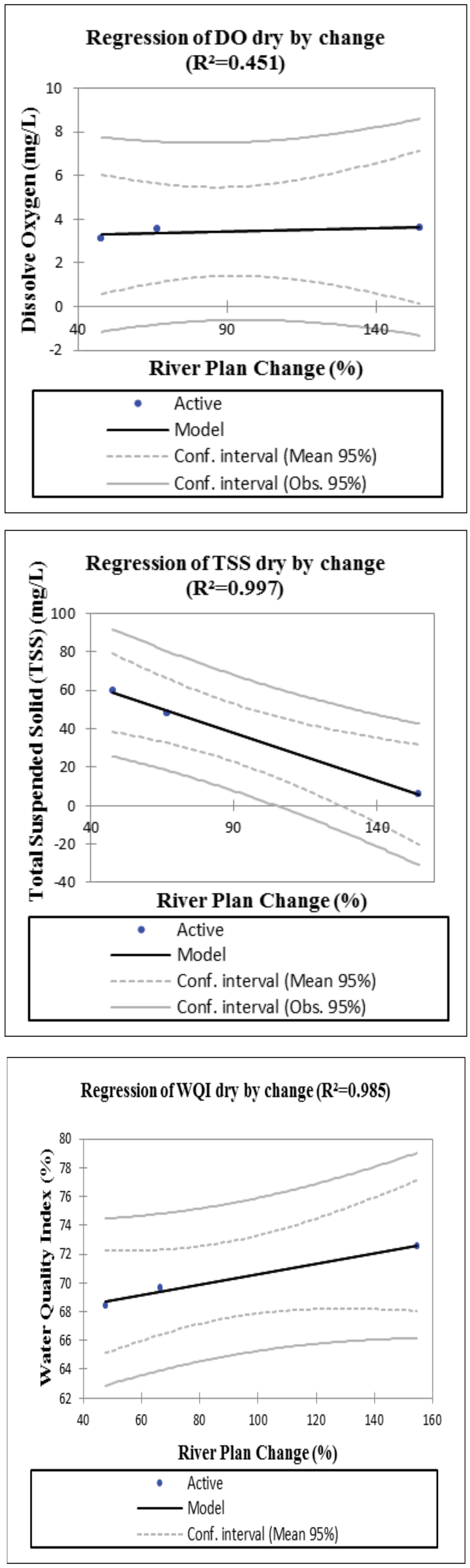

Fig. 9. Regression plots for dry season in Terengganu River.

to 63.58 colored dark green which are more severe and are mainly at the downstream of the river while others have a better range up to 73.89–75.37 colored pink which are mostly at the upstream and middle stream. The variation in the WQI value is affected by anthropogenic factors. Example River areas and areas around agricultural land around cities get more polluted than those that are not [38,39]. Spatial destruction proves a parallel result as Class III of WQI with a few variations to the river plan change in water quality is higher compare others. Moreover, based on a perfect relationship of river plan change with water quality, Fig. 12 shows the fluctuation of river plan changes with respect to different locations in Terengganu River. Proving the relationship of river plan change with water quality, showing worst WQI results where river plan has high changes based on evidence from Figs. 5–6.

For the dry seasons, Fig. 13 shows the range of DO quality across Terengganu River during the dry season. The quality of DO varies from upstream to downstream, each having different water quality standards as a result of different contributing factors or pollutants from each location. Moreover, the upstream of the river has a classification of 5.62–6.03 with dark green, 5.21–5.62 with green, 4.79–5.21 with light green, 3.96–4.38 with yellow which are class II and class III, while the middle stream DO ranges from 3.55 to 3.96 with light orange, 3.13 to 3.55 with orange, and 2.72 to 3.13 with dark orange which are class IV and the downstream ranges from 3.13 to 3.55 with orange, 2.72 to 3.13 with dark orange, and 2.31 to 2.72 with red which are also class IV. It shows the upstream to be less polluting while the middle and downstream are more polluted. But it is important to note that based on the result of relationship between river plan change and water quality, the spatial distribution proves river plan change to have a minimal relationship with water quality. By showing a concentration of the worst DO quality where river plan has the lowest change as shown in Fig. 6.

