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Subbasins Flood Risk Simulations Using 3D and Swat in the River Catchment of Terengganu

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Authors' contributions

This work was carried out in collaboration between both authors. Author IS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author RBZ managed the literature and analyses of the study and cross-checked the formats. Both authors read and approved the final manuscript before submission.

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ABSTRACT

Real-time 3D simulation of the flood was conducted to identify and predict flooded zones in Terengganu river catchment. The use of GIS techniques in conjunction with remote sensing data obtained from ASTER DEM provides satellite imagery of high resolution. The flood was simulated with a visual prediction of very high flood risk zones to shallow flood risk zones within the catchment. The 3D from the ArcScene environment of ArcGIS 10.3 including ArcSWAT software package is used for the creation of flood risk models for mitigation. The models describe how 25 individual subbasins parameters were affected by flood in the catchment area of Terengganu. The flood models would be useful to relevant authorities for early warning scheme for robust mitigation, planning, and management.

Keywords: 3D; ArcSWAT-GIS; simulation; subbasins; modeling.

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1. INTRODUCTION

Flood events are a part of nature. They have existed and will continue to exist. As far as feasible, human interference into the processes of life should be reversed, compensated and, in the future, prevented. According to [1] stated that annually flooding causes more property damage in the United States than any other type of natural disaster Considering the evolution and trends, the approach to natural hazards requires a change of paradigm. One must shift from defensive action against dangers to the management of the risk and lives with floods, bearing in mind that flood prevention should not be limited to flood events which occur often. It should also include rare events. Web-based hydrological modeling system permits integrated handling of real-time rainfall data from a wireless monitoring network. A spatially distributed GIS-based model is incorporated with this incoming data, approximating real-time to produce data on catchment hydrology and runoff. [2]; emphasises that flood forecasting and a warning is a prerequisite for successful mitigation of flood damages. Its effectiveness depends on the level of preparedness and correct response. Therefore the responsible authorities should provide timely and reliable flood warning, flood forecasting and information. We use GIS tools to provide more accurate measures of flood risks [1]. Specific preparedness to alert, rescue and safety measures should be planned and implemented at all levels, including the public, by maintaining regular necessary information and continuous ongoing training actions. The appropriate and timely information, preparedness, everyone who may suffer the consequences of flood events should be able to take if possible- his/her precautions and thus severely limit flood damages. Three methods of GIS have relevance; raster data, Triangulated irregular network and contour based line network [3]. Flooding has many impacts. It damages property and endangers the lives of humans and other species. Rapid water runoff causes soil erosion and concomitant sediment deposition elsewhere (such as further downstream or around the coast). The flood risk increases where risk is defined as the probability of occurrence multiplied by its impact. The likelihood of flooding is expected to increase: the earth's climate is changing rapidly. Since the warm period in the Middle Ages and after the Minor Boulder, the land is undeniably growing warmer again. Scientists reached agreement on this point at a conference in Shanghai in early 2001. According to [4], based on remote sensing technology, the GIS grid model generated by digital elevation model (DEM) is utilised to analyse the flood submergence. Utilizing this method, the flooding situation including the extent of flood submergence and water depth distribution is attained. A nationally integrated system using remote sensing, geographic information systems, the Global Positioning System, and other technology for monitoring and evaluating flood risk can be employed. The system has played an important role in flood mitigation during the trial and has become a vital part of the flood management system [5]. Flood damage depends on the hydraulic factors which include characteristics of the flood such as the depth of flooding, the rate of the rise in water level, propagation of a flood wave duration and frequency of flooding, sediment load, and timing [6].

SWAT model is a continuous, extended- time distribution of imputed parameters as a model. The uses of the SWAT helps in the simulation of the surface water flow, soil erosion, sediment deposition and nutrient movement in the watershed [7]. The products of SWAT output from the hydrologic response units (HRU) such as the subbasin parameters developed from the catchment was integrated with 3D simulation in the ArcScene environment to produce flood risk models. Floods are climatologic phenomena influenced by the geology, relief, soil, geomorphology and vegetation conditions [8]. There is need to monitor the activities of the flood by applying the modern technology of Geographic Information System [9]. The system will assist in mitigation and controlling flood. The issue of flood disaster is a global phenomenon that requires attention in other to control life and properties. Flood inundation can be detected from remotely sensed data [10]. Flood hazard models are a useful tool for planning the urban city and layout designs [11,12,13]. Geographic information system (GIS) and remote sensing (RS) techniques have significantly contributed to natural hazard analysis [14,15,16,17].

2. MATERIALS AND METHODS

A complete account of flood model is provided by [18]. In this study, the flood zoning was done in ArcScene compatible to ArcGIS 10.3. The other variable materials were obtained from the Drainage and Irrigation Department (DID) in Malaysia. The data used are the georeferenced map of the study area. Aster DEM satellite image with a resolution of 30 meters was obtained from ASTER DEM, land use/ cover, and soil from the digitised map of Terengganu catchment area. Fig. 1 is the detail data manipulation done in Terengganu river catchment.

This study is conducted based on the flowchart in Fig. 1. The ArcGIS 10.3 software is used for both the ArcSWAT 2012 and the ArcScene 10.3. The intermittent results obtained from hydrologic response units HRUs in SWAT was overlaid with the 3D simulation model to observe the scenario of those subbasins that are within or outside the very high flood risk zone or very low flood risk zones [19]. The Fig. 2 is the summary of the flow chart.

2.1 Study Area

The study area that is Terengganu Fig. 3, has been experiencing flash flood particularly during the monsoon period of strong rain-bearing wind. In this study, the effort was made to address the issues of flood impact base on the digital image processing and high multispectral resolution of satellite imagery and GIS 3D environment. It is located at upper left corner 50305.407N, 102 02315.536E and the lower right corner is 403924.251N, 103011 6.211E respectively [20].

