Original Research Article

IMPACTS OF FLOOD SIMULATION IN 3D AND SWAT ENVIRONMENT OF TERENGGANU RIVER CATCHMENT

Abstract

Flood is natural hazard influenced by climatic and anthropogenic factors. The Terengganu River catchment is located near the South China Sea has been flooding during heavy monsoon season with strong rain-bearing winds to the interior coastal zones of Kuala Terengganu. The ArcSWAT extension of ArcGIS 10.3 and ArcScene 10.3 has been used to design 3D models simulations to predict flood risk event through the stream flow and elevation data derived from ASTER DEM. The Hydrologic Response Units (HRUs) provided the sub-basins parameters which are overlaid with the real-time simulations to determine which sub-basins are affected by flood risk. The flood animation is developed for mitigation and quick decision making for safety and evacuation of flood victims in the Terengganu River catchment. The 3D simulations produce flood risk zones models which illustrate the affected zones by the flood. The 25 sub-basins parameters have distinct characters which influence the stream flow, soils, slopes and land cover. That represent areas affected by flood in Kuala Terengganu. The 25 sub-basins parameters have unique characteristics that influence the river flow, land cover, soil and slopes.

Keywords: Flood, Simulation, Sub-basins, Modeling, Planning

Keywords: Simulation, HRUs, Flood 3D, Modeling

Introduction

Flood has been affecting human habitats creating the unsustainable environment. The current study about hazard event in many cities, towns or villages can never be overemphasized due to the fact that climatic conditions are not static. The presence of land covers as well as the geographical settings as tremendous effects on the flood. There is need to highlight the removal of vegetation cover or the types of land cover which may influence flooding, the soil and water assessment tool will monitor the hydrologic response units (HRUs) and the subdivision of the watershed sub-basins within the drainage basin of river Terengganu. There is an issue of excessive use of land cover by an anthropogenic factor for the purposes of agriculture, urbanization as well as other benefits that change the topography. We intend to develop a sustainable land cover system to reduce the rampant overuse of natural land cover through mitigating and create awareness to avoid a flood in the flood-prone areas within the scope of this study. The Geographic Information System (GIS) will be applied in acquiring spatial and non-spatial data. The river flows are quite high during the monsoon, and the water level becomes high, therefore, digital elevation model (DEM) was used to simulate the flow direction at a regular interval in ArcScene. We need to get informed or be informed about the aftermath of flood event as quickly as possible, so as to assess the magnitude of the flood. Flood is a most severe hazard in Malaysia [1]. The study is aimed at highlighting the vital contribution of flood simulation, as well as to serve as a warning and alert to Terengganu inhabitance.

The issue of flood disaster is a global phenomenon that requires attention in other to control life and properties. There is need to monitor the activities of the flood by applying the modern technology of Geographic Information System [2]. The system will assist in mitigation and controlling flood. Many people died and lost their properties as a result of flooding. This study will serve as an eye-opener to people who are vulnerable to flood disasters. Society has become more vulnerable to natural hazards. Although floods are natural phenomena, human activities and human interventions have been affecting the processes of nature such as alterations in the drainage patterns of urbanization, agricultural practices, and deforestation have considerably changed the situation in whole river basins. At the same time, exposition to risk and vulnerability in flood-prone areas have been growing constantly. Flood events are part of nature; they have always existed and will continue to exist. With the exception of some floods generated by dam failure or landslides, floods are climatologic phenomena influenced by the geology, relief, soil, geomorphology and vegetation conditions [3]. Currently, there are advances in the application of Geographic Information System (GIS) in the field of water resource and watershed modeling. The potentiality of the GIS technology was showcased over the years, and nicely displayed the results for future analysis [4] [4]. Distribution of integrated process in models provides wonderful and powerful tools for decision making in understand the overall management of drainage basin. The modeling process provides an insight on the nature and distribution of hydrological processes in a watershed.

Hydrologic Respond Units (HRUs)

The incorporation of HRUs non-spatial in SWAT has supported adaptation of virtually most of the watershed model. The recognition of size ranging from small field to entire river basins in HRUs within sub-watershed is relevant because it keeps the model dependent by allowing soil and land use heterogeneously equal. However, there is a limitation in simulating waterways of grasses because of the channel routing is not simulated at HRU level [5].

According to [6], SWAT contains climatic inputs such as daily precipitation, maximum and minimum temperature, relative humidity, solar radiation, and wind speed.

