Review Paper

Comment [IAC1]: Please note that the edits provided in this manuscript are only meant to guide the necessary major revision: to be used only as a model to improve the paper; the edits are not the only needed revision. The entire manuscript need to be revised. Please use that model to revise the entire manuscript.

ANALYSIS OF HYDROLOGIC RESPONSE UNITS AND IMPACT OF FLOODING RISK IN KUALA TERENGGANU SUB-BASINS RIVER CATCHMENT IN MALAYSIA

Abstract

Triggered by high intesity rainfall, flooding is one of the fundamental environmental disasters occurring in wet tropical environments. Flood is the most frequent natural catastrophe in Peninsular Malaysia, particularly in Kuala Terengganu. In this region, flooding is triggered by the monsoon rains, which inundate riverbanks and displace inhabitant rendering them homeless. The application of Soil Water Assessment Tool (SWAT) to identify the Hydrologic Response Units (HRUs) and flood vulnerability within the Terengganu sub-basins river catchment area was done using the most affected sub-basins. In this study, the impacts of f~~.~~ ~~F~~ive out of the 25 sub-basins ~~are~~ visualized ~~have~~ as affected by high flooding risk are ~~and the impacts of each of them are~~ obtained. The sub-basins are affeected by flood risk are sub-basin 3, 5, 7, 8 and 18. The high flood risk impact was found in sub-basin 3, and less impact was in sub-basin 5. The higher the intensity of rainfall the more and water flow and the more sub-basins are flooded within the catchment.

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Keywords: flood, climate, SWAT, Catchment, Sub-basin

Introduction

According to [2] flood can be defined as a high water flow arising naturally or artificially from the river bank that dominates the surrounding area to cause overflow. The high flow of the water may extend over the floodplain and it becomes a hazard to the society. Flood risk is one of the world's fundamental problem and issues with a range of consequences including economic, political, social, psychological, ecological and environmental damages and manages to cultural heritage. There is substantial literature that provides evidence of existing damages caused by the flood but the recent application of 3D simulation has brought a new dimension of solving the complex problem of flooding occurring in a large basin and watershed.

Through application of~~e recent technology of~~ remote sensing and geographic information system (GIS) technologies areas vulnerable to flooding can be ~~has capabilities of~~ located ~~ing~~, analyzed, mitigated~~ing~~, or informatively ~~-~~managed~~ing~~ ~~and analyze areas vulnerable to flood hazard event.~~. This study involved the application of soil water assessment tool (SWAT) to determine the fundamental Hydrologic Response Units (HRUs) as well as to develop watershed delineation within the river catchment area of Kuala Terengganu. The flood mitigation measures require analytical management of the watershed as affluent to engineering approaches in controlling flood risk and hazard in the environment. The use of 3D to develop flood simulation is paramount especially for quick flood alert warning and emergency relief to flood victims.

The attempt to employ modern techniques of software to determine better warning system, decision making as well as mitigation are however incorporated based on hydrological model and Geographic Information System which was considered as the new technology of solving flood problems. Terengganu is located on the east coast of Peninsula Malaysia which is experiencing heavy rainfall during the Northeast monsoon occurs between October and March that has resulted in a flood in most of Malaysia. But most of the coastal areas along the Eastern location including Terengganu were affected by coastal flooding [1] Another flood event that concurrently happened in Malaysia, were in Johor, Pahang, Melaka and Negara Sembilan. It is essential to identify land cover changes and their classification over time for easy comparison [2]. For instance, the forest land cover changes in Peninsula Malaysia. Previous studies showed and indicated a promising result using SWAT as a hydrologic model [3], [4], [5], [6], [7]. SWAT was used to simulate soil moisture in the large River basin in Taxes by [8]. SWAT was also used by [9] to model soil erosion and the impact of sediment reduction. In India SWAT was used to simulate daily rainfall from 1951 to 2014 [10]. [11] described a simulation stream flow impact with SWAT in response to historical land use at San Pedro watershed in South Arizona.

Flood is frequently occurring in the catchment area of Terengganu. There is an issue of flash flood during the monsoon period around November to January most of the year. The flood along the river banks are mostly influenced by the high among of the rainfall while over

Comment [IAC4]: Revise this paragraph letting the reader know what is cited, and what is your own idea.

