Flood Susceptibility Mapping Using GIS and AHP in Kelantan

By

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Dissertation submitted in partial fulfilment of
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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Approved by,

Dr Muhammad Raza Ul Mustafa
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(Dr. Muhammad Raza Ul Mustafa)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2022

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NURUL NAJIHAH BINTI KHAIRUL ANUAR

ABSTRACT

Flood is the most devastating natural disaster in Malaysia, especially in Kelantan. Kelantan is highly vulnerable to floods, particularly during the northeast monsoon seasons, which occur from November to March. Moreover, a lack of performance in flood management in Kelantan before the occurrence of a flood makes the situation even more severe. The current early warning system implemented by the government is inefficient to avoid or mitigate flood issues in Malaysia. Flood mapping is an effective way to access flood susceptible areas and determine factors that cause floods. However, previous studies using the GIS-based multi-criteria flood risk approach have some limitations, such as inappropriate or unused criteria weighting methods. Therefore, this study is conducted to produce a flood susceptibility map in the study area as well as integrate Geographic Information System (GIS) with Analytical hierarchy process (AHP) to utilize their joined capabilities in flood mapping. The methodology that will be used in this study is the combination of integration Geographic Information Systems (GIS) and Weight Linear Combination Technique (WLC). A total of 10 influencing factors were used for the AHP method including elevation, rainfall, topographic wetness index (TWI), drainage density, distance from drainage, stream power index (SPI), slope, land use/ land cover, normalized differential vegetation index (NDVI), and geology. The parameters were obtained from conventional sources and the digital elevation model (DEM). All the parameters were overlayed in geospatial software. AHP is utilized in this study to find relative weight and produce pairwise comparison weighted criteria of the influencing factors. The findings of AHP can be concluded that rainfall is the most significant in contributing to flooding because it has the highest weight criteria which are 26.6 % and the least significant is SPI with 2.95%. To assess the reliability of the produced ratings, the consistency ratio (CR) was determined; thus, the value of CR is 0.08 which is acceptable as the value is lesser than 0.1. To produce the flood susceptibility map, the calculated pairwise comparison weighted criteria is further used in ArcGIS by using the weighted overlay method. The final map was consisting of 74% moderate flood susceptibility, 21% for high flood susceptibility, and 5% for low susceptibility of the flood. However, moderate areas can change into high susceptibility and very high susceptibility if no proper flood management is taken. The flood susceptibility map is further validated by using the area under the curve (AUC) method. The final result of AUC is 0.711 which is considered acceptable. Therefore, the findings of this study can be used for further study or evaluation for the bigger projects by engineers or other researchers.

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ABBREVIATIONS

AHP	Analytical hierarchy process
ANP	Analytic Network Process
AUC	Area under the curve
CHAID	Chi-squared Automatic Interaction Detection
CR	Constant Ratio
CRU	Climatic Research Unit
DEM	Digital Elevation Model
DID	Department of Irrigation and Drainage
FR	Frequency Ratio
GIS	Geographic Information System
LULC	Land use and land cover
MCDA	Multi-criteria decision analysis
MCDM	Multi-criteria decision making
NDVI	Normalized Difference Vegetation Index
RS	Remote Sensing
SPI	Stream power index
TWI	Topographic Wetness Index
USD	United States Dollar
USGS	United States Geological Survey
WHO	World Health Organization
WLC	Weight Linear Combination Technique
WSM	Weighted sum method

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Floods are a natural disaster and cause severe damage to inland areas near rivers and streams (Khan et al., 2021). Floods can be caused by heavy rain, sea waves, rapid snowfall, or failure of dams and dams (NOAA National Severe Storms Research Institute, 2020). Statistics show that the contribution of floods to global natural disaster volume and damage is 34% and 40%, respectively (Lyu et al., 2019; Petit-Boix et al., 2017). Additionally, from 1998 to 2017, floods affected more than 2 billion people worldwide (World Health Organization, 2019). Flash floods, river floods, and coastal floods are the three most common types of floods. Floods, according to the World Health Organization, can have a negative impact, resulting in loss of life and damage to personal property as well as critical public health infrastructure. Flood casualties and damages are increasing in many areas as a result of social and economic development, which puts pressure on land-use, for example, through urbanization (Ouma & Tateishi, 2014). In the last ten years, floods, droughts, tropical cyclones, heatwaves, and severe storms have caused between 80 and 90 percent of all documented natural disasters (World Health Organization, 2019).

Malaysia is well known for its most devastating natural disaster which is a flood. Floods in Malaysia are commonly categorized as monsoon floods or flash floods (DID, 2009). During the North-East monsoon, the wind blows heavily across the South China Sea to Peninsular Malaysia., particularly in its east coast states as well as western Sarawak (DID, 2009 & Hasni, 2014). The most affected by this annual flood occurrence are usually Terengganu, Pahang, and certainly, Kelantan. Flooding affects approximately 29 000 square kilometers (9 percent of total land area) and over 4.82 million people (22 percent of the population) each year (Ghani et al., 2009). **Figure**

1.1 shows the cost of flood losses in 2021 are estimated to be RM6.1 billion by the Department of Statistics Malaysia (DOSM) in their Special Report On Impact Of Floods In Malaysia 2021. Based on the previous chart, public assets and infrastructure are recorded as the highest losses with RM2.0 billion and agriculture as the lowest losses recorded with RM 90.6 million. **Figure 1.2** shows the percentage of flood losses in Malaysia by types and selected states in 2021. Based on the chart mentioned, Kelantan recorded approximately 75% for living quarters, 5% for vehicles, and 22% for business premises. The factors triggering floods in Malaysia include monsoon seasonal, deforestation, logging, poor maintenance of drainages, and illegal dumping (Butler, 2015; Menon et al., 2017; Nurul Ashikin et al., 2021).

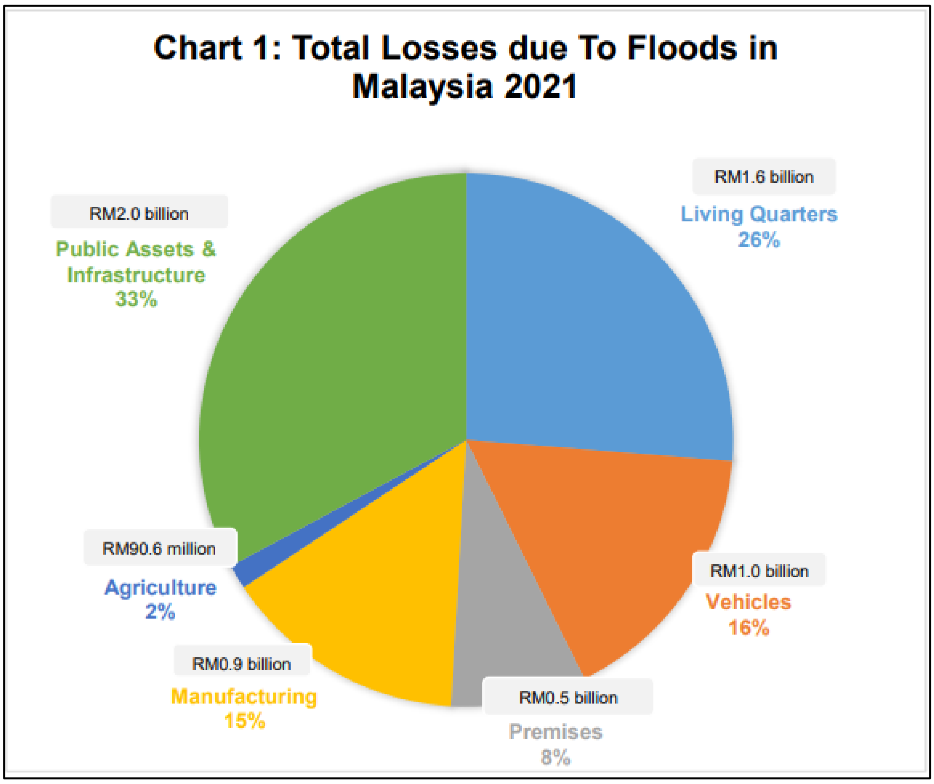


FIGURE 1.1. The Cost of Flood Losses In Malaysia 2021.