Fig. 14 shows the TSS distribution for the dry season across the river. The TSS value of Terengganu River is categorized as class I, class II, and class III according to the results found. Furthermore, class I values range from 0.43– to 14.48 with dark green and 14.48 to 28.53 with light green which are mainly found at the upstream of the river and minimally discovered in the middle stream, while class II is reaching from 28.53 to 42.58 with brownish yellow and 42.58 to 56.63 with light brown found in the middle and downstream. Lastly, class III with fields of 56.63–70.67 with brown, 70.67–84.72 with dark brown, 84.72–98.77 with dark purple, 98.77–112.82 with light purple, and 112.818–126.866 with light pink classes are found at the downstream and few locations of the middle stream. Spatial distribution model proves TSS to be more polluted in dry season than wet season. Furthermore, this proves the high effect of river plan change to TSS example plot 6 which has the highest change of up to 20% as shown in Fig. 6 with a TSS range of 112.82–126.87 colored light pink as shown in Fig. 14. This brings us to a conclusion that the

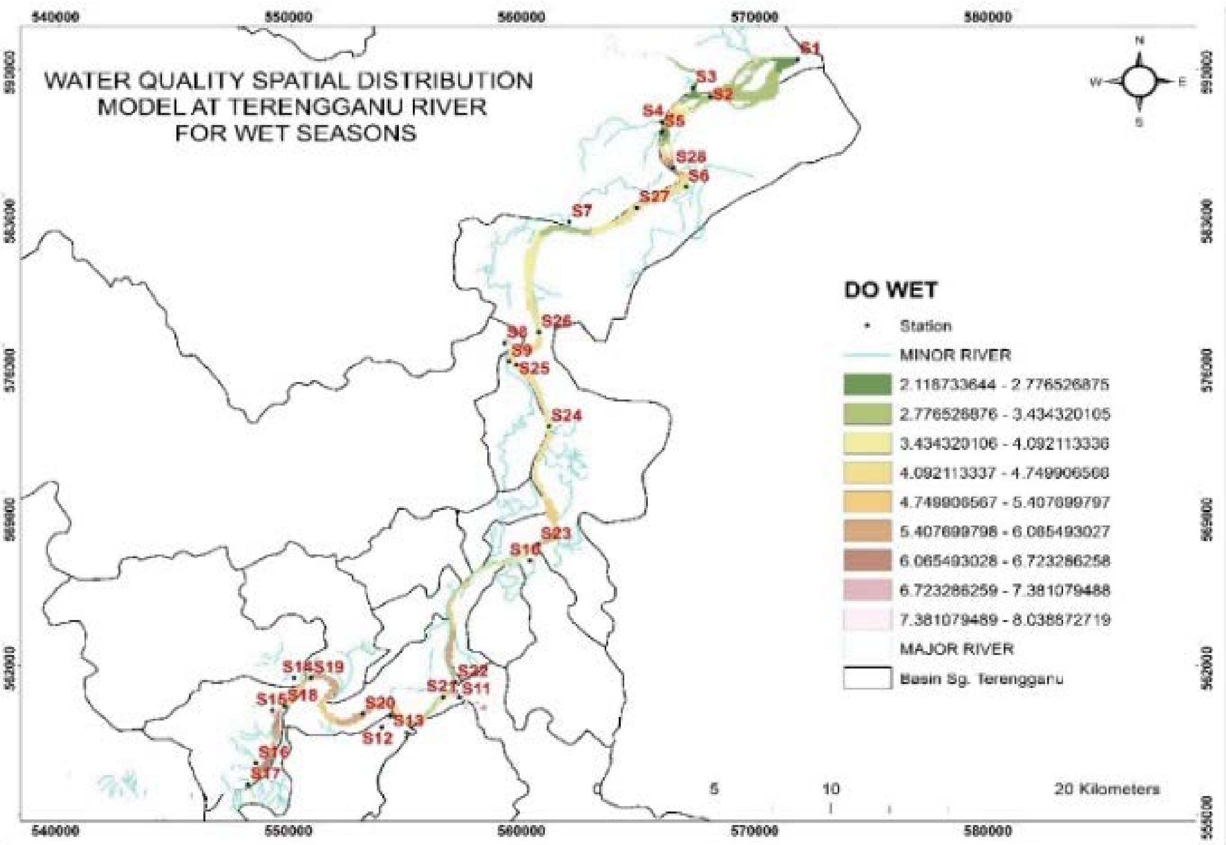

Fig. 10. Spatial distribution model of DO during wet season in Terengganu River, Terengganu.