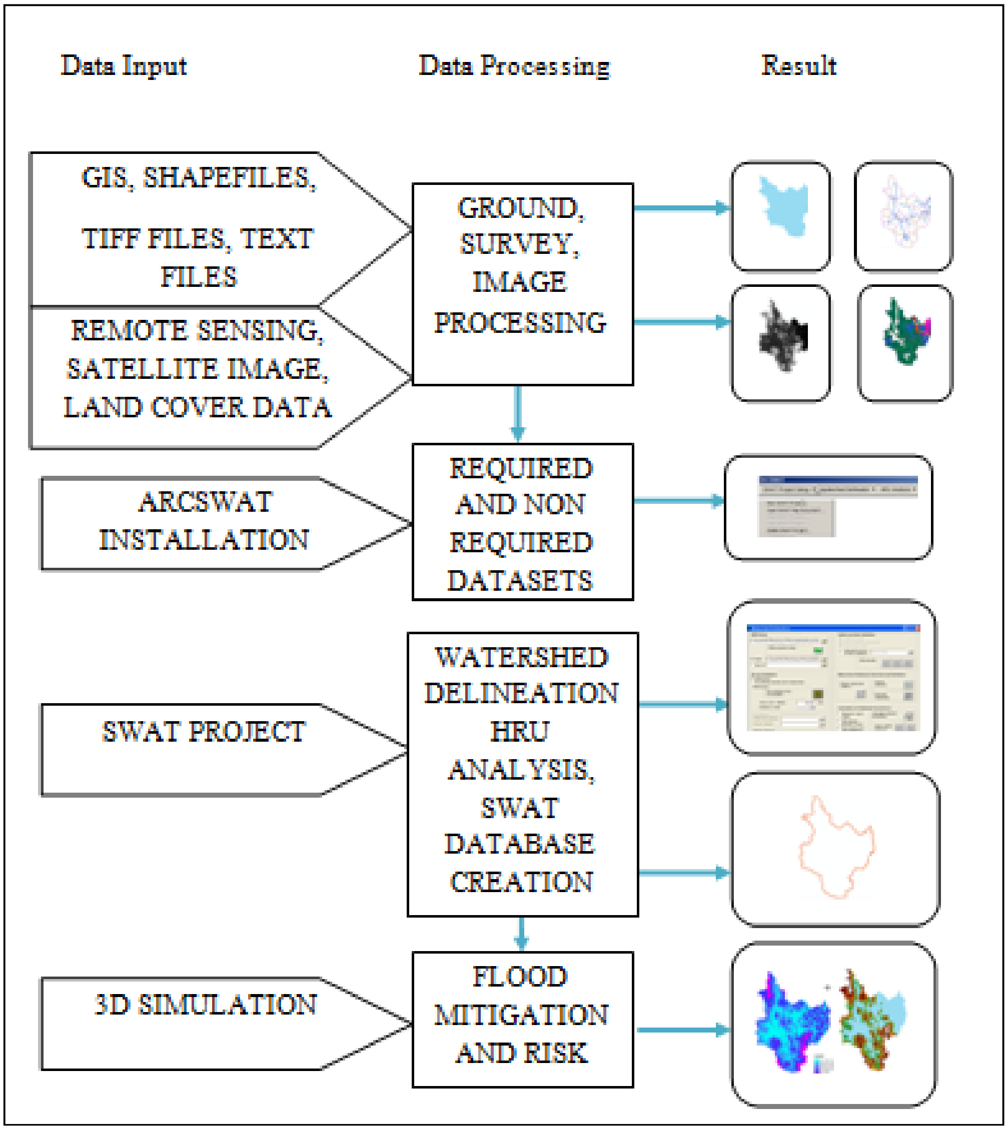


Fig. 1. Data manipulation in GIS

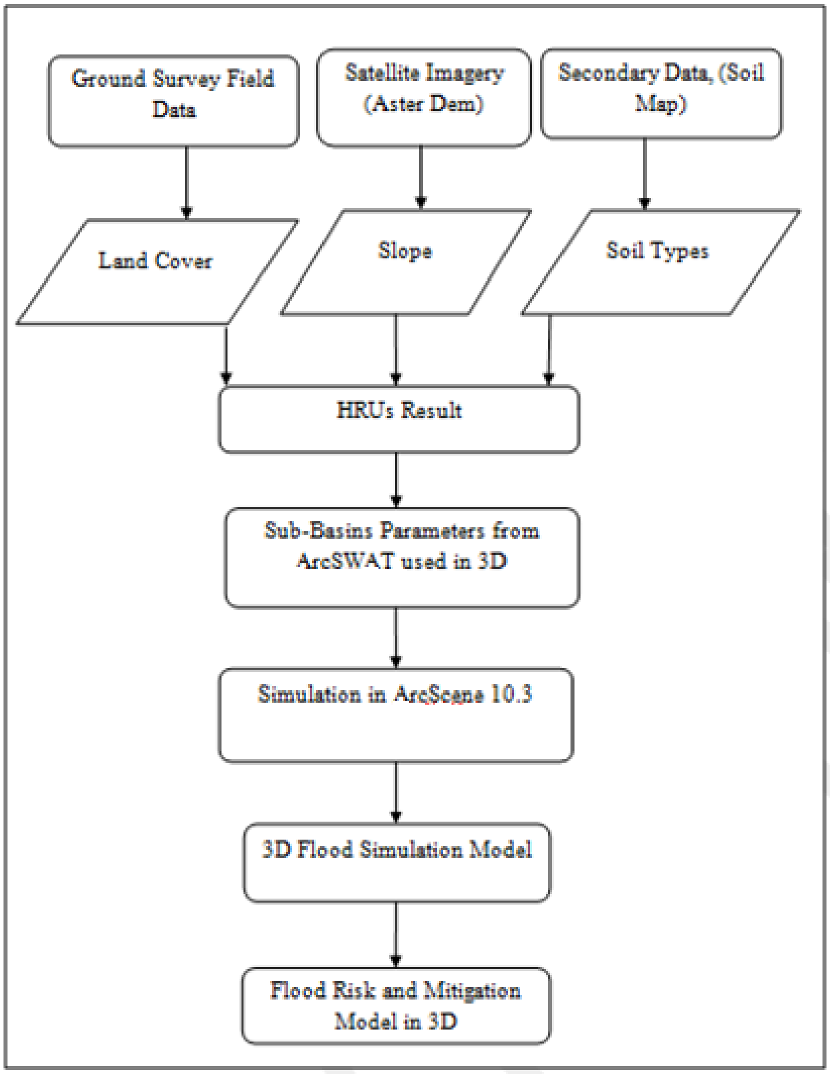


Fig. 2. flow chart

3. RESULTS AND DISCUSSION

The recent technology of remote sensing and geographic information system (GIS) has capabilities of locating, mitigating, managing and analyzing areas vulnerable to flood hazard event. The data input has been analysed in the ArcSWAT environment Fig. 4, once the HRU is completed the model is ready for simulation.

In this study. About 7 out of 25 subbasins parameters were simulated and are vulnerable to flood hazard and risk as shown in Fig. 7. There are about 25 different sub-basins in the study area created by the SWAT. There are about 25 sub-basin in the Terengganu watershed, 305 HRUs, with the total in hectares and acres as shown in Table 1.

Each of the sub-basins was characterized by a distinct parameter for easy classification and hydrologic analyses. Fig. 5 shows the classified sub-basins in Terengganu River catchment.