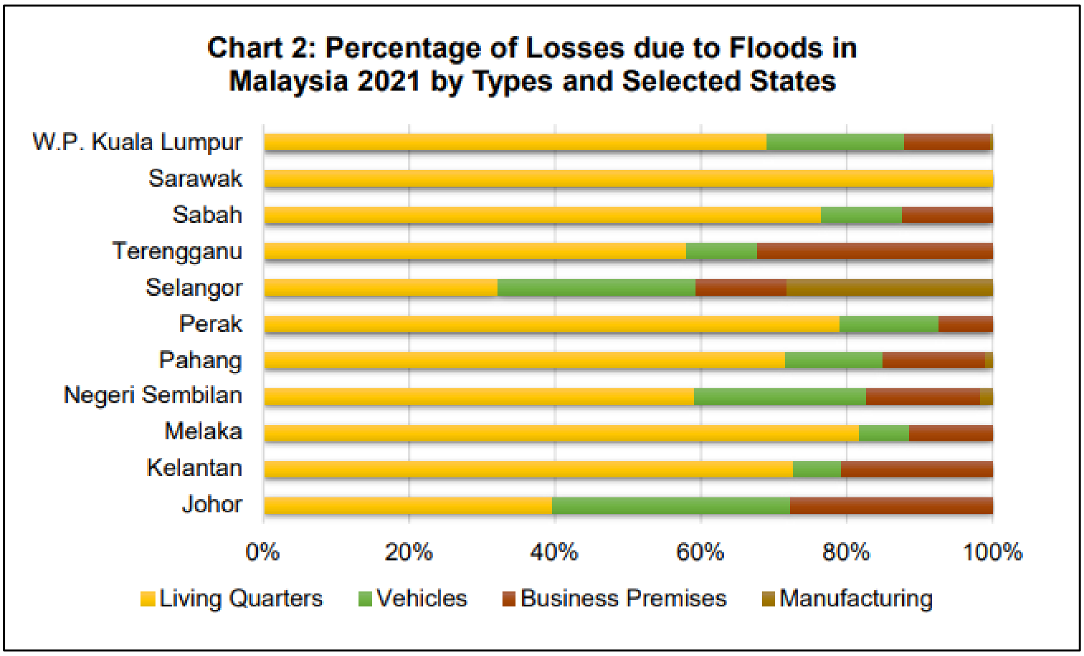


FIGURE 1.2. Percentage of Flood Losses in Malaysia by Types and the Selected States in 2021

[Source: Special Report On Impact Of Floods In Malaysia 2021]

Even though different flood early warning systems have been implemented to mitigate floods, the results of mitigation projects are still ineffective for the country to oversee the issue. In this case, the warning system could be based on a siren system, remote sensing, television, or other means (Khalid et al., 2015). Flood mapping is an effective way to assess flood susceptible areas and determine factors that cause floods. According to Samanta et al. (2018), Multi-Criteria Decision Analysis (MCDA), Remote Sensing (RS), and Geographic Information System (GIS) techniques are remarkably useful in the analysis and mapping of flood-prone zones. Therefore, this study integrates Geographic Information System (GIS) with a technique of Multi-Criteria Decision Method (MCDM) which is Analytical hierarchy process (AHP) to utilize their joined capabilities in mapping present and future flood susceptibility in Malaysia.

Due to its benefits over traditional maps, GIS is commonly acknowledged as essential in disaster mitigation. The use of GIS in urban planning and regional development control in Malaysia around the year 1990 is estimated to rise rationality in the process of developing effective decision making (Selamat et al., 2012). GIS has a broad array of applications, including identifying flood-affected areas and forecasting areas that are highly probable to be inundated by major flooding (Dano et al., 2011). RS and GIS techniques provide a good basis for manipulating and analyzing all appropriate data to conveniently define appropriate hazard areas (Samanta et al., 2018). However, the preparation and analysis of data source are essential to the achievement of GIS integration. In this study, GIS is utilized to process all thematic layers which are influencing factors that cause flood and to calculate the weighted criteria utilized by AHP. AHP proposed by Saaty in 1980 is a Pair-wise Comparison method which is widely known for addressing complex issues. Thus, choosing AHP technique as the support decision making tool is believed as efficient in this study. A variety of researchers have developed the integration of GIS with analytical hierarchy process to prepare flood susceptibility maps such as D U Lawal et al., (2014), Elkhrachy (2015), Das (2020) and many more.

1.2 Problem Statement

Flooding in Kelantan was mostly due to continuous rainfall occurred during northeast monsoon started from November to March. Due to this flood disaster that happened annually in Kelantan, it impacted the casualties, personal property and put health infrastructure in critical condition. Most of affected people due to flood were needed to evacuate to safer places such as schools, mosque and public hall. When the height of flood keeps rising, the number of people needed to be evacuate also rising. This caused uncomfortable surrounding and daily activities interrupted. Moreover, due to this annual occurrence, personal property such as cars, houses or even important documents are might or might not retrieved from the flood. Furthermore, flood disaster that happened in Kelantan impacted the victims health in physically and mentally. It might cause depression, stress or physical health.

A lot of researchers have used geospatial tools to produce flood susceptibility maps over several river basins with different level of accuracies, consistency, and validations which some of them resulted less reliable information to be used in flood mitigation plan. Previous studies using the GIS-based multi-criteria flood risk approach have some limitations, such as inappropriate or unused criteria weighting methods (Rincón et al., 2018). To overcome the problem of accuracy, consistency and validation, GIS software is combined with one of the MCDM methods which is AHP in this research to enhance the validity of the results in order to provide more precise information for flood mitigation strategy.

1.3 Objectives & Scope Of Work

Objective

The main objectives of this flood susceptibility mapping using GIS and AHP study are:

1. To produce flood susceptibility map with high accuracy of results by integrate GIS and AHP.
2. To validate flood susceptibility map using area under the curve (AUC) method.

Scope of Work

1. To identify flood susceptible areas and factors that triggering flood in Kelantan.
2. To develop flood susceptibility map using GIS and AHP to address flood risk in study area.
3. To use one of the Multi-Criteria Decision Method (MCDM) methods as the decision support tool in this research.
4. This research will only use ArcGIS desktop as the software to develop the flood susceptibility map.
5. To do literature review on past research for further understanding of the project and references for the project.
6. This research will only use area under the curve (AUC) to validate the final findings.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Flood is recognized as a hazard that can be avoided or minimized not only by constructing structural mitigation, but also by utilizing modern technologies that provides information on flood risk areas (Cinque et al., 2003). Therefore, analyzing flood susceptibility is a significant task for early warning systems in developing mitigation strategies for future flood incidents (Tehrany et al. 2015). GIS is well known for its superior performance in the control of flood threats, as well as the evaluation of risk zones based on specific geographical regions (Hanifah et al., 2012). This literature review will enable researchers and readers with a comprehensive understanding of GIS approaches in flood susceptibility mapping along with AHP and empower researchers in addressing accurate solutions in flood related issues.

2.2 Flood Occurrence

Flooding is becoming more common as a result of ongoing climate change and human-caused land-use changes (Hirabayashi et al., 2013; Sofia et al., 2017). Flood maps depicting flood instances are an essential resource for the incorporated flood risk assessment dynamics, ecosystem dynamics, and susceptibility needed in the planning, design, and operation of flood structures, conservation areas, and land management measures (Qi et al., 2009). Floods are influenced by meteorological variables and catchment area characteristics (Khosravi et al., 2019), which may also affect the area's vulnerability to flooding

Kelantan river basin is vulnerable to flood in Malaysia due to its location in east peninsular Malaysia which is annually affected by northeast monsoon and climate changes. The worst scenario of flood occurrence in Kelantan was in 2014. The water level area results in Jebur et al. (2014) research show that most of the Kelantan catchment area is associated with flood risk levels in 2014, with the Lebir and Kelantan rivers showing high and rising levels. **Figure 2.1** shows the flood events in Kelantan over the past decade. However, in Yusoff et al. (2015) research paper stated the relationship between rainfall and water level is pretty weak and suggested to broaden its investigation to look into other variables that may have contributed to the flood occurrence. According to Syed et al. (2014) findings in their study reflect a lack of performance in flood management in Kelantan prior to the occurrence of a flood.