Comment [IAC5]: Removed "recent" because they are no longer new technologies

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2500mm to 3500mm per annum. This has a lot of impacts on environmental resources such as the land use/land cover, local soil types and the slope. The impact of land cover, soil and the slopes are the primary concern in visualizing the effects of flood risk within the watershed of Terengganu. The land cover detection and changes have influenced the water flow, the sediment yield as well as the concentration of predominant vegetation. The local soils have played an important role in water retention and flow. The slope determines the degree and gradient of the water movement, the particle sizes and erosion. The climate condition of Terengganu is located ($30^{/}.40^{//}$ N, 102^{0} $23^{/}$ $15^{//}$ E and4^{0} $39^{/}$ $25^{//}$ N, 103^{0} $11^{/}$ $62^{//}$ E), experiences high rainfall and high temperature with different vegetation species.

Table 1**:** Malaysian History of Flood Events

Flood Events	**Risk Encountered**	**Year of Occurrence**	**Number of Human Casualties/ Death**
Flood hazard is known as "the storm forest flood."	Land cover destruction, properties, and crops	1926	NA
Flood hazard as a result of Tropical Storm Greg in Keningua (Sabah State)	About 300 million Ringgit	1996	241
Flood hazard caused by excess rainfall in Kelantan and Terengganu	Million of Ringgit	2000	15
Tsunami in Asia	Millions of Ringgit	2004	68
Flood in Johor State	489 million Ringgit	Dec2006/Jan 2007	18
Flood Hazard in the state of Johor	21.19 Million Ringgit	2008	29
Flood Hazard in Kedah and Perlis	8.48 Million Ringgit	2010	4
La Nina that brought a flood	NA	2011 &2012	NA

Source: [12]

In Table 1, the major catastrophe in Malaysia is flooding. the flood claimed not only human lives but also animals and farmlands. The resultant effect is a loss of millions of Dollars to recover from such a disaster.

However, there is a limited study of combining SWAT and 3D to obtain flood impacts assessment in the watershed. Most of the researches conducted by SWAT discuss more of sediment yield and deposits, soil erosion, nutrients loss, stream flow, rainfall intensity and groundwater movement and not on impact assessment of flood in Terengganu.

For this purpose, this study will focus on how both SWAT and GIS analysis on assessment are combined to obtain the 3D of flood assessment zones in Terengganu River catchment area. The recent application of geographic information system (GIS) and remote sensing helps in monitoring flood activities. The issue is how to overcome causalities if flooding occurs at a particular point in time and the main objectives include; to Used 3D in visualizing flooded zones, list HRUs affected by flood risk zones and find the impacts of the flood in the catchment.

Calculation of flood hazard according to Wade et al (2005) is based on the following formula below;

Flood Hazard Rating (HR) = DX (V + 0.5) Where

V = velocity (m/s)

D = Depth (m)

DF = debris factor can (0, 0.5, 1 depending on probability that debris will lead to a significant greater hazard)

Flood risk can be evaluated using the criterion of weight index which also is adapted base on the flood risk assessment model.

$$Risk_i = \sum_{i=1}^{n} Wi \ li \ (x,y)$$

$$= w_1 l_1 (x, y) + w_2 l_2(x, y) + w_3 l_3(x, y) + w_4 l_4(x, y) + w_5 l_5(x, y)$$

$$+ w_6 l_6 (x, y) + w_7 l_7(x, y) + w_8 l_8(x, y) + w_9 l_9(x, y)$$

Where *wi* can be the weight *li* (*x, y*) as criterion index, *x, y* as the geographical coordinate and the other sequences can be the remaining variables such as the slope, elevation, density, flow depending on the site selection and the input data of the study area.