Table 1. Result of Terengganu watershed

Watershed no of sub-basins	Area [ha]	Area [acres]	Number of HRUs
25	286,5073500	707,9739872	305

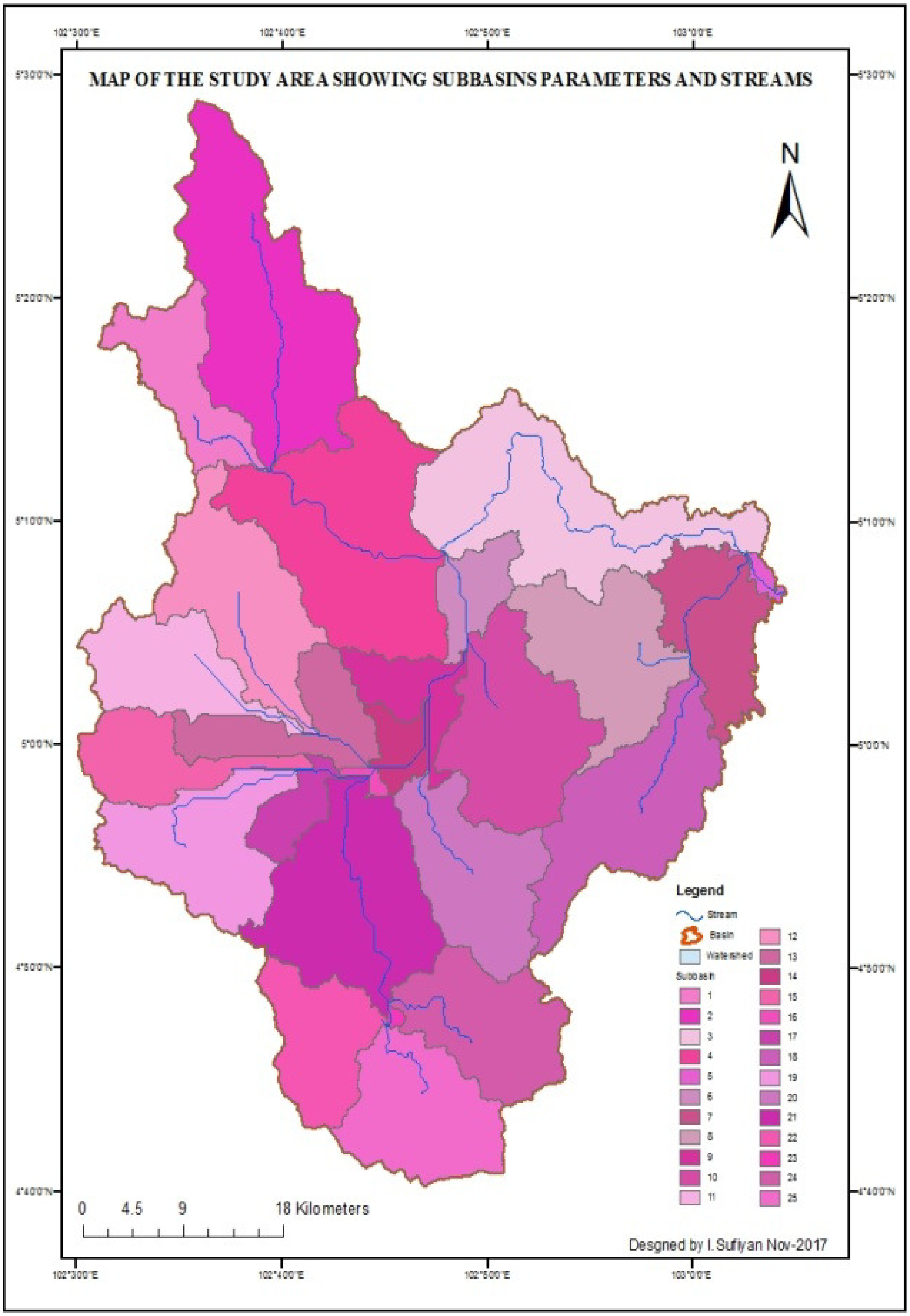
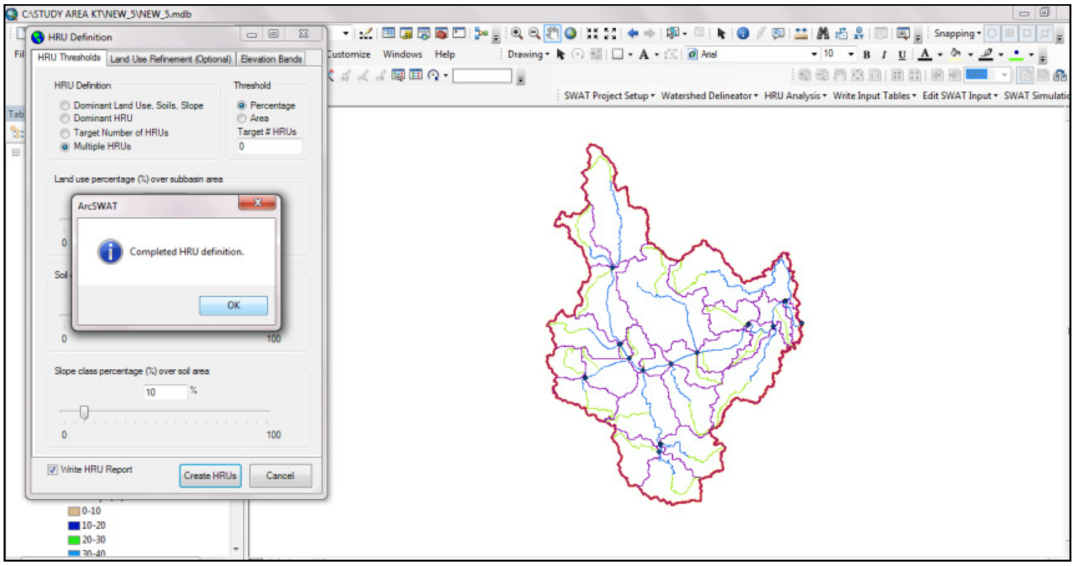


Fig. 3. Map of the study area



HRU Definition
○ Dominant Land Use, Soils, Slope
○ Dominant HRU
○ Target Number of HRUs
● Multiple HRUs

Threshold
● Percentage
○ Area
Target # HRUs: 0

Land use percentage (%) over subbasin area

Completed HRU definition.

Slope class percentage (%) over soil area: 10 %

☑ Write HRU Report

Fig. 4. Hydrolgic Response Unit (HRU) definition completed in ArcSWAT-2012

The major streams in Terengganu as shown in Fig. 6 and Fig. 8 are connected by the stream links to the watershed and appended to the whole catchment. The 25 individual sub-basins was defined by the water input and the characteristics of all the hydrologic response units (HRUs) with summary results in Table 2 and 3 of subbasins 1 and 2.

3.1 SWAT Watershed Delineation Result

Watershed is also known as a basin or catchment, or simply an area delineated with a specified outlet point that emptied in a large body of water. The figure below represents the delineated watershed of Kuala Terengganu Catchment. The boundary with brown color in Fig. 7 is the demarcation of the delineated watershed of the study area. The blue color is the main Rivers that flow toward the South China Sea. The green color is the minor streams in the sub-basins.

3.2 Stream Network and Reservoirs

The stream links are developed through the stream network. 10 stream links are obtained from the Terengganu catchment. Each stream link had been connected with the defined sub-basin. The 3 major reservoirs were identified within the watershed as shown in Fig. 8.