Materials and Methods

Study Area

The study area covers most of the parts in Kuala Terengganu located at the approximate boundary of South China Sea from the North East, Kelantan to the west, Kuala Terengganu has an area of about 60528.1 [Ha] and is the district in the state of Terengganu as shown in figure 1. Geographically the city is situated at the estuary of Terengganu to the eastern part faces the South China Sea. The study area is located at Lat 5°27'4.05"N, Long 103° 2'47.04"E Lat 5°16'51.43"N, Long 103°10'39.30"E, Lat 5°13'14.65"N Long 103° 1'56.06"E, Lat 5°21'27.38"N, Long 102°53'13.88"E. Terengganu has the largest population of 406,317 in 2010. It was named to Kuala Terengganu with the title *Bandaraya Warisan Pesisir Air* (English: Coastal Heritage City) on 1 January 2008.

Figure 1: Map of the study area, Terengganu River catchment

The image from the remote sensing data was acquired and is one of the prerequisites. The topographic data from was acquired through the use of digital elevation model (DEM) which has been received from Advanced Space-Borne Thermal Emission and reflection Radiometer (ASTER). [7]. The ASTER DEM for this study has a spatial resolution of about 30 meters. Another rainfall data variable were computed from 2000 to 2010 in from the agency which handles flood in Malaysia," Drainage and Irrigation Department Malaysia (DID) and analyzed based on the catchment parameter. The ArcSWAT were used to simulate the result by inputting the available data from the weather, rainfall and soil Zhang et al. (2009). These techniques will ensure that the output data will be a model useful for further studies.

Data Requirement

The different application uses different data variable for modeling spatial data. This includes

1. ASTER DEM
2. Global Land use/Land cover data
3. Soil data
4. Weather parameters

Figure 2: Flowchart

Result and Discussion

The Impacts of Hydrologic Response Units (HRUs) on Flood Risk Zones in Terengganu River Catchment

The hydrologic response units (HRUs) are one of the components in the catchment or watershed studies that explain the relationship between the different hydrological units. The Arc SWAT interface was able to generate results of a particular watershed under study. In this study, we employ the assessment of impacts of HRUs in different sub-basins parameters to determine how flood risk zones.

Base on the results obtained from ArcSWAT, there are many impacts of hydrologic response units can be deducted. These include;

1. Land cover impacts
2. Local Soil impacts
3. Slope impacts
4. Flood impacts

And individual sub-basins impacts on flood risk.

Impacts of land cover on flood risk in Terengganu River Catchment

Land use/cover is one of the important parameter found in the study are of Terengganu River catchment. The land cover found in the Terengganu River catchment is locally sampled. This includes Water body (WTBY), Oil Palm (OILP), Orchard (ORCD), Rubber Trees (RUBR), Grassland (GRSS), Forest Evergreen (FRSE), Residential High Density (URHD) and Residential Low Density (RLD) as in figure 3. Table 1 presents the summary of the land cover of Terengganu River catchment. The watershed is occupied by Forest evergreen with a total area of 73.93%. We are concerned with the effects of land covers and the vital impacts produced by it. This indicates that vegetation covers is denser and have an influence on plant growth and runoff in Terengganu. The water movement especially the surface runoff affects the soils in sloppy gradient. Another impact of land cover is the modification of climate. The green plants (in tropical equatorial climate) have luxuriant sunshine for photosynthesis; the plant enjoys and continues its growths. More importantly, there is a reciprocal relationship in gaseous exchange of carbon dioxide and oxygen. The plant's litters contribute to the organic contains to the soil.

Table 1: Impacts of land cover on Flood Risk Zones

Figure 3: impact of land cover on flood risk

The land cover is attached to the sub-basins parameters to see how individual subbasin is influenced by it. The overall development of land-use is applicable to different sub-basins. Figure 4 displays the impacts of land cover on the individual sub-basin parameter. The more the land cover types presented in the sub-basins, the more influences impacted on it. For example, the sub-basin number 3, 5, 7, 8, and 18 are having more impacts of different land covers such as oil palm, rubber and paddy land. While subbasins number 6, 10, 12, and 13 are impacted by the large artificial Lake Kenyir. The water body has a tremendous impact on those sub-basins by influencing the water supply which determines attraction through tourism. These are confined within the flood free zones as explained in figure 4.