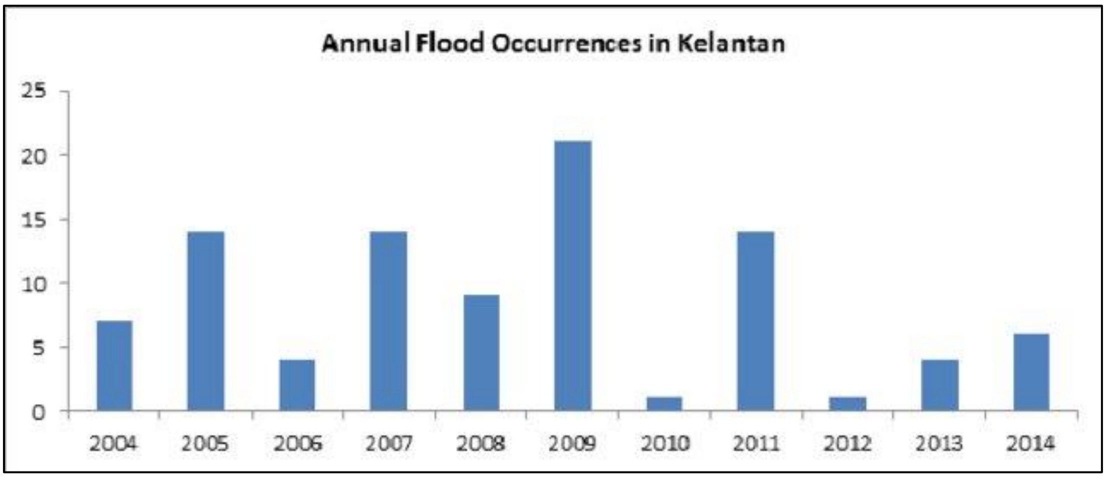


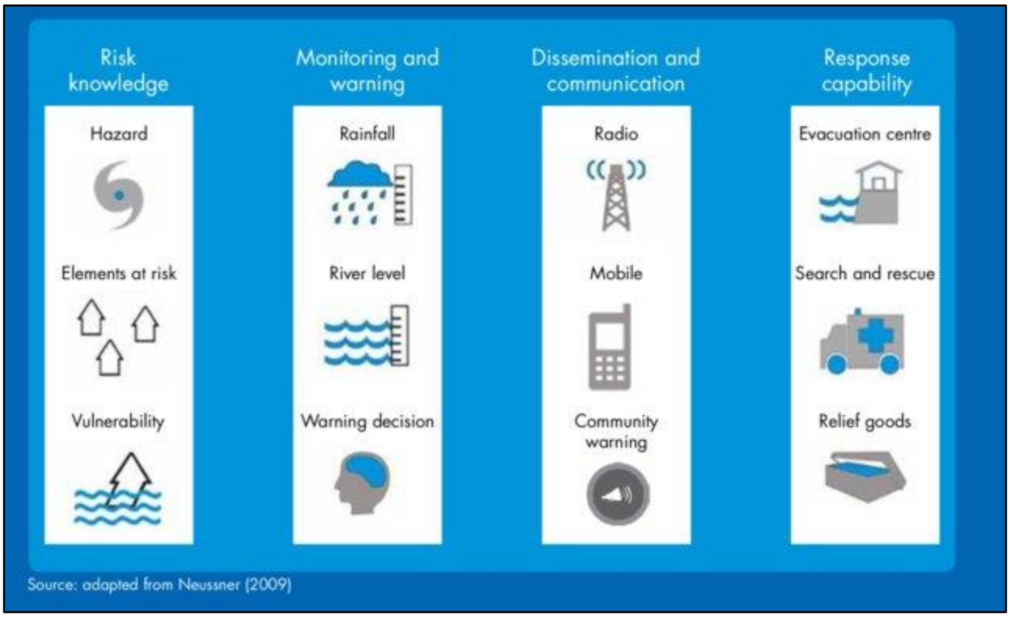
FIGURE 2.1. Flood Events In Kelantan Over The Past Decade

[Source: Department of Irrigation and Drainage

2.3 Flood Susceptibility Mapping Method as The Early Warning System (EWS)

According to the United Nations (UN), an early warning system (EWS) is a climate change mitigation response that uses effective information systems to help societies in planning for potentially hazardous weather-related events. There are four essential components in EWS (Zambrano et al., 2017); risk awareness, risk monitoring, response efficiency, and warning communication. **Figure 2.2** shows the essential components for a flood early warning system. There are a few ways deliver EWS to the communities. In Kafle (2014)'s book, they used a set of sensors and automatic sirens in Tsho Rolpa, Nepal. However, due to insufficient operation and maintenance and destruction made by citizens, the system became less effective.

According to Shah (2022), Malaysia used monitoring and warning systems as EWS but still fall short in alerting people from caught in flood.



Source: adapted from Neussner (2009)

FIGURE 2.2. The Essential Components for a Flood Early Warning System.

Therefore, using flood susceptibility map as EWS can give government and authorities a further analysis so that they can taking immediate action in response to issued warnings. Flood mapping and sensitivity analysis are critical components of early warning systems because they classify the most susceptible areas depending on the spatial conditions that cause flood trends (Adger, 2006; Jacinto et al., 2015). Many researchers across the globe have created flood vulnerability maps with incredible accuracy in recent years using remote sensing data and GIS tools (Pradan, 2009; Bates, 2012; Tehrani et al., 2014, Zaharia et al., 2017). The projected flood sensitivity mapping method, according to Hong et al. (2017), can aid professionals and localities in flood prevention measures.

2.4 Geographic Information System (GIS)

A geographic information system (GIS) is a system for storing, managing, assessing, and visualizing geographical data, as well as modeling and representing geospatial data to solve complex planning and management problems (Sánchez-Lozano et al., 2013; Rudini et al., 2018). Each layer in GIS represents data and specific details based on geographical location and defined relationships (Hanifah et al., 2012). GIS techniques are designed to provide a useful framework for manipulating and analyzing all appropriate data in order to quickly identify corresponding danger zones. (Khan et al. 2008; Saha et al. 2005; Wang et al. 2013; Pourghasemi et al. 2014). In recent years, advancements in GIS and remote sensing have been integrated into the assessment of geo-environmental disasters, facilitating the advancement of flood susceptibility mapping, assessment of flood hazard and flood management (Dano et l., 2011).

Darwin et al., (2018) has utilized GIS to estimate the flood area and the road network that has been impacted by the flood in Bandung in the form of map. Other than that, Usman et al. (2017) used GIS flood simulation to create flood susceptibility maps for flood monitoring and evaluation in Lagos, Nigeria. **Table 2.1** shows the researchers that used integration of GIS as flood mapping tool.

TABLE 2.1. Researchers That Used GIS as Flood Mapping Tool.

Series no.	Authors	Year Published	Methods used
1	D U Lawal1 , A N Matori, K W Yusuf, A M Hashim and A L Balogun	2014	GIS
2	Ismail Elkhrachy	2015	GIS / AHP
3	Usman Kaoje & Ismail	2017	HEC-RAS / GIS
4	Sailesh Samanta, Dilip Kumar Pal & Babita Palsamanta	2018	GIS / RS / FR
5	Darwin, Benecditus Kombaitan, Gatot Yudoko, HeruPurboyo	2018	GIS / CHAID
6	Matej Vojtek and Jana Vojteková	2019	GIS / AHP

2.5 Multi-Criteria Decision Making approaches (MCDM)

Malczewski (2007) and Pavan and Todeschini (2009) define MCDM as a decision-making method involved in complex decision problems with unique multiple criteria. To rank the alternatives in the MCDM model, three distinct steps are used: determination of the relevant criteria and alternatives, weighting of the criteria and numerical measures for the effects of the alternatives on these criteria and finally processing of the numerical values to create a ranking score for each alternative to be determined (Hwang & Yoon, 1981). There are various MCDM methods that can be implemented through specific decision-making software in many fields such as education, business, and climate events. MCDM methods include AHP, ANP, WSM, TOPSIS, ELECTRE, VIKOR, and others (Sun et al., 2020). **Figure 2.3** illustrates the hierarchical structure of MCDM techniques. The use of multicriteria decision-making (MCDM) tools in flood risk management can be beneficial (de Brito & Evers, 2016). **Table 2.2** shows methods of MCDM and their applications (Patel et al., 2017). Because of its convenience of use and adaptability, AHP is the most commonly used MCDM technique in flood hazard mapping (Mahmoud & Gan, 2018). (de Brito & Evers, 2016).