Methodology

Study Area

The study focuses on the flood risk hazard in one of the flood-prone regions in the Eastern part of Peninsula Malaysia called Kuala Terengganu River Catchment. The Terengganu catchment has a total area of the Terengganu River catchment area is 286,507 [ha] or 707,973 [acres]. There are about 25 sub-basin parameters and 305 Hydrologic Response Units (HRUs) the catchment lies within the wet tropical equatorial climate that exhibits vital roles in manipulating weather that generate monsoon from the North-East, soil, organic matter and sediment yield are all drained into the South China Sea. It is located at upper left corner 5^{0} $30^{/}.40^{//}$ N, 102^{0} $23^{/}$ $15^{//}$ E and the lower right corner is 4^{0} $39^{/}$ $25^{//}$ N, 103^{0} $11^{/}$ $62^{//}$ E.

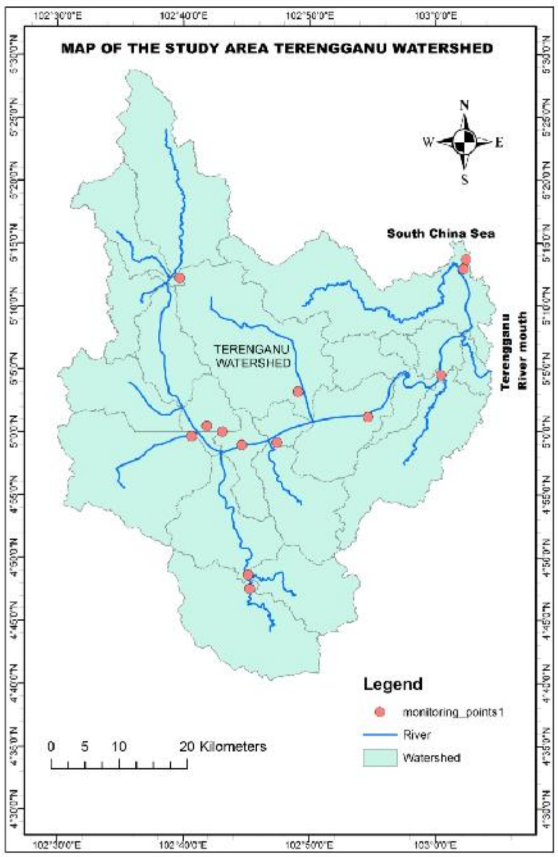

Figure 1: map of the Study Area Showing Terengganu River Catchment

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Study Flow

1. The Digital Elevation Model DEM was set up and loaded from the stored location in C drive from the computer
2. The DEM coordinate was transformed and setup
3. The Masked of River Terengganu was superimposed and loaded from the C drive
4. The Burn In was also defined and loaded
5. The River Flow direction and accumulation were calculated based on the DEM

6. The result of the stream definition was obtained of the total area in hectares and the calculated raster cells of the catchment.
7. Stream network and outlets were created
8. The whole watershed outlets from the Terengganu River mouth was formed
9. All the watershed in the River Terengganu Catchment has been delineated
10. The Sub-basins parameters within the catchment area under study were also calculated
11. the watershed of Terengganu was delineated and 25 Subbasins parameters was calculated

Result and Discussion

Delineation of the watershed was done using ArcSWAT 2012, the result is showing the boundary of the watershed of the Terengganu River, refer to figure 2.

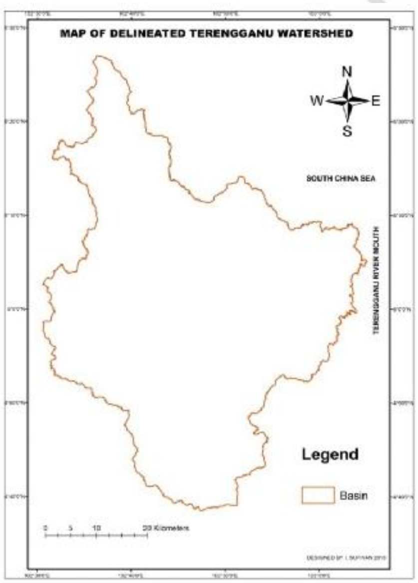

Figure 2: the Delineated Terengganu watershed

Stream network

The streams network in figure 3 is interconnected to each of the sub-basin, meaning that the river flows through the channels and drain toward the opening to the river mouth and empty into the sea. Most of the river banks are flooded during the high flow of monsoon season from November to January each year. The more the rainfall intensity the more the river flows and that cause flooding in Terengganu.