Figure 4: impacts of land cover on sub-basins

The more the land covers are fully represented the more it influences water movement, retention as well as surface runoff. Therefore, the sub-basins that are devoid of land cover might experience flood due to absent of forest canopy. We can observe that the lower regions of Terengganu where there is very high flood risk are not fully covered by forest land cover, perhaps due to the slope gradient and the soil composition coupled with urbanization.

Impacts of Local Soils on Sub-basins and flood Risk Zones in Terengganu River Catchment

The soil is a loosed surface material found on the Earth surface which is developed in-situ. There are many impacts of soils that have contributed in the drainage basin, especially the local soils found at certain locations of the study area. Terengganu River catchment is characterized by the following local soils: Kuala Brang, Marang, Rudua, Telemong, Tok Yong, Peat and steep land. Each of these local soils has different characteristics of structures, porosity, water retention capacity, soil profiles, and many others. For the purpose of this study, 7 different local soils were discovered within the Terengganu catchment. The impacts of these local soils on individual subbasins are presented in table 1. The highest local soil in Terengganu is the steep-land with about 69.85%.

According to the Malaysian Standard, Steepland (MS 1759 2015) SM 1001, these are land showing average slope exceeding 25 degrees. The soil is formed due to erosion and unsuitable for agriculture. It has a miscellaneous soil contain that soak little water there has less impact on flood since the water drains away from the soil. Peat (MS 1759 2015) GA 1200, this type of soil is derived from organic matter that contains organic materials of about 50 to100 cm of the soil profile. It is also called Histosol it has a very low impact on the flood. Tok Yong, (MS 1759-

2015) SF 1366, this type of soil is formed from the alluvium recent riverine brown, fine sandy clay. It is characterized by well drain soil porous to water. Flooded zone with this type of soils has little time for flood water to drain away. It is also called ultisol. Kuala Brang, (MS1759-2015) SF1154 this is well-draining soil is derived from brown shale and characterized by the rock fragment or saprolite. Flood impacts are high on this type of soil because it allows water to drain quickly.

Rudua (SB 1022) is another type of local soil found in the catchment area of Terengganu. It is characterized by sandy beach ridges in other word is called spodosols. Therefore, this soil is easy to drain and wash away. Flood water does not retain for a longer time.

Telemong (MS1759-2004) SK 1041, this is sandy loam, yellow-brown easily drained at low saturation. The soil is characterized by large pore spaces that soak water. For the flood impacts, this soil allows water to past through easily. It occupies the areas of very high flood risk in the lower zones of Terengganu River catchment.

Marang (MS1759-2004) SF1193 is one of the families of fine siliceous loamy yellow Alik Tualembuts. It is richly developed from the iron-poor sandy shale. It is characterized by the pale yellow, olive, clay loamy subsoil, and fine sandy at the top. It impacts on flood is the deposition of clay particles on the buildings and road after the flash flood Panton (1958)[8] and [9][10].

The local soil impacts are base on the individual sub-basins found in the Terengganu catchment. The 25 sub-basins parameters showing in figure 5 below indicate the position each soil occupies within the Terengganu River catchment. For instance, sub-basin number 3 is located on Telemong soil, sub-basin number 4 is on Tok Yong and sub-basin number 5 is located on Rudua. Base on this analysis we can detected and predict the characters of different soil through it structure, profile, component and so on to ascertain the activities of flooded water. If the local soil has more water retention capacity, then the (clayey soil) the flood event will last for long because the water cannot soak away in time. And the clayey structure of the soil will have an impact on tar roads, buildings which can stick to the wall and many labours must be employed to curtail the problems.

Figure 5: impacts of local soils on individual sub-basins

The 7 identified local soils in Terengganu catchment have tremendous impacts aside from the sub-basins parameters. The categories of soils in particular flood risk zones were distinct from one another base on the local soil characteristics and composition as seen in figure 6 for comparison; we can select the types of soils from individual subbasin and discuss its effects and impact on the different flood risk zones within the watershed

Figure 6: Local soil impacts on flood risk zones

Impacts of Slope on Flood risk Zones in Terengganu River Catchment

The impacts of the slope are quite different from the digital elevation model (DEM). The DEM defines the elevation of an area base on height above sea level while slope is the degree of steepness of a given land. The Terengganu DEM depicts from 1m to 1542m. The lower DEM is, of course, originated from the area near the South China Sea. The peak DEM is found around the steel and located on the southern coast of Malaysia. As shown in figure 8 below the minimum slope range that has more flood risk impact is from 1 meter and above.