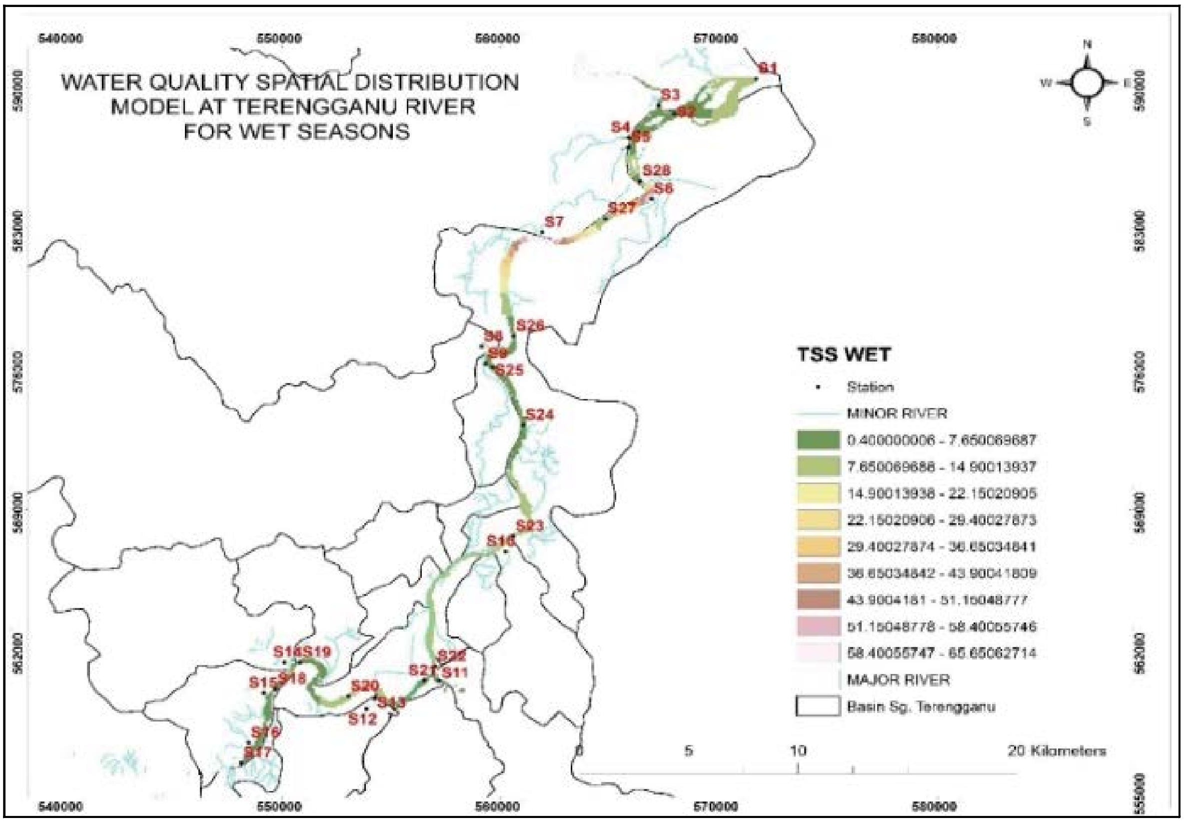

Fig. 11. Spatial distribution model of TSS for wet season in Terengganu River, Terengganu.