Table 2. Summary result of subbasin one

Subbasin	Area [ha]	Area[acres]	%Wat. Area	%Sub.Area
1	8,810.7300	21,771.7544	3.08	
Landuse				
Water [WATR]	60.6302	149.8203	0.02	0.69
Oil Palm [OILP]	808.2826	1,997.3067	0.28	9.17
Forest-Evergreen [FRSE]	7,950.5746	19,646.2673	2.77	90.24
Soils				
Marang	114.8641	283.8348	0.04	1.30
Steepland	8,704.6233	21,509.5595	3.04	98.80
Slope				
0-10	718.8238	1,776.2495	0.25	8.16
10-20	1,822.5097	4,503.5125	0.64	20.69
20-30	2,080.0754	5,139.9704	0.73	23.61
30-40	1,729.3572	4,273.3281	0.60	19.63
40-9,999	2,468.7213	6,100.3339	0.86	28.02

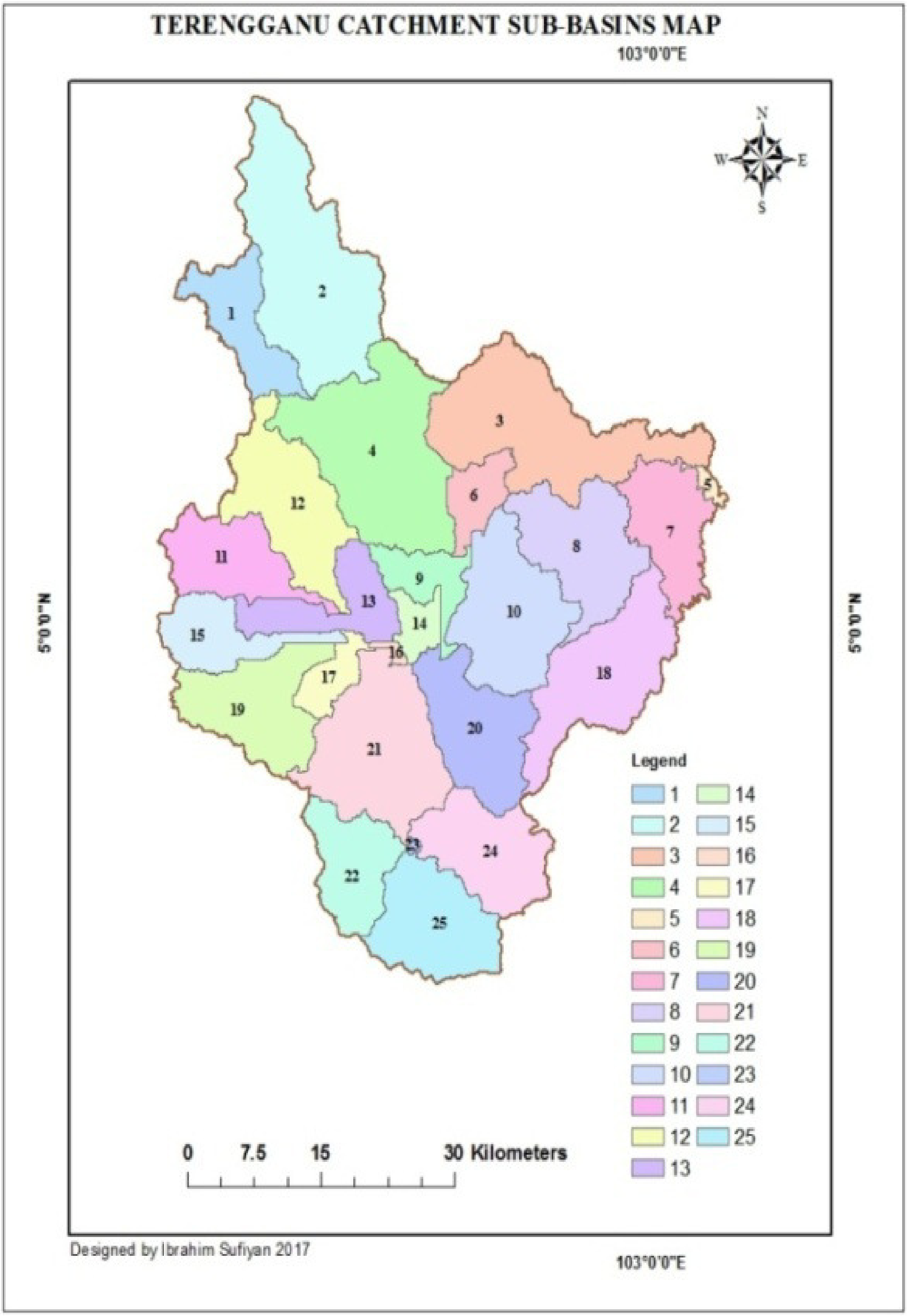


Fig. 5. Subbasins parameters of Terengganu catchment

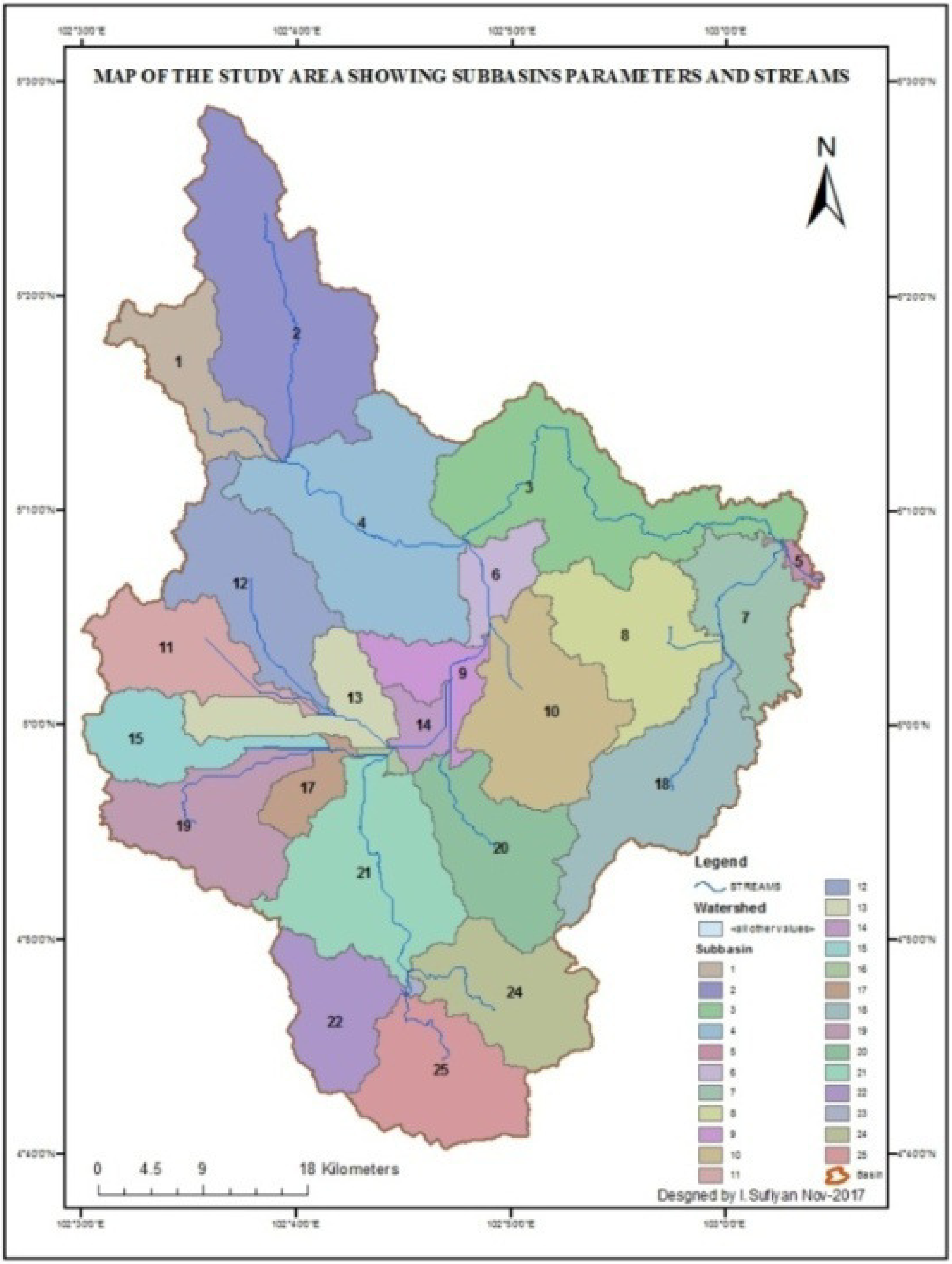


Fig. 6. The streams in the subbasins parameters

The HRU result summary of sub-basin number 2 in Tables 2 and 3 from the 25 different sub-basins obtained.

3D Flood Model developed from the digital elevation model (DEM) of the study area was overlaid with the mask and the Terengganu river flow was considered as a base height. The figure 9 displays the 3D model developed from the ArcScene. At this point, the Z values are calculated in other to create the simulation. The real-time simulation is presented in the same model. While the simulation was displayed, the purpose is to create a quick alert or warning through animation video perhaps all the areas prone to flooding will be easily identified and mitigation action can be applied.