The impacts of the slope are much more advance toward the South China Sea where the slope is too sloppy for 1m. This region is found to be susceptible to flooding and is located in the zones of very high flood risk, the lower the slope, the higher the flood risks. In this study, the slope data was generated from the ArcSWAT analysis confined in the hydrologic response units. The Terengganu River catchment has been classified base on the slope land slope values of 0-1m, 1-2m, 2-4m and 4-999m. The raster data was grouped base on the values of the 4 classes as shown in figure 8, the slope impacts are more from 1m and above.

The individual slope impacts of sub-basins parameter are found mostly within the sub-basins number 3,4,5,6 and 7 as shown in figure 7 below.

Figure 7: impact of slope on individual sub-basin

Most of the slope impacts in the study areas are more pronounced on flat land, buildings below 1m, roads, and urban populations near the river banks.

Impacts individual Sub-basins on Flood Risk Zones in Terengganu River Catchment

Comparing the impacts of hydrologic response units in Terengganu River catchment, the subbasins are different parameters. Different sub-basins have different HRUs and that their impacts also vary at different levels, for instance, sub-basin number 1 might have different soil composition, land cover and slope gradient than sub-basin number 2 and vice-versa.

The sub-basins density as shown in the figure 10 displays the result obtained from the ArcSWAT. The sub-basins are classifies into 5 classes; 1-5, 6-10, 11-15, 16-20 and 21-25. The impacts of the sub-basins density can be analyzed base on the lower slope density of very high flood risk zones near the South China Sea as we can see in the illustrated figure 8, subbasins number 3, 7 and 18 found on the very high flood risks zones.

Figure 8: sub-basins density of Terengganu river catchment.

The individual sub-basins parameters can be identified through the symbolized length of individual sub-basins as shown in figure 9 below. The areas occupied by these sub-basins vary from one another depending on the geographical locations sites and situations.

Figure 9: classification of sub-basins base on length and area

The impacts would have to be on stream flow, soil structures, land cover density and receiving rainfall intensity. The results obtained from this study, have categorizes the individual subbasin in Terengganu River catchment refers to figure 10. The SWAT HRUs, is capable of identifying all the Sub-basins parameters. All the sub-basins (25) have unique values and characteristics that influence river flow and the flood risk hazard.

Figure 10 Individual sub-basins parameters and their impacts

Conclusion

One of the effective ways of flood monitoring is to see it physically occurring or happening in real-time. The solution is to set the model at the simulation in the 3D environment. The Terengganu River catchment was successfully delineated and simulated using the sub-basins to identify zones that are affected by the flood risk. The impacts of flood risk usually take place during the monsoon period, especially in Peninsular Malaysia. The Terengganu catchment is liable to flooding during the period of monsoon. The average rainfall during flash flood reaches to 3000mm of rain, with more than 24 hours of a continuous heavy rain shower. The flood event mostly affects peninsular Malaysia between Decembers to January.

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Table 1: Impacts of land cover on Flood Risk Zones

The Land Use, Soil, Slope Distribution

Detailed LANDUSE/SOIL/SLOPE distribution SWAT model class Date: 13-Jun-17 12:00:00 AM Time: 05:29:00.1098602

Number of Subbasins: 25	**Watershed**	**Area [ha]**	**Area [acres]**	
		286,507.3500	**707,973.9872**	
LANDUSE:		**Area [ha]**	**Area [acres]**	**%Wat. Area**
Water	WATR	42,684.6541	105,475.9145	14.90
Oil Palm	OILP	13,251.0778	32,744.0757	4.63
Paddy	PADD	3,209.3467	7,930.4563	1.12
Orchard	ORCD	46.8465	115.7601	0.02
Rubber Trees	RUBR	11,981.4471	29,606.7548	4.18
Residential-High Density	URHD	3,346.7332	8,269.9450	1.17
Residential-Low Density	RLD	167.2060	413.1745	0.06
Grassland	GRSS	10.9008	26.9365	0.00
Forest-Evergreen	FRSE	211,809.1378	523,390.9698	73.93
SOILS:				
KUALA BRANG		35,604.8842	87,981.4491	12.43
MARANG		26,762.6042	66,131.7330	9.34
PEAT		4,732.3090	11,693.7721	1.65
RUDUA		1,357.6481	3,354.8163	0.47
STEEPLAND		200,117.6886	494,500.8145	69.85
TELEMONG		10,250.0178	25,328.3066	3.58
TOK YONG		7,682.1981	18,983.0956	2.68
SLOPE:				
	0-10	62,167.7600	153,619.6434	21.70
	10-20	59,973.9917	148,198.7322	20.93
	20-30	54,392.6797	134,407.0312	18.98
	30-40	43,842.4838	108,336.9695	15.30
	40-9,999	66,130.4348	163,411.6109	23.08