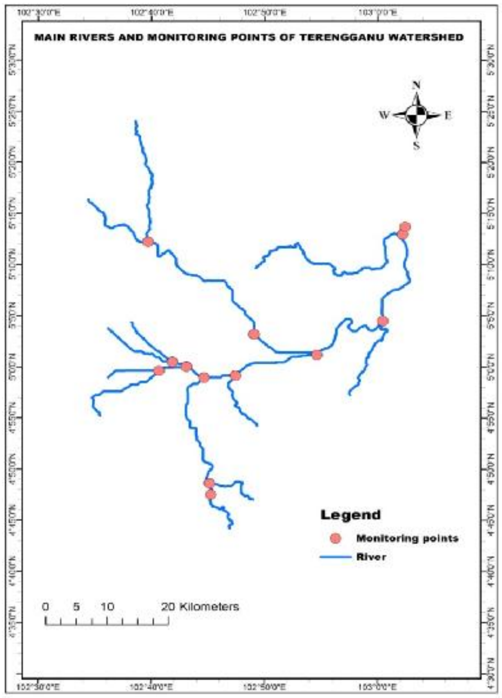

Figure 3: The monitoring point and the Stream
network of Terengganu watershed

The Digital Elevation Model obtained from satellite ASTER-DEM clearly show from SWAT analysis, the stream links and the stream outflow toward the South China Sea close to the Terengganu River mouth as shown in figure 4.

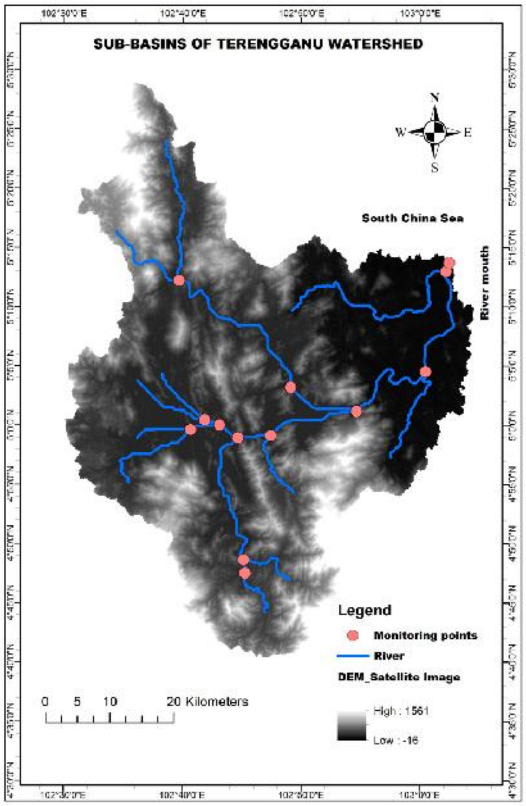

Figure 4: The satellite image DEM and the main rivers of Terengganu watershed

Flood Risk Model of Terengganu River Catchment Area

The flood risk model was shown in figure 5. The yardstick is to measure the magnitude of the flood risk in the catchment area of River Terengganu. The model categorizes the flood risk from the highest risk to moderate and to no risk zones within the watershed. The flood risk map represents the risk zones which can be used for mitigation, planning, and a warning to the public. From the model in figure, people occupying residence near the river banks are at very high flood risk in Terengganu, followed by those on the flatlands from 1 to 2m which are on very high flood risk. The slopes to the lower course of the Terengganu River entered into the South China Sea through the significant outlet.