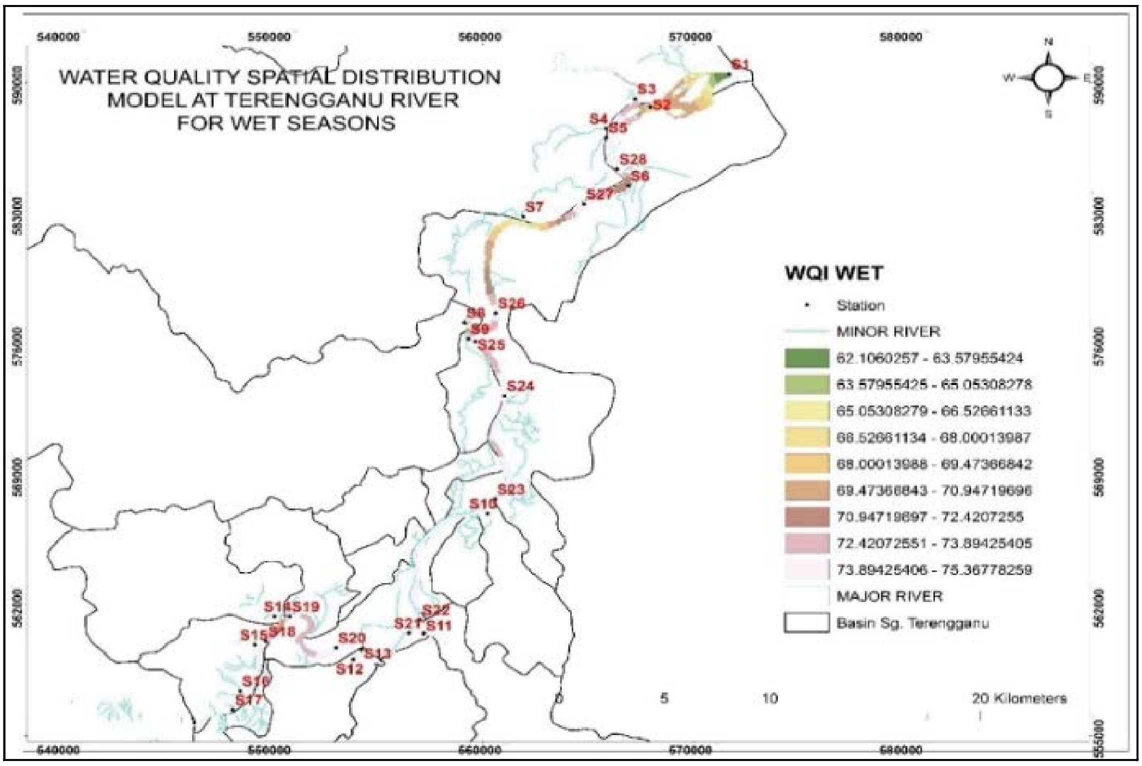

Fig. 12. Spatial distribution model of WQI for wet season in Terengganu River, Terengganu.

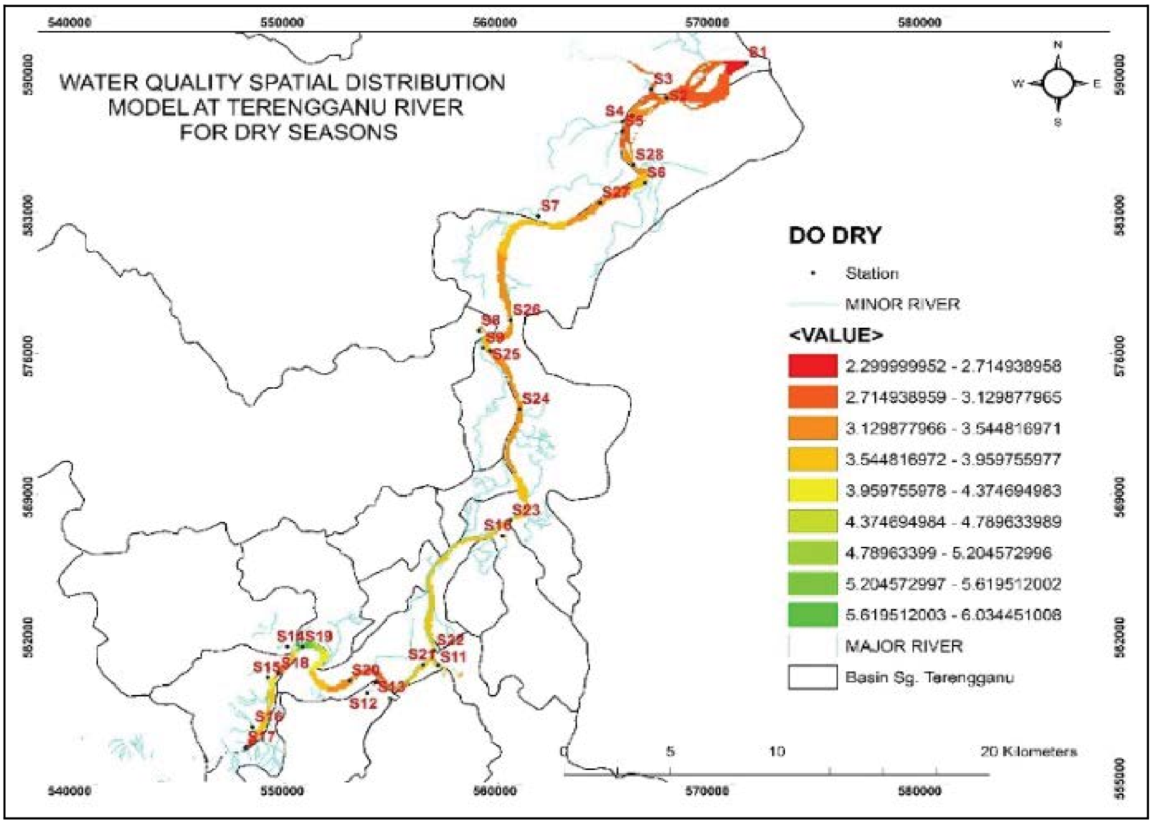

Fig. 13. Spatial distribution model of DO for dry season in Terengganu River, Terengganu.