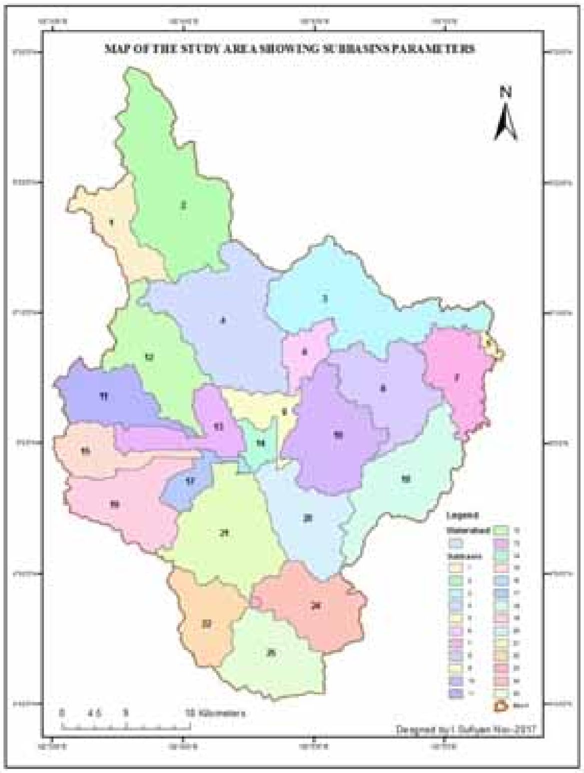

Figure 1: Map of the study area, Terengganu River catchment

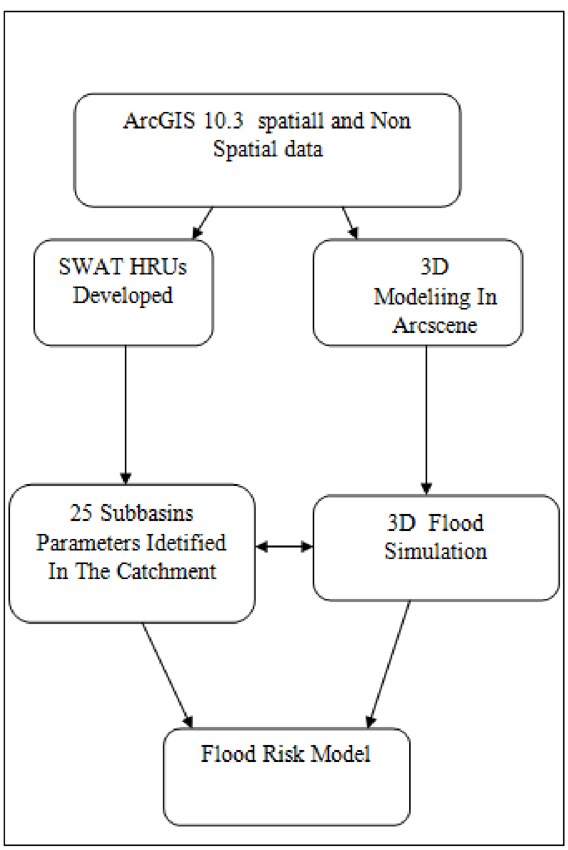

Figure 2: Flow chart

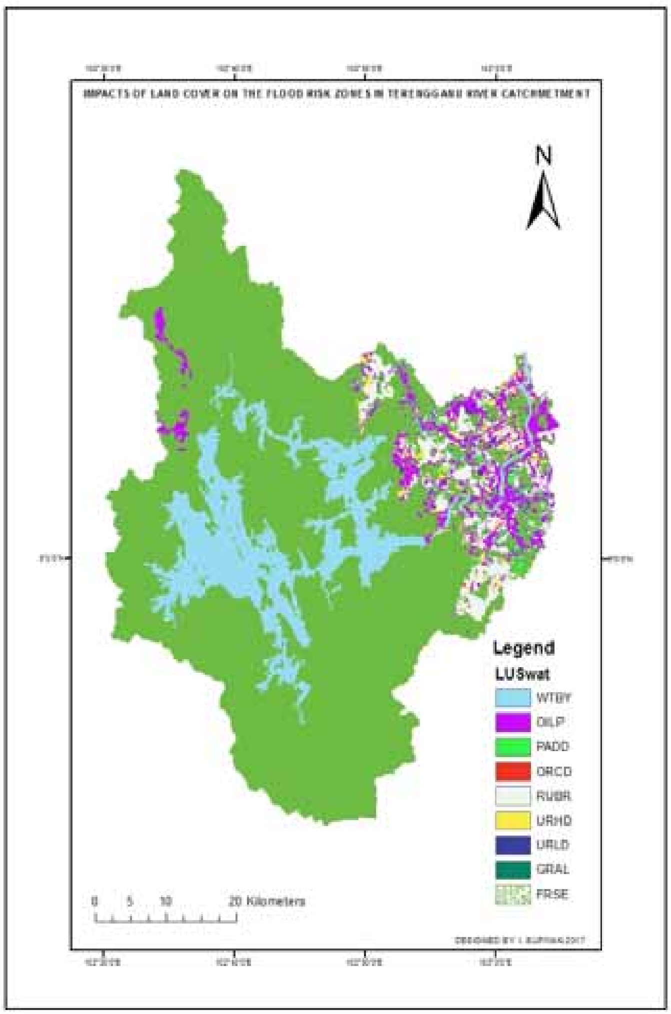

Figure 3: impact of land cover on flood risk