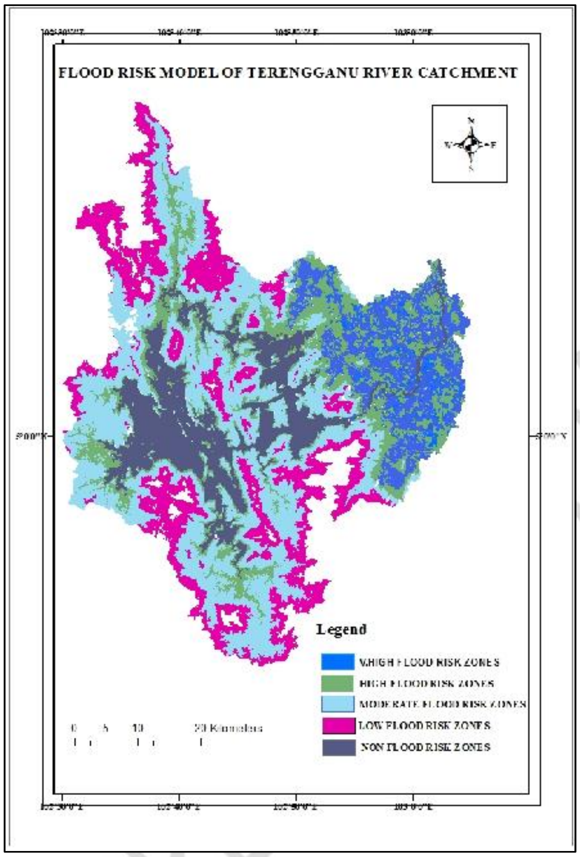

Figure 5: High and Low Flood Risk model of
Terengganu River Catchment Area

Figure 5 is the model produce using 3D simulation and this has identified the major flood risk zones using ArcGIS 10.3 within the catchment area. The very high-risk area is cropped for detail visualization of the impact of HRU within the sub-basins.

Sub-basins Parameter

There are about 25 different sub-basins in the study area created by the SWAT. Each of the sub-basins was characterized by a distinct parameter for easy classification and hydrologic analyses. Figure shows the classified sub-basins in Kuala Terengganu catchment. From this analysis, 5 major sub-basins are found to fall within the very high flood risk zone. These are sub-basin number 3, 5, 7, 8 and 18 with associated HRU from each one of the sub-basin.

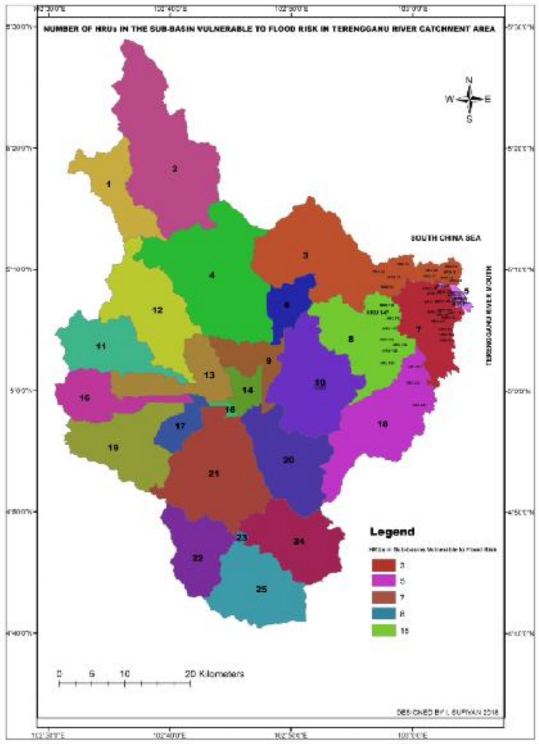

Figure 6: The total sub-basins found in the Terengganu watershed

The impact of individual HRU was done using the appropriate index to calculate the magnitude of the flood in each of the sub-basin.

The result from the Individual Impacts of Hydrologic Response Units (HRUs)

The hydrologic response units (HRUs) results in consist of the land use, soil types, and the catchment slope. They are characterized by unique performance and distributions of the individual report within the catchment area. In this study, 5 different sub-basins with their Hrus are categorized have a very high flood risk. the details of each Sub-basin are discussed in figure 8, 9,10,11 and 12.