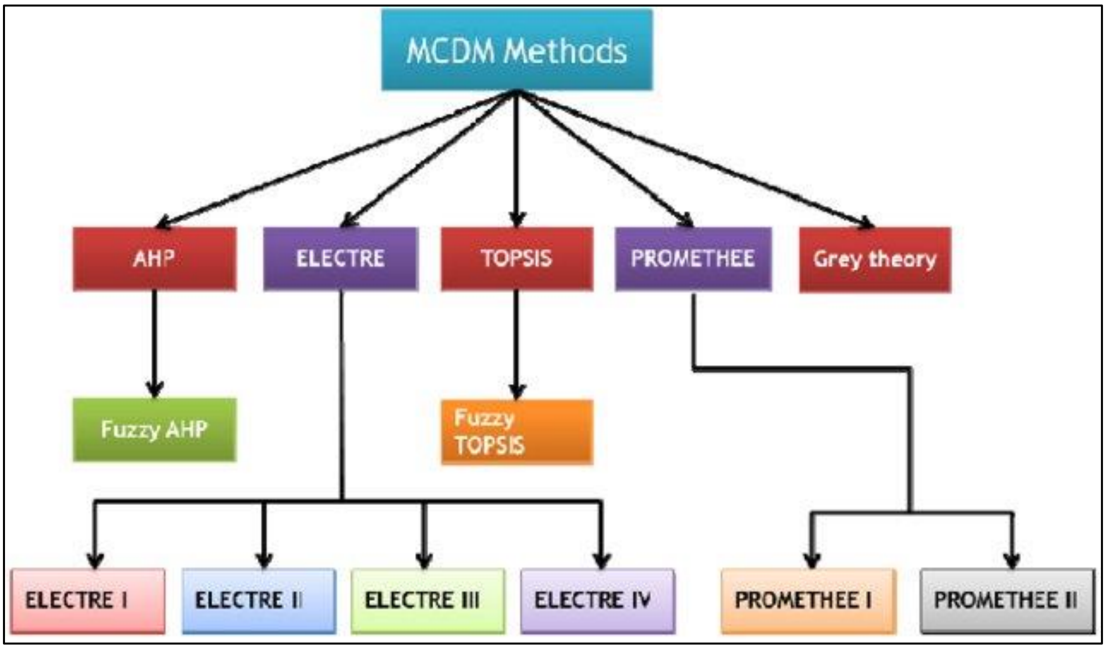


FIGURE 2.3. Hierarchical Structure for MCDM Techniques.

[Source: Igbinovia & Krupka, 2017]

TABLE 2.2. Methods of MCDM and Their Applications

No	Methods	Area of application
1	Multi-Attribute Utility Theory (MAUT)	Economics, finance, actuarial, water management, agriculture
2	Simple MultiAttribute Rating Technique (SMART)	Transportation and logistics, planning, environmental, construction, military, manufacturing and assembly problems.
3	Analytic Hierarchy Process (AHP)	Performance-type problems, resource management, corporate policy and strategy, public policy, political strategy, and planning
4	Case-Based Reasoning (CBR)	Businesses, vehicle insurance, medicine, and engineering design.
5	Data Envelopment Analysis (DEA)	Economics, medical, services, road safety, agriculture, retail, and business problems.
6	Fuzzy Set Theory	Engineering, economics, environmental, social, medical, and management.
7	Goal Programming (GP)	Production planning, scheduling, healthcare, portfolio selection, distribution systems, energy planning, water reservoir management, scheduling, wildlife management.
8	ELECTRE	Energy, environmental management, water management, and transportation problems.
9	PROMETHEE	Environmental, hydrology, water management, business and finance, chemistry, logistics and transportation, manufacturing and assembly, energy, agriculture.
10	Simple Additive Weighting (SAW)	Water management, business, and financial management

11	TOPSIS	Supply chain management and logistics, engineering, manufacturing systems, business and marketing, environmental, human resources, and water resources management

2.6 Analytic Hierarchy Process (AHP)

Analytic Hierarchical Process, AHP is a pairwise comparisons technique that makes use of priorities and multi-level hierarchies (Saatey, 1980; Elkhrachy, 2015). Furthermore, AHP is the most favored technique used to create flood susceptibility mapping (Vojtek et al., 2019). There are two methods to multicriteria decision analysis research (Chandio, 2013). The first method is to assess the research on various aspects of the study, and then create concluding remarks and supporting remarks.

The second method is to check the entity to alternative similar entities in order to investigate and correlate these comparisons (Saaty 2008).The method entails the use of 9-point scales assembled on a criteria basis, allowing you to rate a relative preference against options on a one-to-one basis (Althuwaynee et al., 2014). The primary benefits of AHP are that it enables for adaptive changes (inconsistency) at marginal rates, based on decidable data, and includes a large number of commercial computer systems that simplify calculations (Das, 2020)

A lot of researchers have utilized AHP in producing weighted criteria for flood susceptibility map. Ouma et al., (2014) have integrated AHP and GIS to forecast the extent of flood hazard areas in Kenya. They used a multi-parametric approach that incorporates physical and socioeconomic components as calculated by morphometric and topographic parameters. Moreover, Danumah et al., (2016)'s method is based on physical, hydrogeological, and human factors. According to them, normalization and weighting measures for these factors are essential for reducing bias and lack of certainty in the end outcome. Furthermore, Siddayao et al., (2014) determined the criteria weights with AHP and integrating the weights with some GIS-based procedure such as layer overlay, raster reconfiguration, and some clipping to create a flood hazard map in the Philippines. Other than that, Kittipongvises et al., (2020) used nine factors map and overlayed using weighted linear combination to examine how previous experience influenced public flood preparedness and to evaluate the geographic range of flood hazards, have identified and produced map areas of flood risk in Abidjan using AHP through GIS. Koem et al., (2020) used 10 x 10 pairwise matrix in AHP to evaluate the relative significance of each variable and determine the weight of each variable. **Table 2.3** shows the compilation of AHP by researchers around the word in flood mapping.

TABLE 2.3. Compilation of AHP Integration by Researchers in Flood Mapping

Series no.	Authors	Year Published	Objective of the study
1	Yashon O. Ouma and Ryutaro Tateishi	2014	To model and forecast the size of flood risk areas by integrate AHP and GIS in Eldoret, Kenya.
2	Jean Homian Danumah, Samuel Nii Odai, Bachir Mahaman Saley, Joerg Szarzynski, Michael Thiel, Adjei Kwaku, Fernand Koffi Kouame & Lucette You Akpa	2016	To identify, and map areas of flood risk in Abidjan district.
3	Generino P. Siddayao, Sony E. Valdez, and Proceso L. Fernandez	2014	To analyses, evaluate and produce flood risk map in Enrile, Philippine using AHP method and GIS
4	Suthirat Kittipongvises, Athit Phetrak, Patchapun Rattanapun, Katja Brundiers, James L. Buizere & Rob Melnick	2020	To assess the geographical distribution of flood hazards and to examine how previous experience influenced community flood preparedness
5	Chhuonvuoch Koem & Sarintip Tantanee	2020	To assess flash flood hazard levels throughout Kampong Speu Province using the analytical hierarchy process (AHP) and a geographical information system (GIS) with satellite data

2.7 Combination of GIS and AHP Technique

The advancement of geographic information and remote sensing systems, as well as MCDM methods, has allowed for significant advancements in hydrological modeling, particularly in flood mitigation and forecasting (Das, 2020). The classification method, like the AHP method, is the best for floodplain classification (Khosravi et al., 2016). A variety of researchers have developed the integration of GIS with analytical hierarchy process to prepare flood susceptibility maps such as D U Lawal et al., (2014), Elkhrachy (2015), Das (2020) and many more. Doe et al. (2017) used spatial data techniques and AHP to assess potential floodable areas, and the results were very effective. According to Gigovic et al. (2017), AHP in a GIS environment is an efficient method for producing accurate flood risk maps. According to Das (2020), the validation of the flood susceptibility map using GIS and AHP demonstrates a very high level of precision. A compilation of AHP technique with GIS used by researchers around the world is presented in **Table 2.4.**

TABLE 2.4. The Usage of AHP with GIS Around The World by Researchers

Series no.	Authors	Year Published	Country of Study Area	Methods used
1	Dano Umar Lawal , Abdul-Nasir Matori , Ahmad Mustafa Hashim , Khamaruzaman Wan Yusof , Imtiaz Ahmed Chandio	2012	Malaysia	GIS / AHP
2	Ismail Elkhrachy	2015	Saudi Arabia	GIS / AHP
3	Matej Vojtek & Jana Vojteková	2019	Slovakia	GIS / AHP
4	Sumit Das	2020	India	GIS / AHP
5	Michael M. Msabi , Michael Makonyo	2020	Tanzania	GIS / AHP