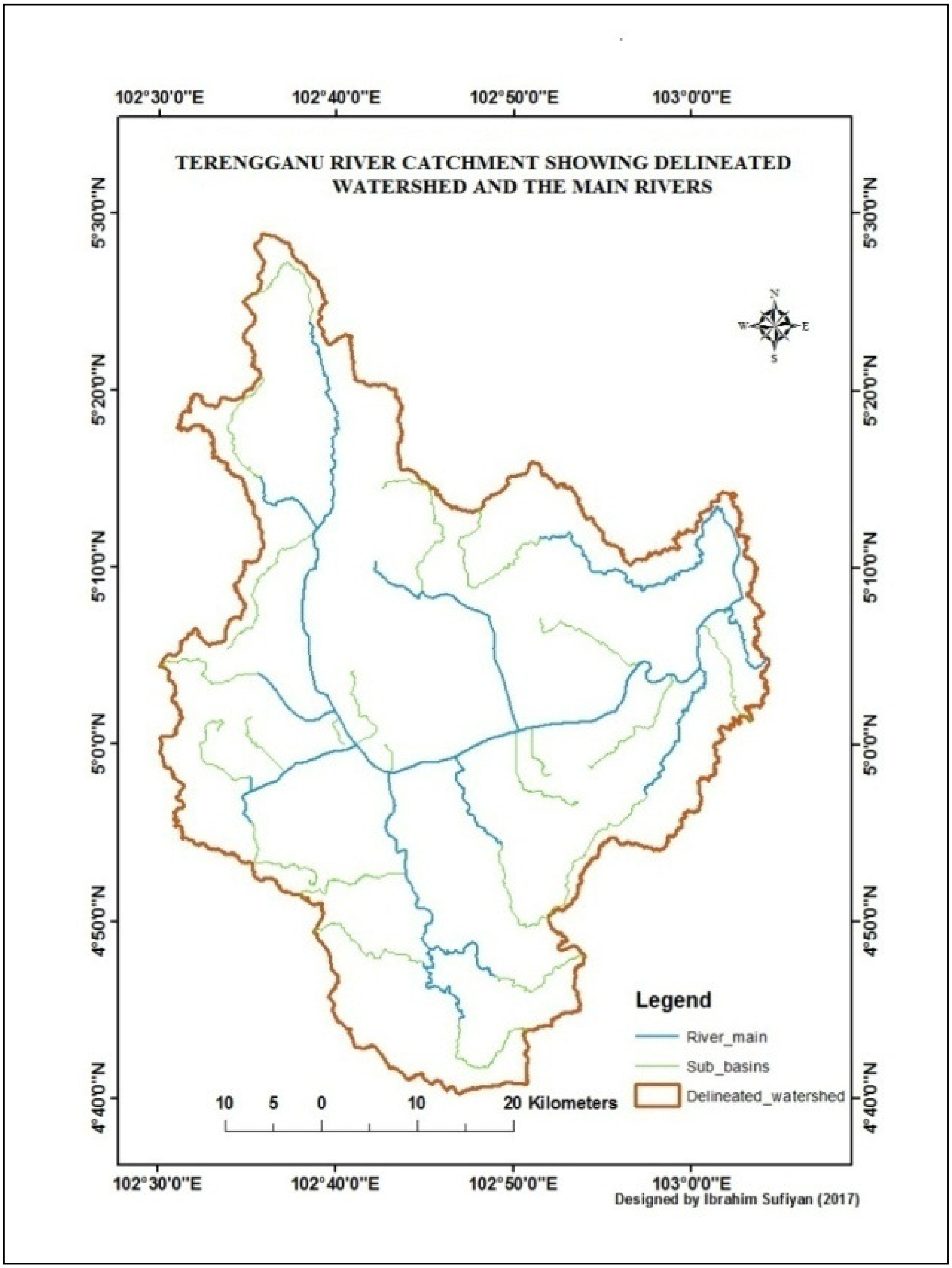


Fig. 7. Delineation of the watershed and the main rivers of Terengganu catchment

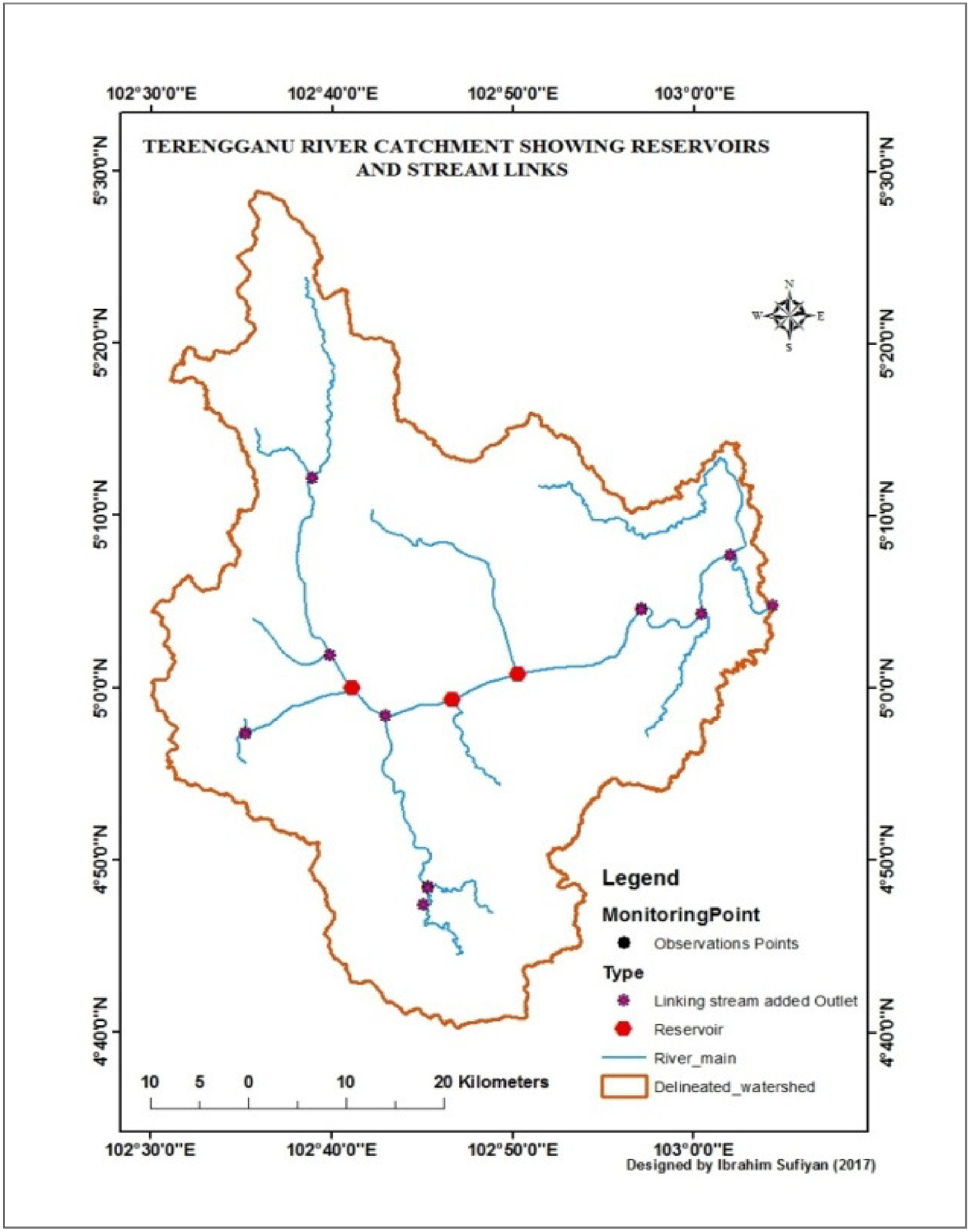


Fig. 8. Stream links and reservoirs

The 3D view visualizes the digital elevation model exposing height of the Terengganu River catchment. The streams within this catchment enter into the subbasins. The DEM was set on floating layer above 3.5 meters and the mask of the water level is on 3 meters. The Z translation values are from 0-100, 200, 300 to the required Z values as seen in Fig. 5. The results of flood risk model predicted that the Terengganu catchment has the lowest flood from 3 meters level to the highest 5 meters in the real-time simulation models as shown in Fig. 10a,b.

Table 3. Summary result of subbasin two

Subbasin	Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
1	27,019.5300	66,766.6096	9.43	
Landuse				
Water [WATR]	164.1430	405.6055	0.06	0.61
Oil Palm [OILP]	3.1531	7.7915	0.00	0.01
Forest- Evergreen [FRSE]	26,878.9097	66,419.1297	9.38	99.48
Soils				
Marang	3,939.7921	9,735.4231	1.38	14.58
Steepland	23,106.4137	57,097.1036	8.06	85.52
Slope				
0-10	2,347.6411	5,801.1386	0.82	8.69
10-20	5,411.6736	13,372.5160	1.89	20.03
20-30	5,918.3367	14,624.5058	2.07	21.90
30-40	5,157.8916	12,745.4080	1.80	19.09
40-9,999	8,210.6629	20,288.9584	2.87	30.39

Flood Risk and Mitigation Model of Terengganu River catchment were developed The flood risk model was shown in Fig. 11. The yardstick is to measure the magnitude of the flood risk in the catchment. Here we arrived at the categories of flood risk from the highest risk to moderate and to no risk zones within the watershed. The flood risk model represents the risk zones which can be used for mitigation, planning, and a warning to the public. From the model below the survey conducted and shows that people despite the warning given to them still occupying residence near the river banks which are at very high flood risk in Terengganu, followed by those on the flatlands from 1 to 2 meters which are on high flood risk.