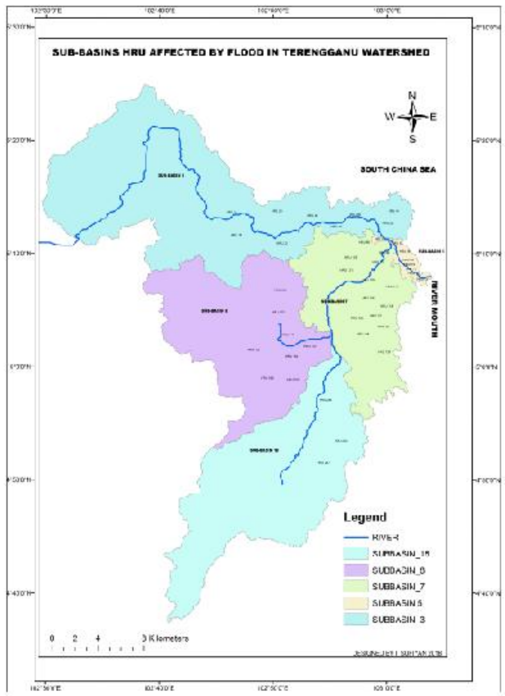

Figure 7: showing the affected sub-basin and its HRUs

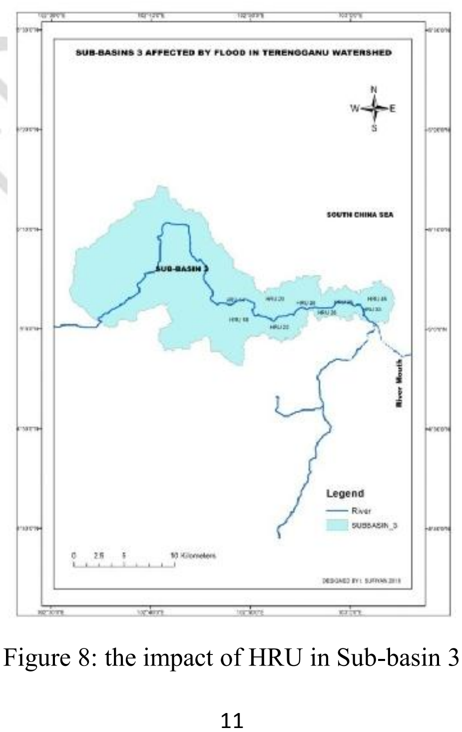

Figure 8: the impact of HRU in Sub-basin 3

There were 8 difference Hydrologic Response Units (HRUs) identified in sub-basin 3 indicated in figure 3, with each having a unique combination of land use, soil type and slope. The detail contribution is Hydrologic Response Units (HRUs) to flood risk are listed in Table 2. It has the largest impact on flood with about 36,323 of the total catchment.

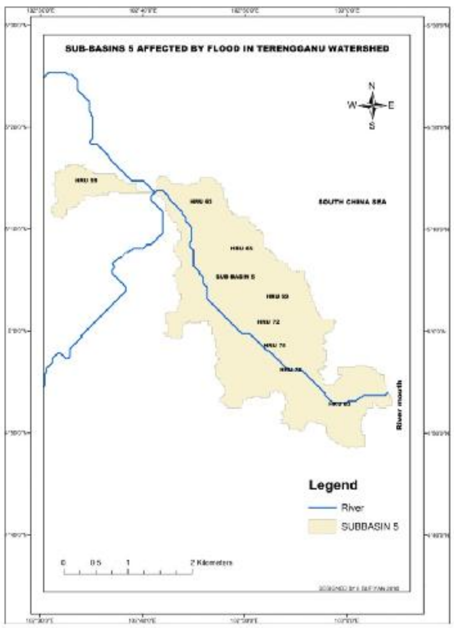

Figure 9: the Impact of HRU in Sub-basin 5

The sub-basin 5 in figure 9 consists of 8 different HRUs. Its the last sub-basin with the major stream outlet that drained into the South China Sea through the river mouth. The total flood impact in this sub-basin is 2,394.