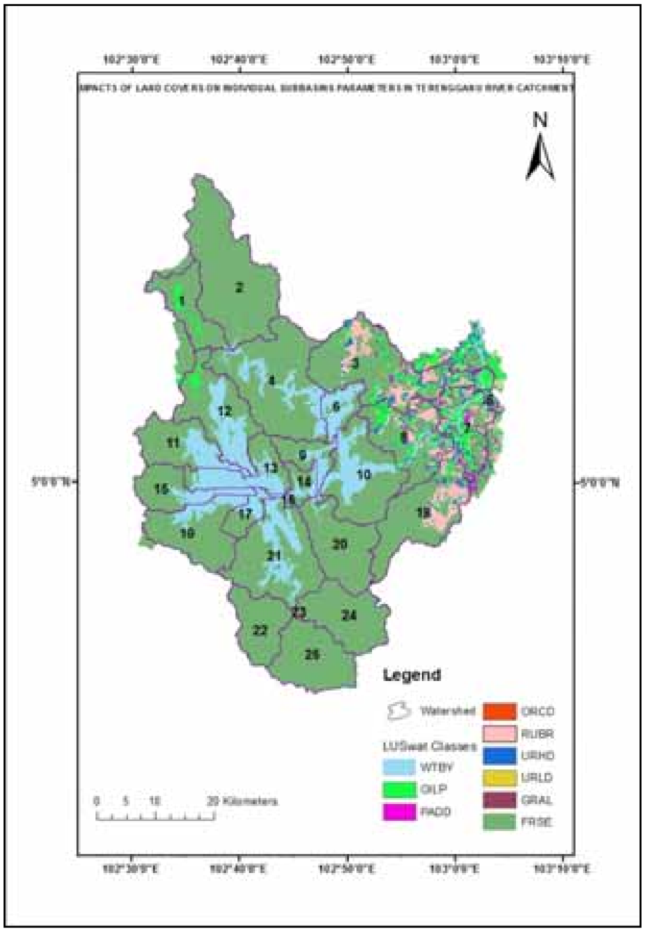

Figure 4: impacts of land cover on sub-basins

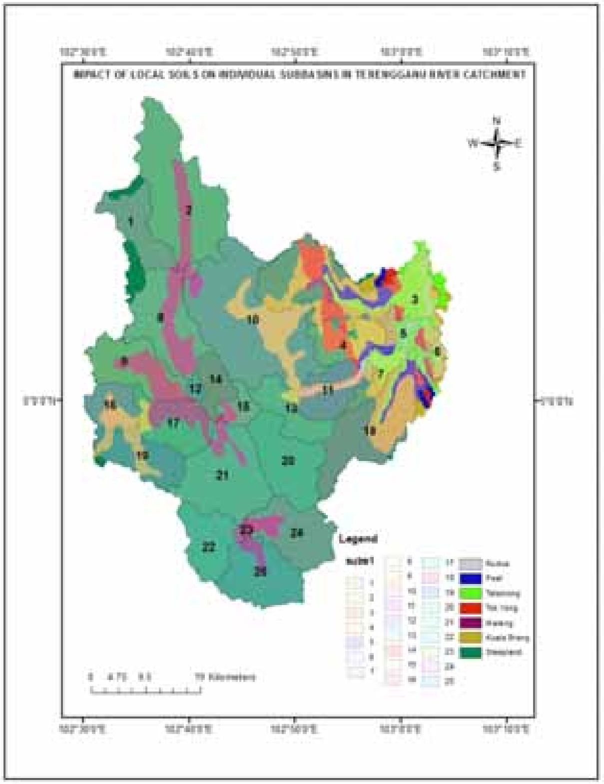

Figure 5: impacts of local soils on individual sub-basins

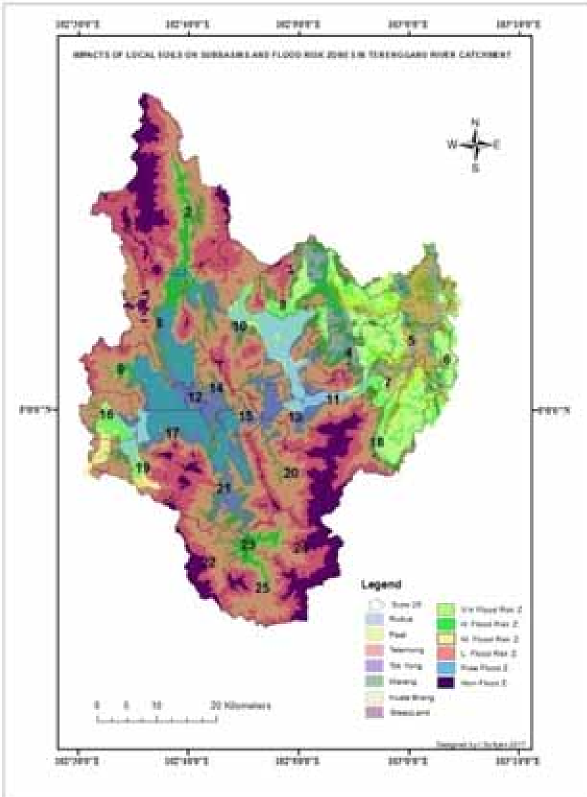