Flood risk can be evaluated and validated using weightage criterion index can also be 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 is waa also applied to field of hydrology Ticehurst et al. [21].

The flood risk assessment was shown in Fig. 12. Each of the 25 subbasins parameters have a different magnitude of flood risk developed from both the ArcSWAT hydrologic response units HRUs and the 3D simulation model. Basically, the simulation shows which zone within each subbasin is severely affected by flood in the 25 subbasins of the study area.

Fig. 13 demonstrates the years of flood occurrences in Terengganu. The year 2014 has 50%, 2016 with 33%, 2015 has 14% and rest of the years has had very low flood events. While Fig. 14 shows the bar graph with a maximum point of flood occurrence.

The expected heavy rainfall in Terengganu is during months November and December. During this period, monsoon rain commences and the flood is experienced. This occurs in most parts of the Peninsular Malaysia. Fig. 15 clearly illustrates the highest month of rainfall in the study area. Base on this information, we are expected to have been prepared for the flood occurrence.

The model outputs will be useful in demarcating areas liable to flood and help in notifying people about predicted simulation of flood hazard Although floods are natural phenomena, human activities and human interventions has been affecting the processes of nature such as alterations in the drainage patterns, urbanization, agricultural practices, and deforestation have considerably changed the situation in whole river basins. In 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. The flood risk assessment as shown in Fig. 12, categorises the sub-basin parameters base on individual flood risk. Each of the 25 subbasins parameters have a different magnitude of flood risk developed from both the