2.8 Validation Methods

Validating a result is crucial in every study as it will indicate whether the finding is accurate and reliable to use for future purposes. There are various ways to conduct validation of flood mapping results. For instance, Ouma et al., (2014) used flood area extent and depth to validate their flood zonation results and obtained up to 92% of accuracy level. Moreover, Siddayao et al. (2014) only used standard consistency index to validate the results and received 0.03 which is reasonable as it is lesser than 0.1. Other than that, the findings by Ibrahim et al., (2020), that integrated AHP with GIS were validated by comparing them to the inventories of landslide events derived from satellite imagery. Moreover, Vilasan and Kapse (2022) used the receiver operating characteristic (ROC) curve approach to verify the prepared flood susceptibility map and their findings are considered as acceptable and excellent. However, in this research study, area under the curve (AUC) method is to be use in final step of this research. This is due to the fact that no training data is required to run the knowledge-based AHP model, unlike ROC (Das et al., 2021). Moreover, researchers widely use AUC method to validate their research (Das et al., 2021; Msabi et al., 2020; (Nsangou et al., 2022).

2.9 Summary of Literature Review

This literature review presents an extensive review of methodologies in this study. Kelantan river basin is vulnerable to flood in Malaysia due to its location in east peninsular Malaysia that is annually affected by northeast monsoon and climate changes. Flood susceptibility map have help researchers around the world to create a better decision for mitigation plan. GIS methods include an excellent framework for manipulating and evaluating all appropriate data in order to create the flood susceptibility map. The compatibility of GIS and AHP is also proven to be accurate in generating the flood map as the early warning system. Area under the curve (AUC) method is suitable to check the validity due to the fact that no training data is needed to run the knowledge-based AHP model. This is why developing flood susceptibility map to assess flood-prone area and validate the final result in study area using GIS and AHP as a tool will be beneficial to the topic study as it will fulfill the objectives of the study.

CHAPTER 3
METHODOLOGY

3.1 Overview

This chapter will explain the methodology used in this study to accomplish the mentioned objectives. Background of study area is also shared in this chapter. Align with the objectives of this study, combination of AHP with GIS is implemented to obtain the final result which is flood susceptibility map of Kelantan and to verify the result with area under the curve (AUC) method. In this study, all influencing factors (parameters) are processed in ArcGIS software and therefore, the maps of parameters were obtained. Furthermore, in AHP, to determine the relative importance of each variable and its weight, a 10 x 10 pairwise matrix is used. To ensure the weighted criteria is acceptable, consistency ratio (CR) is used for further assessment.

3.2 Study Area

Kelantan is located in the northeast corner of Peninsular Malaysia between latitudes 4°33' and 6°14' North, and longitudes 101°19' and 102°39' East, with a total area of 15113.55 km2 and the highest elevation (2,187m) of Mountain Tahan at the Kelantan-Perak border. It is bounded to the north by Thailand's Narathiwat Province, to the south-east by Terengganu, to the west by Perak, and to the south by Pahang. The major river in Kelantan is Kelantan river which located in the northern Kelantan and met at the convergence of Galas river and Lebir river close to Kuala Krai district. Based on **Figure 3.1**, Gua Musang is located in upstream, Kuala Krai, Jeli, Tanah Merah and Machang is in mid-stream and the rest of Kelantan district which are Pasir Mas, Pasir Puteh, Tumpat, Bachok and Kota Bharu are in downstream. According to the International Hydrological Programme (IHP United Nations), the drainage basin of the Kelantan River covers approximately 13,100 km2 and accounts for more than

85 percent of Kelantan state. It is made up of flat to mildly sloping regions in the north and steep scrapes and greater slopes in the south of the drainage basin (Pradhan et al., 2009). Approximately 95% of its basin is steep mountain terrain rising to a height of 2,135 m (Nashwan et al., 2018).

Based on the geographical location adjacent to the shore of the South China Sea and the settlement expansion on flat topography, Kelantan is highly vulnerable to floods, particularly during the northeast monsoon seasons, which occur from November to March (Yahaya et al., 2015). According to Wong et al., (2016), the northeast zone of peninsular Malaysia, which includes Kelantan and other eastern coast has the highest average rainfall of 2940 mm/year. During the worst flooding of 2014 in Kelantan, the rain continuously pouring from 14th to 19th December 2014 and the rivers started to overflow into their surroundings area on 17th December. When the discharge of river is increased due to the intense and prolonged rain, the water volume at the upstream increased and lead to overflow at the intersection of Kelantan River, Galas River, and Lebir River.

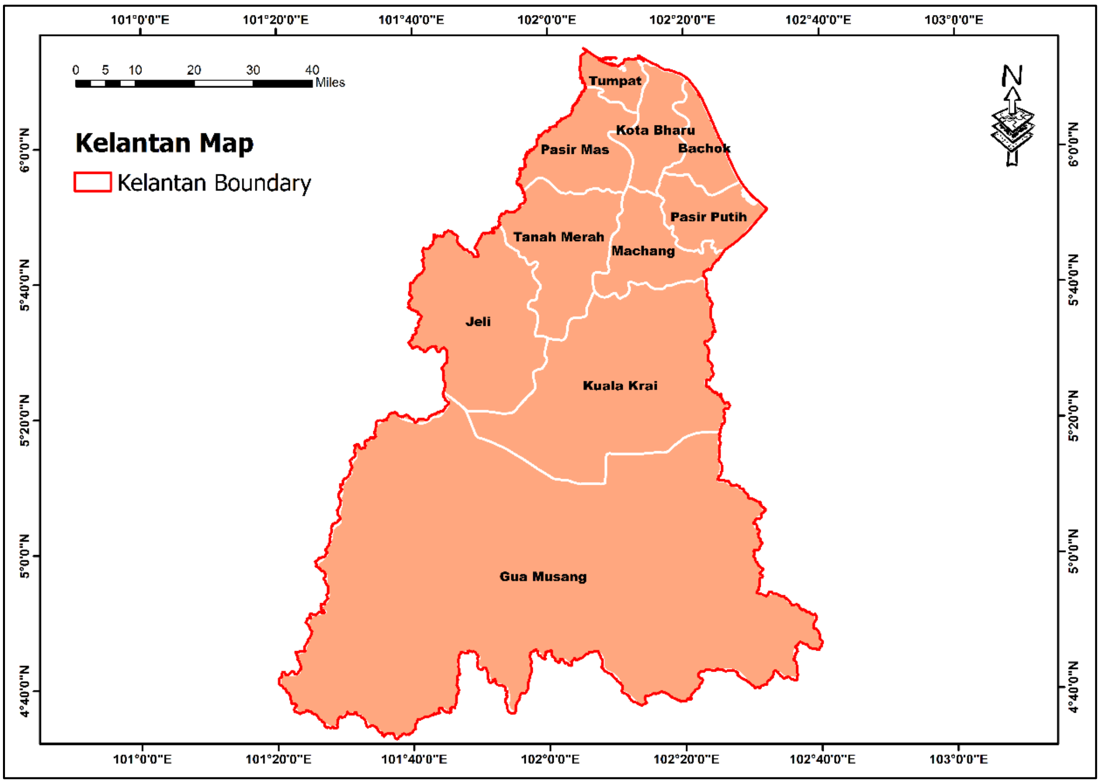


FIGURE 3.1. Map of Kelantan, Malaysia

3.3 Geospatial Data Source and Influencing Factors

The main methodology of this study is GIS-based multi-criteria decision analysis for flood susceptibility mapping. To create a susceptibility map of the research area, it needs a number of multi-source geospatial datasets. Hence, the influencing factors are gathered from variety of sources including digital elevation model (DEM), Landsat 8 OLI and rainfall as shown in **Figure 3.3.** The spatial database for flood influencing factors included rainfall, geology, distance from river, land use, topographic wetness index (TWI), stream power index (SPI), slope, drainage density, normalized difference vegetation index (NDVI) and digital elevation model (DEM). Based on **Figure 3.2**, five factors can be obtained from extraction of DEM using spatial analyst tool in ArcGIS software. The process to obtain slope map is quite direct from DEM raster. However, TWI and SPI have to obtained by extracting flow direction and flow accumulation and calculated using raster calculator through spatial analyst tool. Using the same flow accumulation raster, two factors were obtained by using spatial analyst tool which are density drainage and distance from drainage

Flood susceptibility variables were divided into five categories: very low susceptibility, low susceptibility, moderate susceptibility, high susceptibility, and very high susceptibility. The classes are determined by the significance of flood mapping criteria. In a GIS, all elements (the factors) are combined using the Weighted Linear Combination (WLC) method with the weights calculated (Matori et al., 2014). The final computation of the flood forecasted areas are obtained by overlaying and calculating the thematic layers using weighted overlay (special analyst). The results of the final analysis made it possible to map the flood plains in the study area.