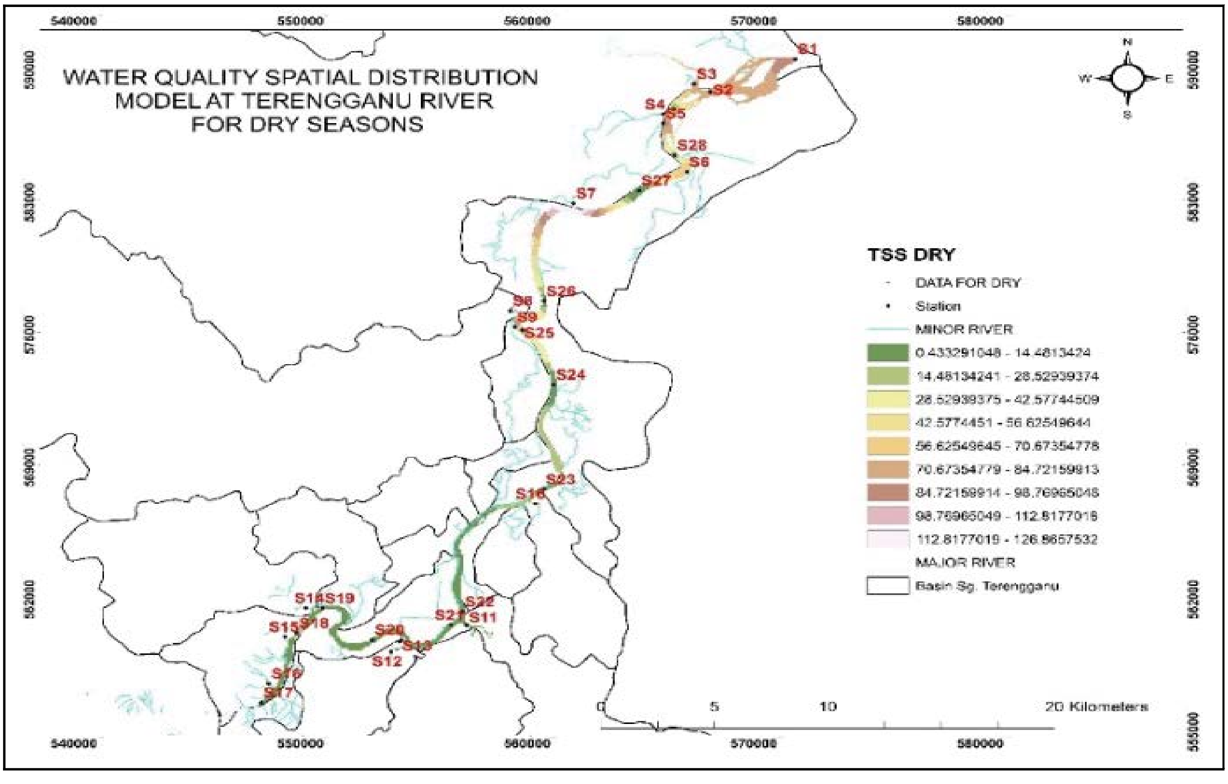

Fig. 14. Spatial distribution model of TSS for dry season in Terengganu River, Terengganu.