Figure 6: Local soil impacts on flood risk zones

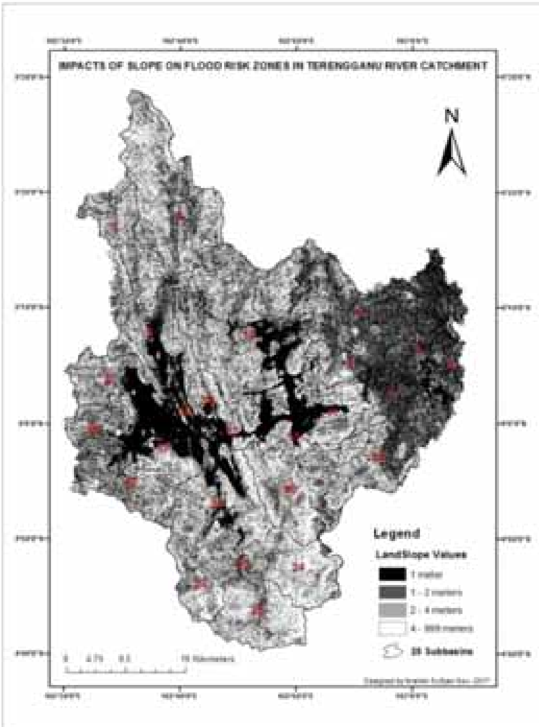

Figure 7: impact of slope on individual sub-basin

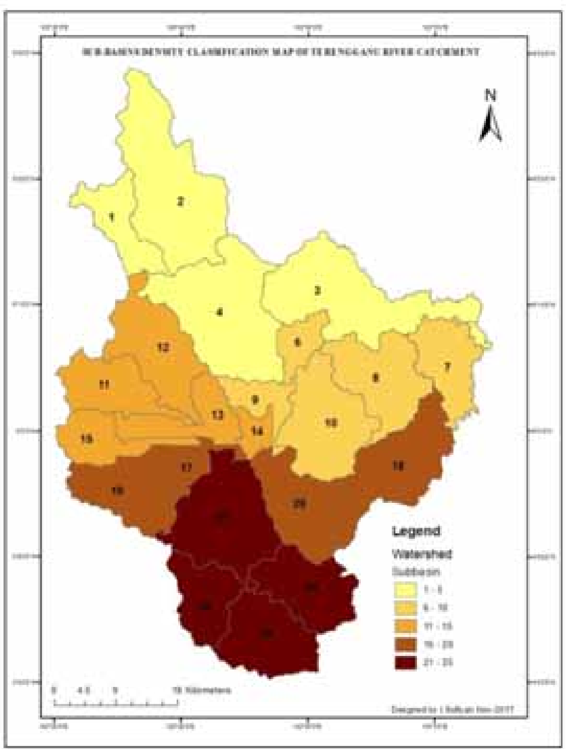

Figure 8: sub-basins density of Terengganu river catchment.