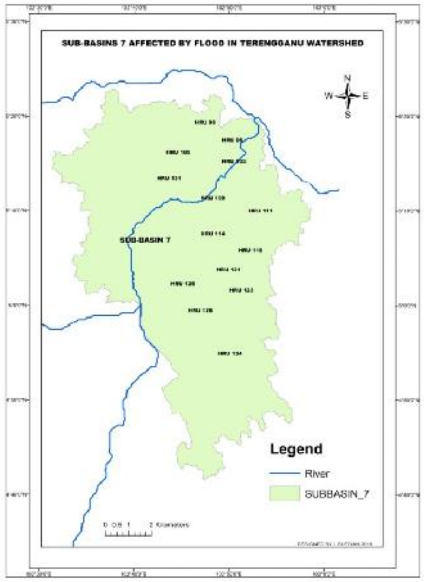

Figure 10: the impact of HRU in Sub-basin 7

The sub-basin 7 contained 14 HRUs . its total flood impact on HRUs is 34,582

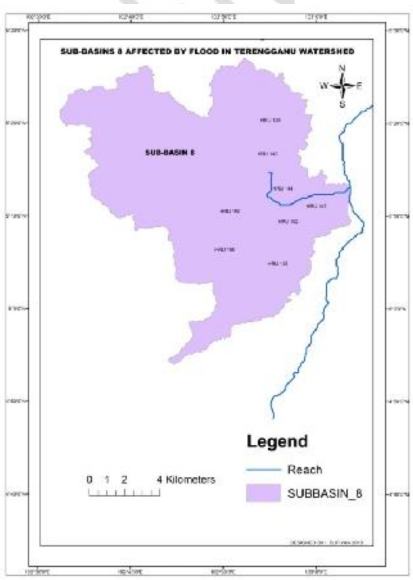

Figure 11: the impact of HRU in Sub-basin 8

The sub-basin 8 of the Terengganu river catchment has 8 HRUs and the total flood risk impact of 19,780. As shown in figure 11.

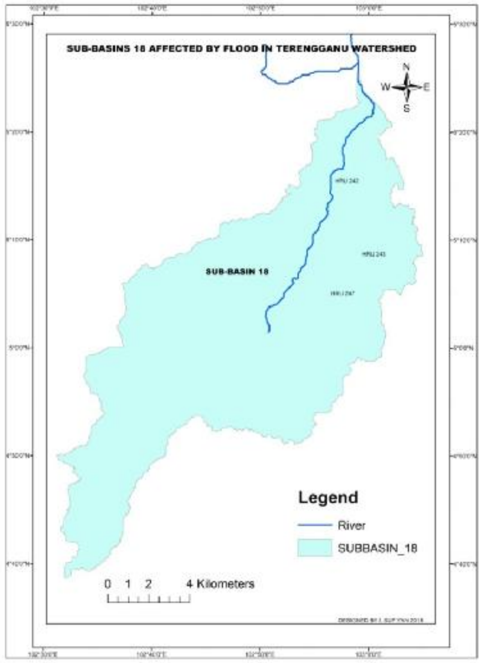

Figure 12: the impact of HRU in Sub-basin 18

The last sub-basin 18 is having about 3 HRUs with least effect within the Terengganu catchment. It also has the total impact of flood risk of about 14,350.

The Table 2, are the total impacts of all the flood risk at different Hydrologic Response Units (HRUs) affected in the Terengganu watershed. Sub-basin 3 has the highest flood impact followed by sub-basin number 7 and the less flood risk impact was found iin sub-basin 8.

Table 2: The Summary of Impacts of HRUs in selected Sub-basin in Terengganu River Catchment Area

No. Sub-basins involved in Flood	No. HRUs	Total flood Impacts
3	9	36,323
5	8	2,394
7	14	34,582
8	8	19,780

18	3	14,350
Total	42	107,429

Conclusion

The new method of identifying flood risk zones is applicable to all watersheds using the Soil Water Assessment Tool (SWAT). Among the 5 sub-basins that are vulnerable to high flood risk in Terengganu River catchment area, the most affected HRUs with high flood risk impacts are found in sub-basin 3 with 36,323 ha, followed by sub-basin 7 with 34,582 ha then sub-basin 8 with 19,750 ha, followed by the sub-basin 18 with 14,350 ha and the lowest impact are found in sub-basin 5 with 2,394 ha.

However, out of the total area of Terengganu River catchment area of (286, 507 ha) from the SWAT output refer to Table, (107, 429 ha) of the area are expected to have affected by the flood risk impacts. The remaining 179, 078 ha of the Terengganu River catchment area is located at flood free zones.

The flood risk simulations overlaid with the major HRUs that are vulnerable to flood are presented in figure 5. Out of 305 HRUs, about 42 HRUs falls within the range of 0-10 meter of slope and are located at very high flood risk zones in Terengganu River catchment area.

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