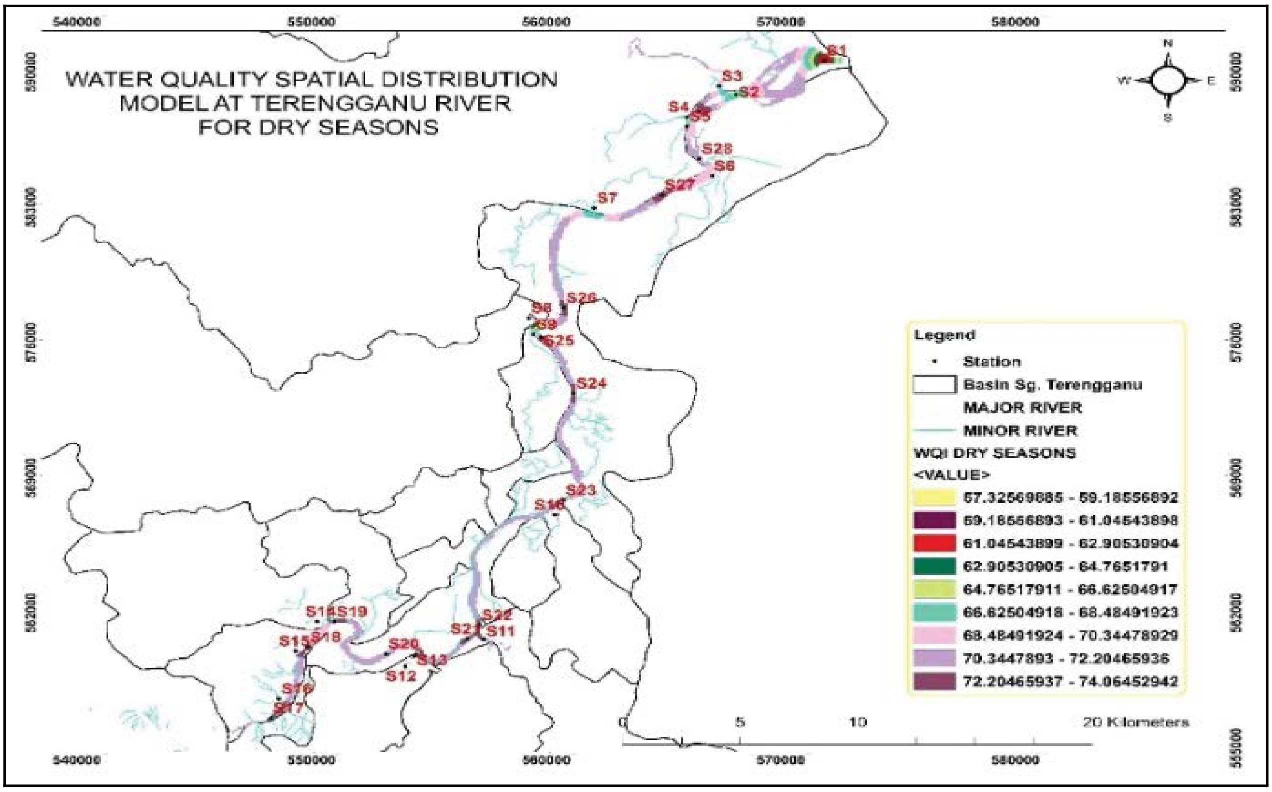

Fig. 15. Spatial distribution model of TSS for dry season in Terengganu River, Terengganu.

distribution is as a result of changes in river plan and effects on TSS water quality distribution.

Fig. 15 shows the WQI distribution for the dry season. However, the upstream, middle stream, and downstream have all fallen under class III with the difference in terms of the values. Additionally, some values range from 57.33 to 59.19 with yellow which are more severe and are predominantly at the downstream of the river while others improve to a better range up to 73.89–75.37 colored purple which is mostly at the upstream and middle stream. This is as a result of variations in the changes of river plan as it affects the WQI. The change rate of river plan change is shown in Fig. 6 which is related to the WQI and proven in Fig. 15, which also signifies the distribution.

The spatial interpolation has been used with the aid of ArcGIS to elaborate critically the distribution of water quality in Terengganu River, showing the range of water quality from clean to polluted with respect to locations. Besides that, the relationship among the river plan change to water quality parameter (DO, TSS, and WQI) determined along Terengganu River Basin showed from the previous findings. All Three parameters DO, TSS, and WQI have been analyzed and discussed for both wet and dry seasons, showing their difference and distribution from upstream to downstream of the river with reasons and proof.

4. Conclusion

Based on the results obtained, Terengganu River has shown a high inconsistence on its riverbanks with high evidence of river plan change with regard to both increase and decrease. An effect has shown increase as high as 154.67 ha and decrease as much as 17.90 ha. Additionally, water quality of Terengganu River requires extreme treatment based on findings, which have a strong correlation with river plan change.

Results on spatial model have also revealed areas where river plan change has high effects on water quality and places with less effects. However, authorities and related agencies should also note that river plan change is a contributing factor to the pollution of water quality and not to have all attention on anthropogenic and other natural factors.

This study is significant for river construction and short- or long-term planning, similarly help in the safety, management, and other regulations that may be applied by local authorities alongside relevant stakeholders

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