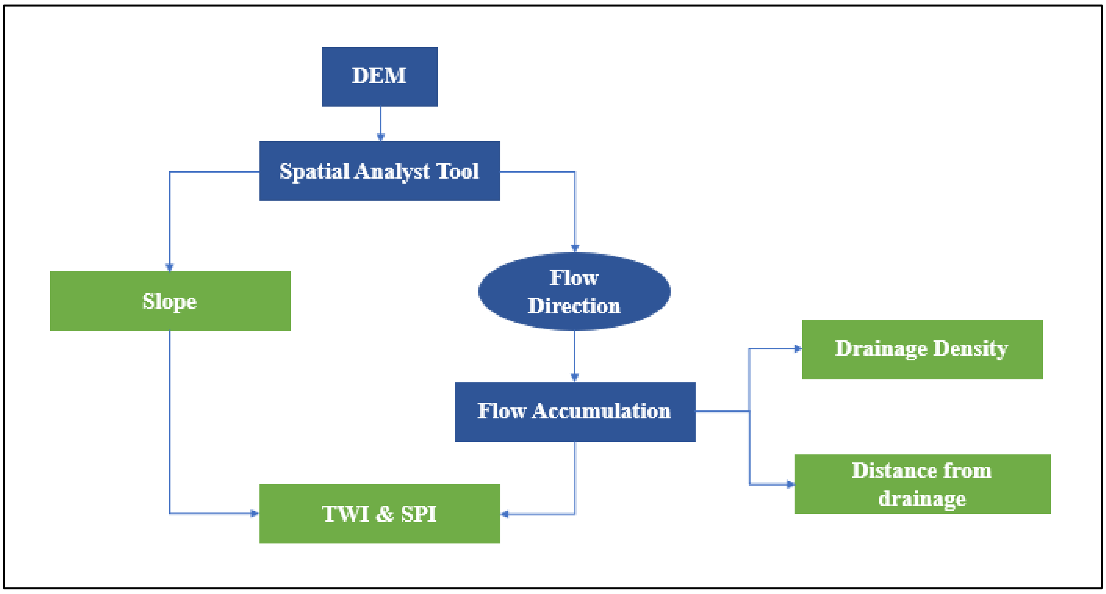


FIGURE 3.2. Methodology Flowchart of Collecting Data Using ArcGIS

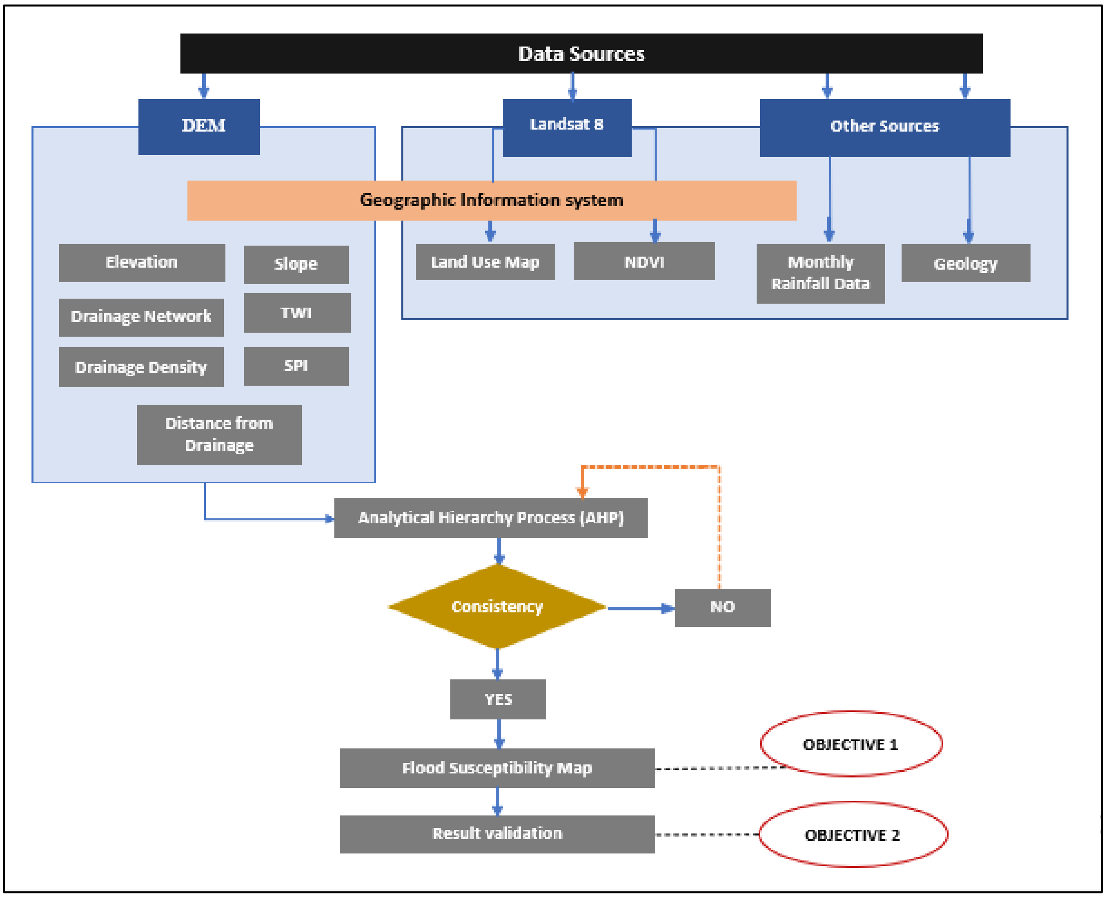


FIGURE 3.3. The Adapted Methodology to Produce Flood Susceptibility Map of Kelantan Region.

3.3.1 Elevation

According to Mojaaddadi et al.,(2017) in their research, elevation is the most significant factor influencing flood occurrence. The drain always flows rapidly from high to low elevations. Low-lying areas are more prone to flash flooding than high-altitude areas (Dahri and Ubaidah, 2017). **Figure 3.4** shows the elevation map of Kelantan. The elevation map was computed from a Digital Elevation Model (DEM) in ArcGIS. The raster file was obtained from the United States Geological Survey (USGS) website and further processed the raster file in ArcGIS. The elevation varies from the lowest to highest in meters (25 - 2183). The highest elevation indicates the upstream of Kelantan and the lowest elevation in the upper part of Kelantan's map is the downstream of Kelantan.