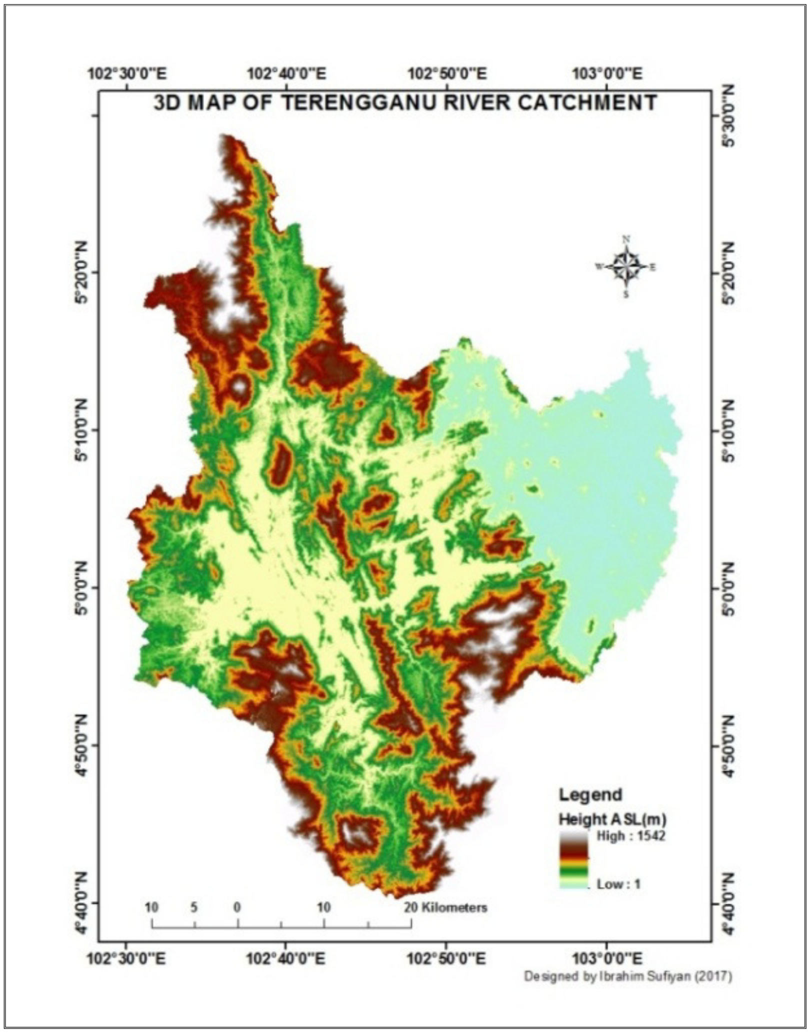
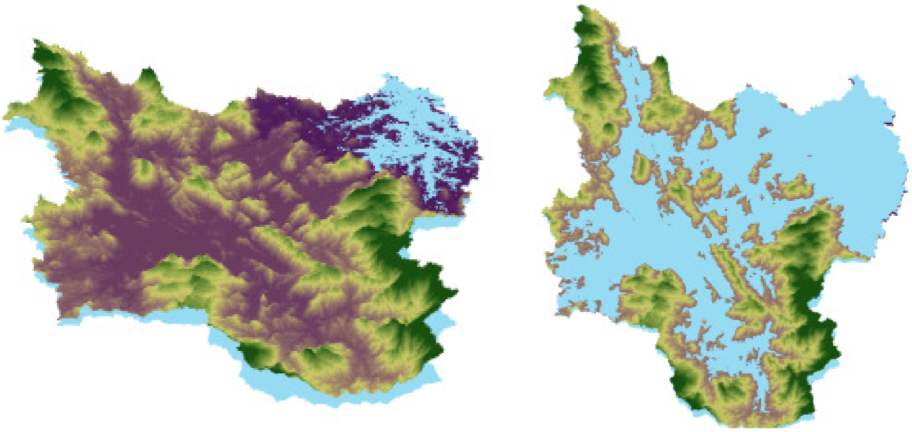


Fig. 9. 3D model of flood event of Terengganu river catchment



3Da **3Db**

Fig. 10. 3Da,b predicted flood simulation model of Terengganu catchment

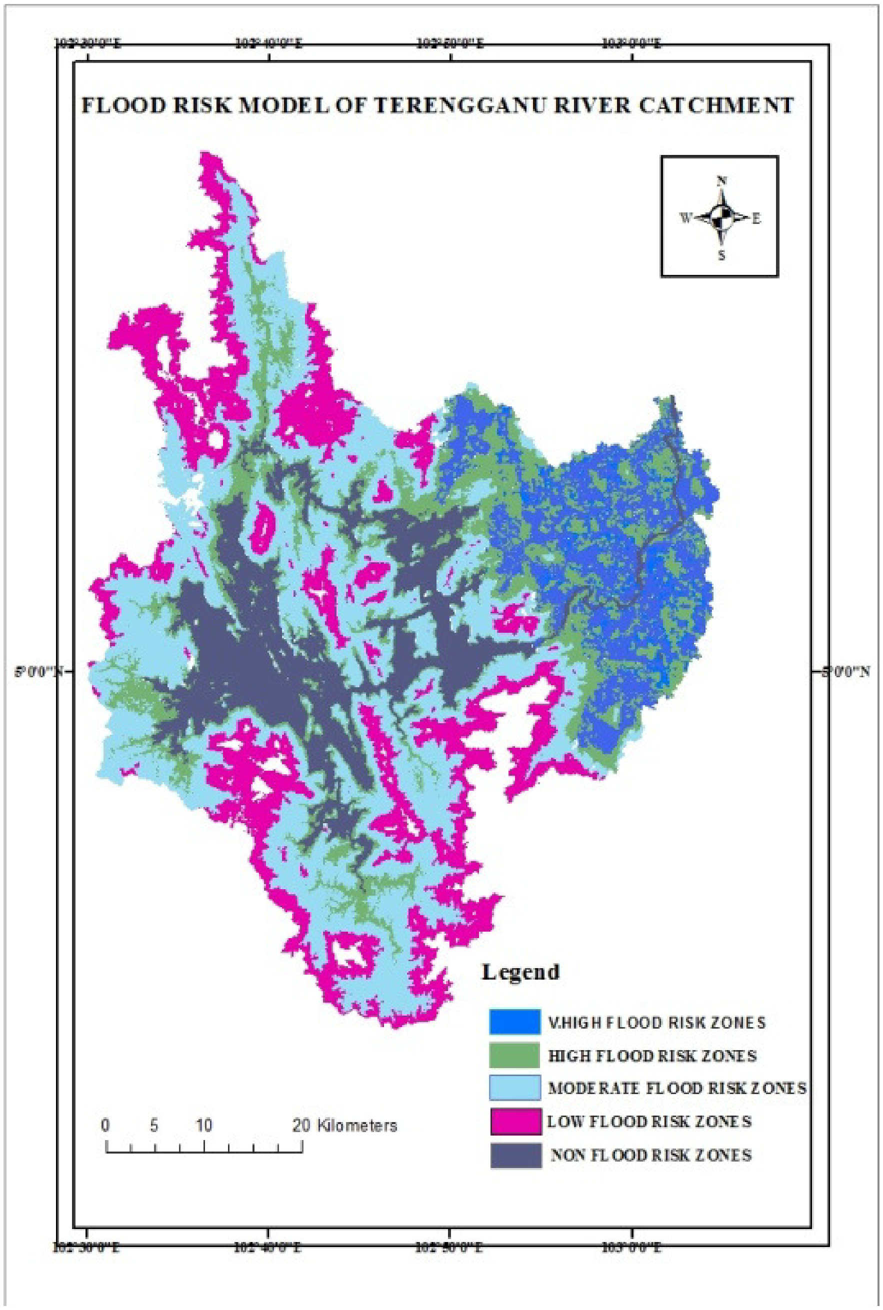


Fig. 11. High and low flood risk model of Terengganu catchment

ArcSWAT HRU and the 3D simulated model basically to appended to it and show which zone within each subbasin is severely affected by the flood. The 25 subbasins in the study area follow the slope magnitude of the DEM. for mitigation action, we can select and predicts which subbasins in the catchment are highly suitable and liable to flood at each point in time, depending on the intensity and duration of the rainfall. The simulation predicted subbasins that are affected by the flood. These are subbasin number 3, 5, 6, 7, 8, 10, and 18 in the Terengganu catchment. The problems of accessability to some areas, the data capture and financial background are the major challenges of the study. The further research should prepare more GIS exparts and technicians for expansion.