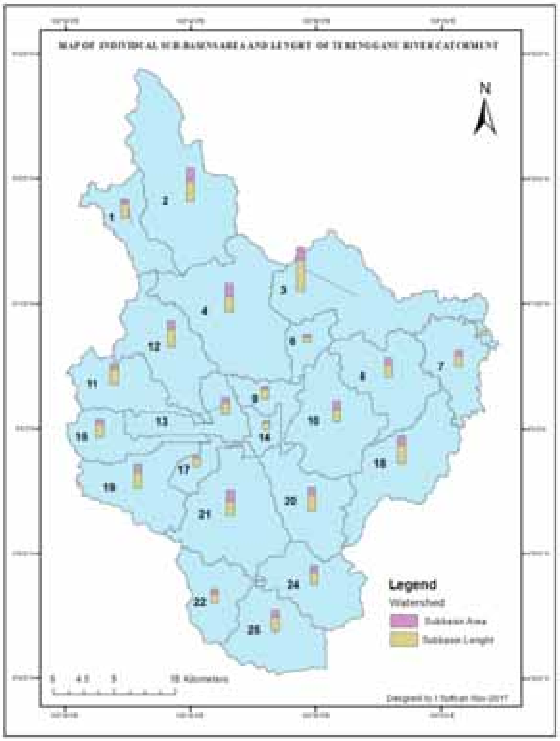

Figure 9: classification of sub-basins base on length and area

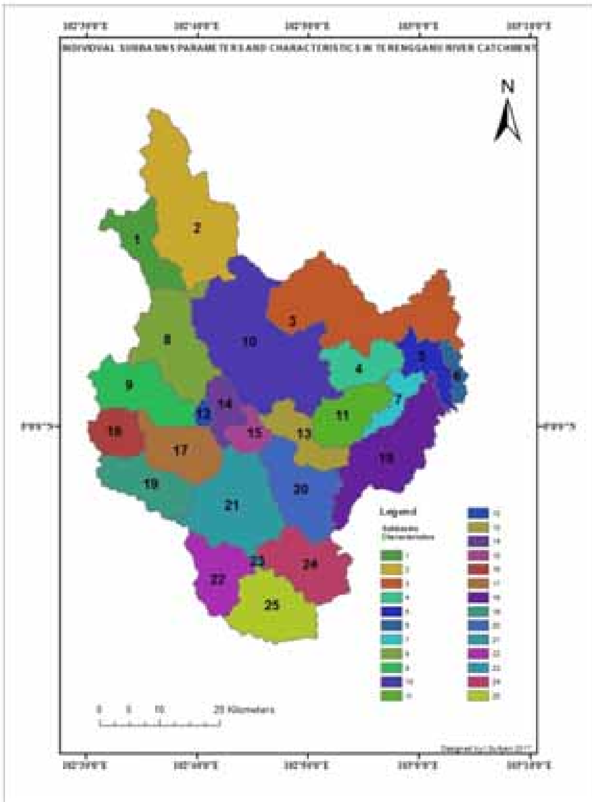

Figure 10 Individual sub-basins parameters and their impacts