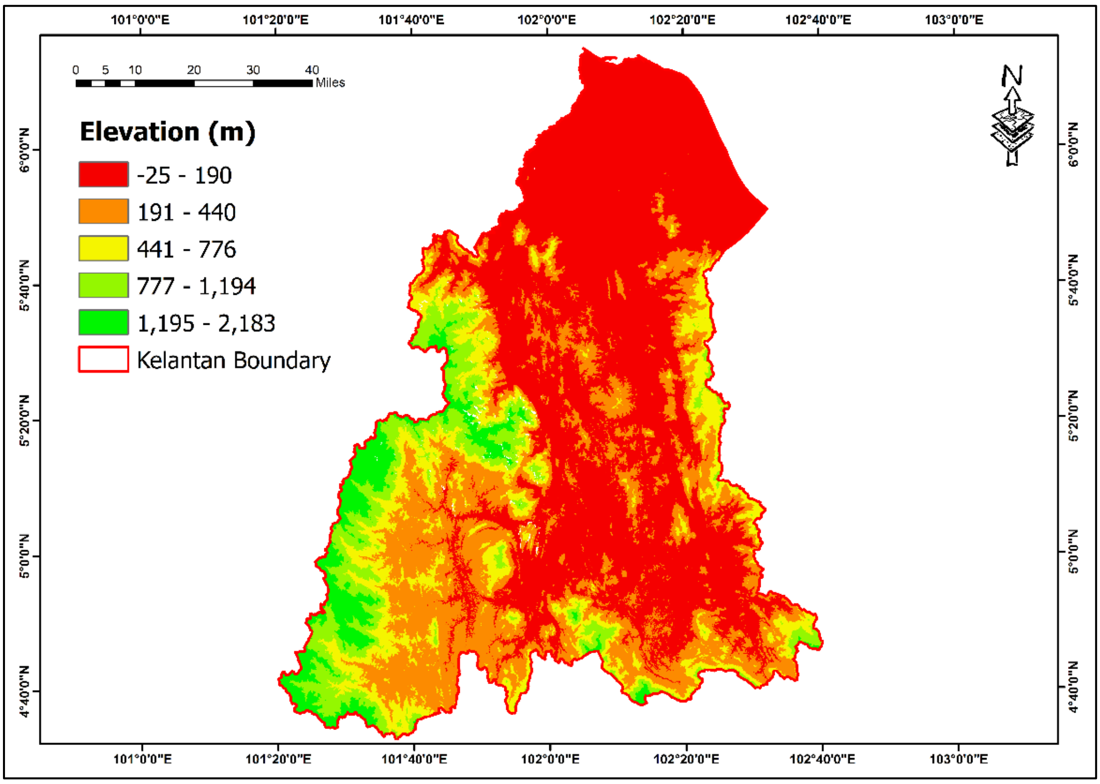


FIGURE 3.4. Elevation Map of Kelantan

3.3.2 Rainfall

Rainfall is a major cause of flooding (Das & Gupta, 2021). Flooding is frequently affected by severe rains, which prevent river systems from transporting excess water. When the process of infiltration cannot be done, the excess water due to rainfall will flow down as surface runoff because of gravity. It is most certainly crucial as Kelantan is highly vulnerable to floods, especially when Kelantan is one of the northeast states that have to go through annual monsoon. **Figure 3.5** illustrates the monthly rainfall map of Kelantan in 2020. The monthly rainfall data (2020) were obtained from Climatic Research Unit (CRU) website. The rainfall varies from lowest (2485 mm) to the highest (5846 mm). It is observed that Jeli and a minor part of Gua Musang district are in high and very high of monthly precipitation respectively. Furthermore, Kuala Krai and Tumpat show in very low monthly rainfall.

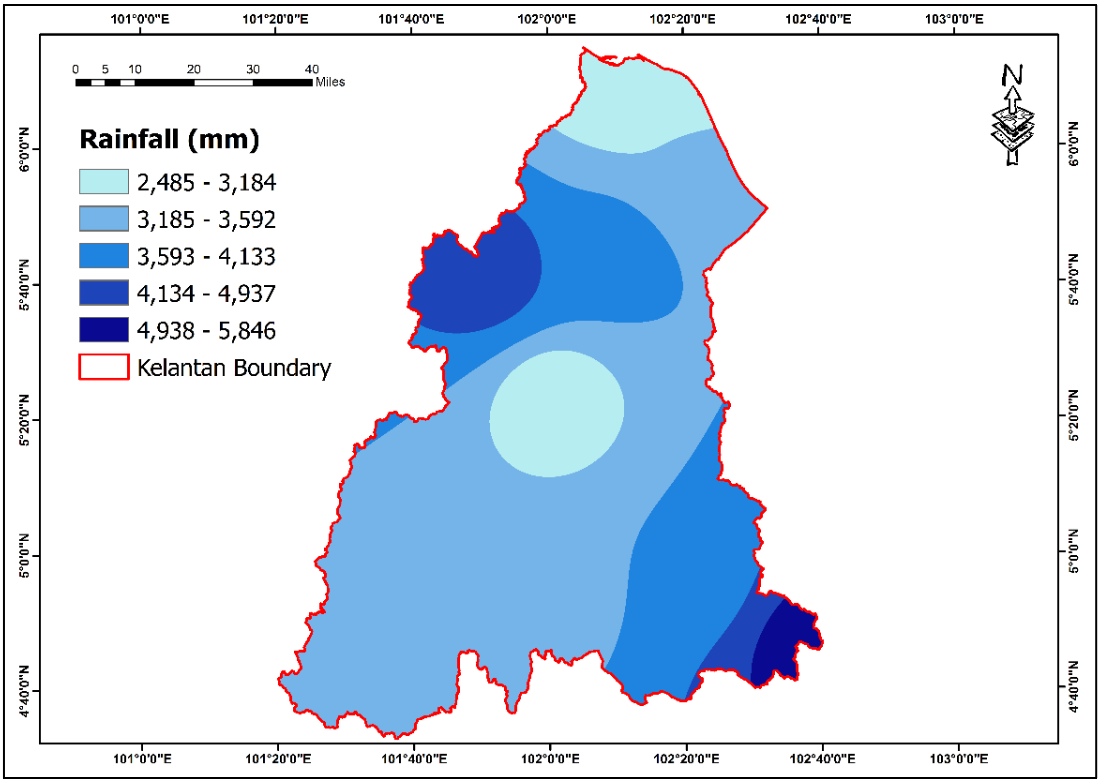


FIGURE 3.5. Monthly Rainfall Map of Kelantan

3.3.3 Topographic wetness index (TWI)

Beven et al. (1984) demonstrated the TWI as an indicator determining areas vulnerable to wetland surfaces and regions with a high possibility for generating overland current flow. Das et al., (2021) identified TWI as a significant aspect in flood susceptibility mapping. TWI map was computed from slope data and flow accumulation that can be obtained from DEM data. Using **Equation 3.1,** TWI is calculated using raster calculator from spatial analyst tool in ArcGIS software. **Figure 3.6** shows the TWI map of Kelantan. TWI values vary depending on the landscape's topography. Area with greater upslope drainage areas and flatter slopes will therefore have greater TWI values, showing a greater proclivity for runoff. The TWI values vary from 2.1 to 19.8. It is observed that the upper part of Kelantan map is mostly covered in high value of TWI. This shows that the affected regions have high runoff.

$$TWI = In\left(\frac{As}{tan\beta + C}\right) \qquad \text{Equation 3.1}$$

where As = total area of upslope drainage, tanβ = local slope gradient, C = 0.001