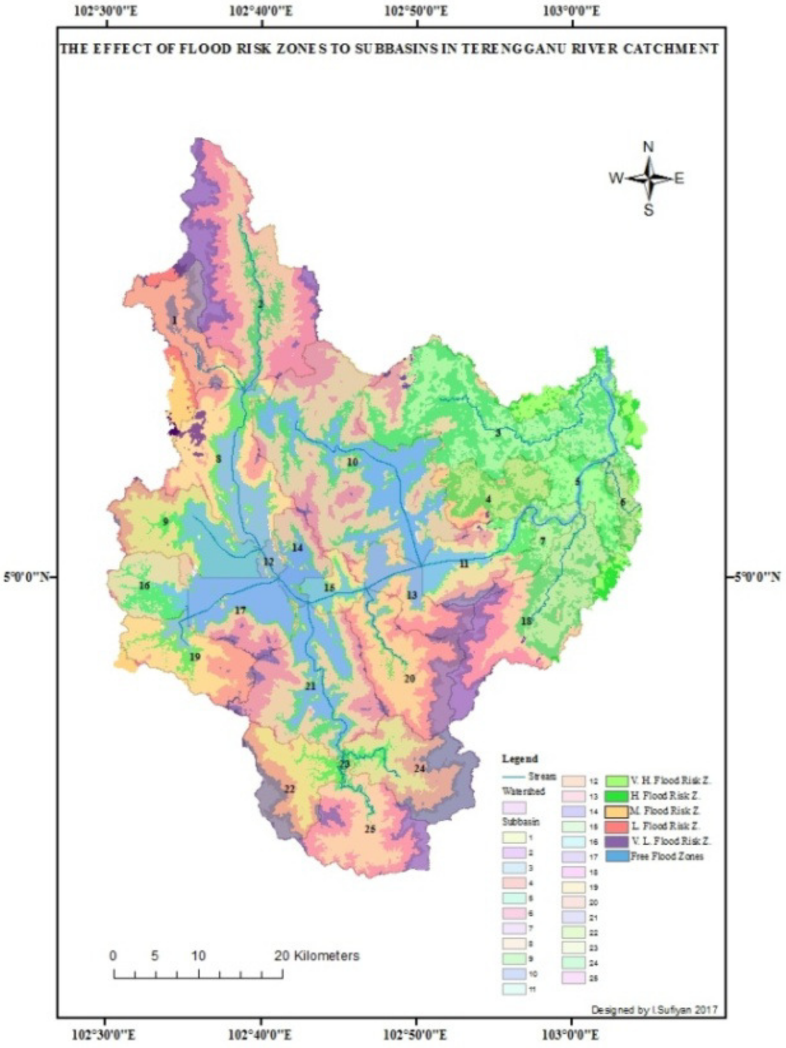


Fig. 12 individual subbasins flood risk analysis

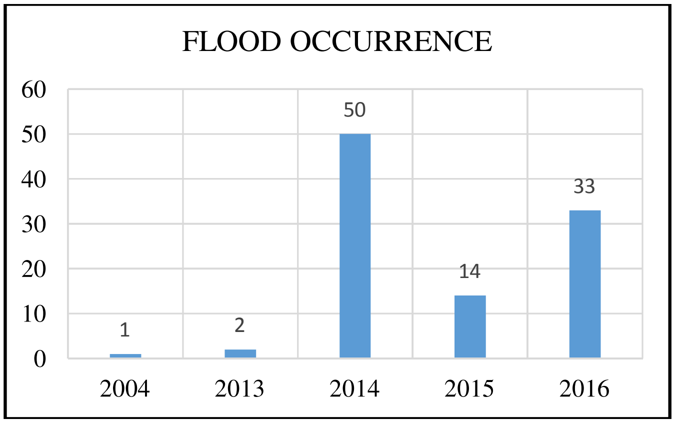


Fig. 13. Highest year of flood occurrences in Terengganu

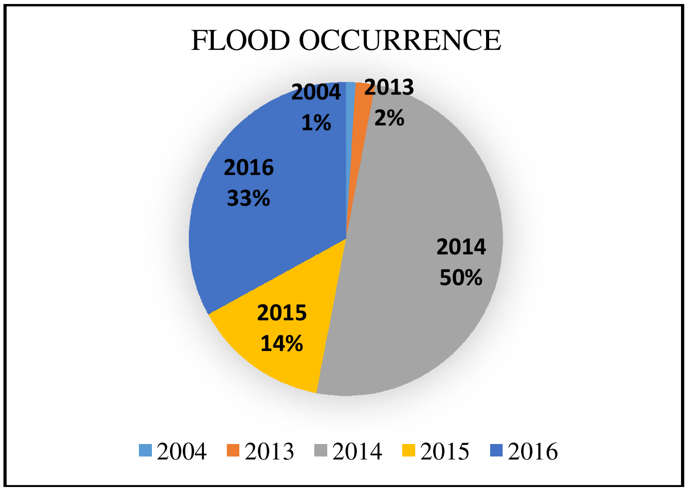


Fig. 14. Percentages of years of flood occurrence Terengganu

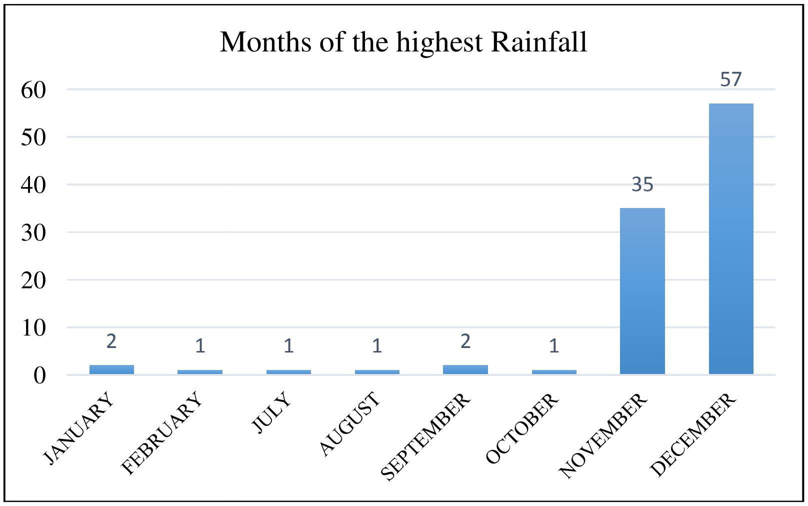


Fig. 15. The two highest months of rainfall

4. CONCLUSION

Flood usually occur around November to early January in Terengganu. The 3D simulation predicted that about 7 out of 25 sub-basins are subject to high flood risk in Terengganu catchment. The result showed that flood usually affects flat land. Therefore, proper drainage system, reforestation, suitable waste disposal system and public media enlightenment will be part of the solutions. People living around the affected subbasins should take note of the flood magnitude at regular interval. The flood warning and alert, shelter and safety are one of the mitigations required within each subbasin in Terengganu catchment. The flood risk models of Terengganu River catchment was simulated showing flood risk zoning of individual subbasins which can be used for mitigation and planning of flood control.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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