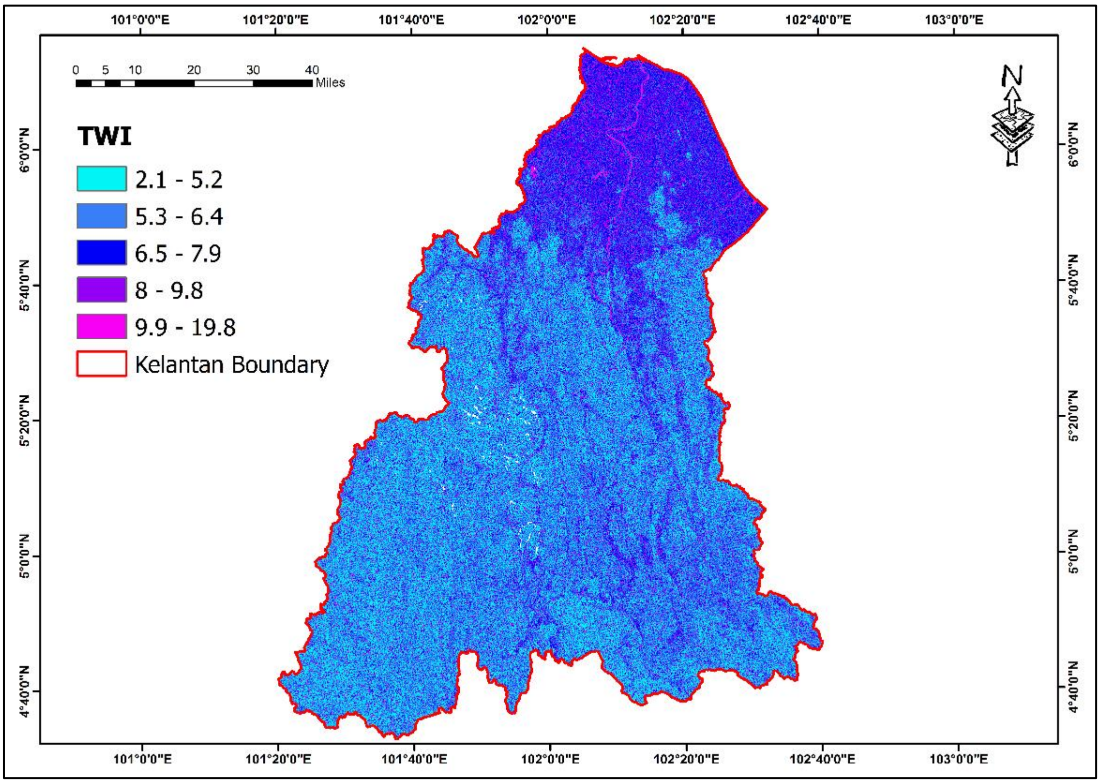


FIGURE 3.6. TWI Map of Kelantan

3.3.4 Drainage density

Since larger drainage density leads to greater surface runoff, so the extent of the flood vulnerability area is determined by the drainage density of a given area (Kumar et al., 2007). The drainage density map was computed from flow accumulation which can be obtained from DEM data using ‘line density’ in spatial analyst tools through ArcGIS software. **Figure 3.7** shows the drainage density map of Kelantan. The values ranked from lowest (0-0.4) to the highest (1.5-1.8) in km-^{1}. It is observed that very high drainage density is covered in the center of Kelantan map which located in Kuala Krai. other than that, the yellow region spotted in the result shows high drainage density are mostly covered by major river basins in Kelantan.

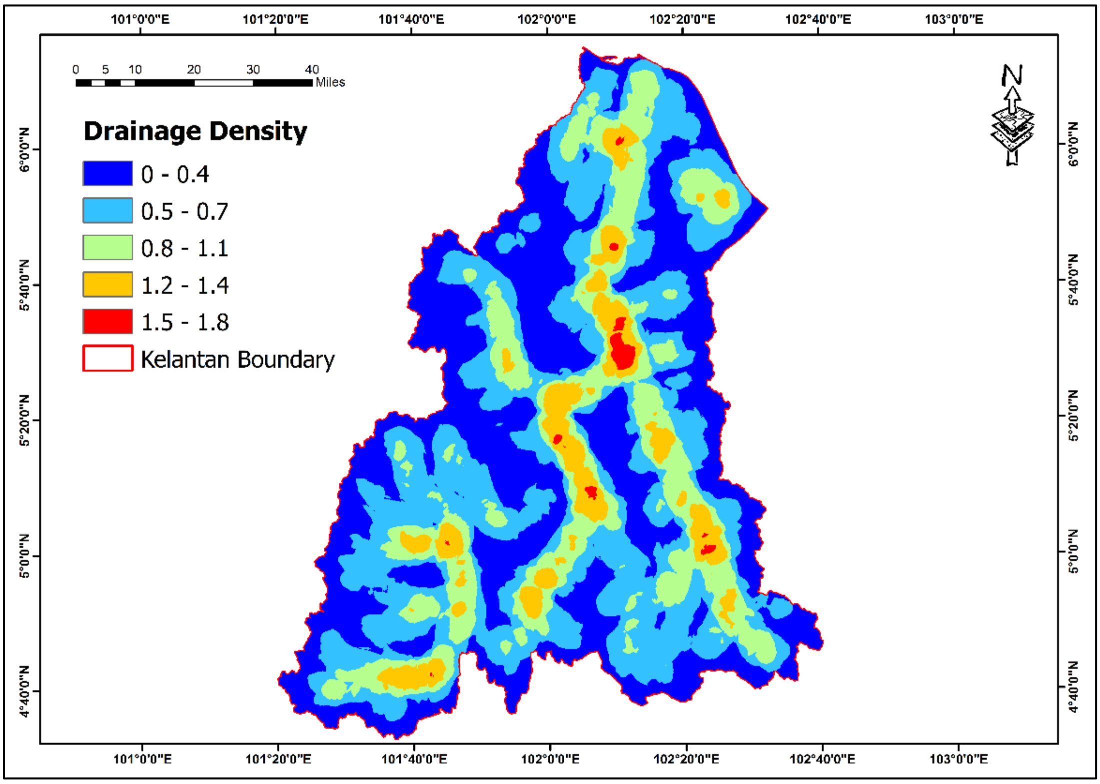


FIGURE 3.7. Drainage Density Map of Kelantan

3.3.5 Distance from drainage

Floods are more common in areas near the drainage than in the distant areas of the rivers (Mahmoud and Gan, 2018). Das (2019) considered 500 m to be the most vulnerable to floods in Western Ghat rivers, and above 2000 m to be extremely unlikely. The map generated for distance from drainage from DEM data using ‘Euclidean distance’ in spatial analyst tools through ArcGIS software. **Figure 3.8** illustrated the map of distance from drainage in Kelantan. It is observed that the study area that fall up 2001 m to 5000 m are considered as areas that are less likely to flood. Meanwhile, the areas that fall within 0 – 2000 m are predicted to be prone to flood.

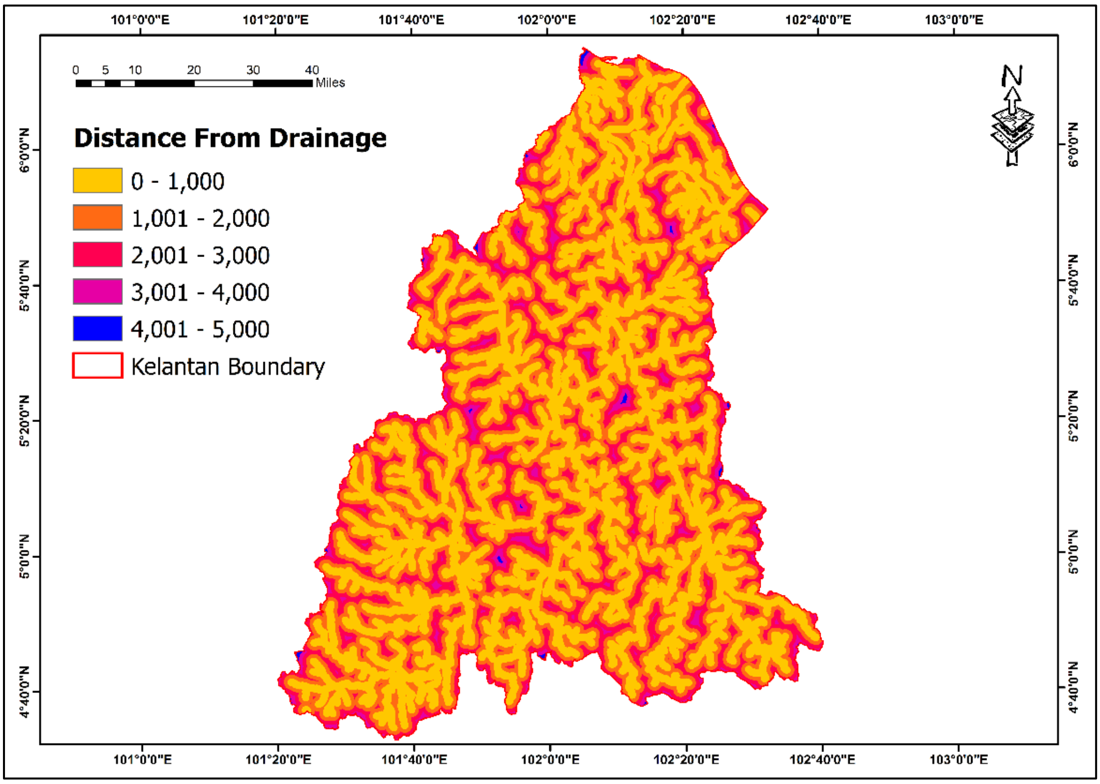


FIGURE 3.8. Distance From Drainage Map of Kelantan

3.3.6 Stream power index (SPI)

SPI is defined by Jebur et al. (2014) as the flowrate with power of erosion of the flowing water within a designated location. The lower the value of SPI, the higher the chances of flood occurrence. The SPI map was generated using slope data and flow accumulation that can be obtained from DEM data. Using **Equation 3.2** (Moore et al., 1991**),** SPI is calculated using raster calculator from spatial analyst tool in ArcGIS software. **Figure 3.9** shows the SPI map of Kelantan. Based on the figure, it illustrates that most of area in Kelantan fall under the high value of SPI. The value of SPI ranges from -5.2 as the lowest to 3.7 as the highest.

$$SPI = Ca\ x\ tan\ s \qquad \text{Equation 3.2}$$

Where Ca = catchment area, tan s = slope

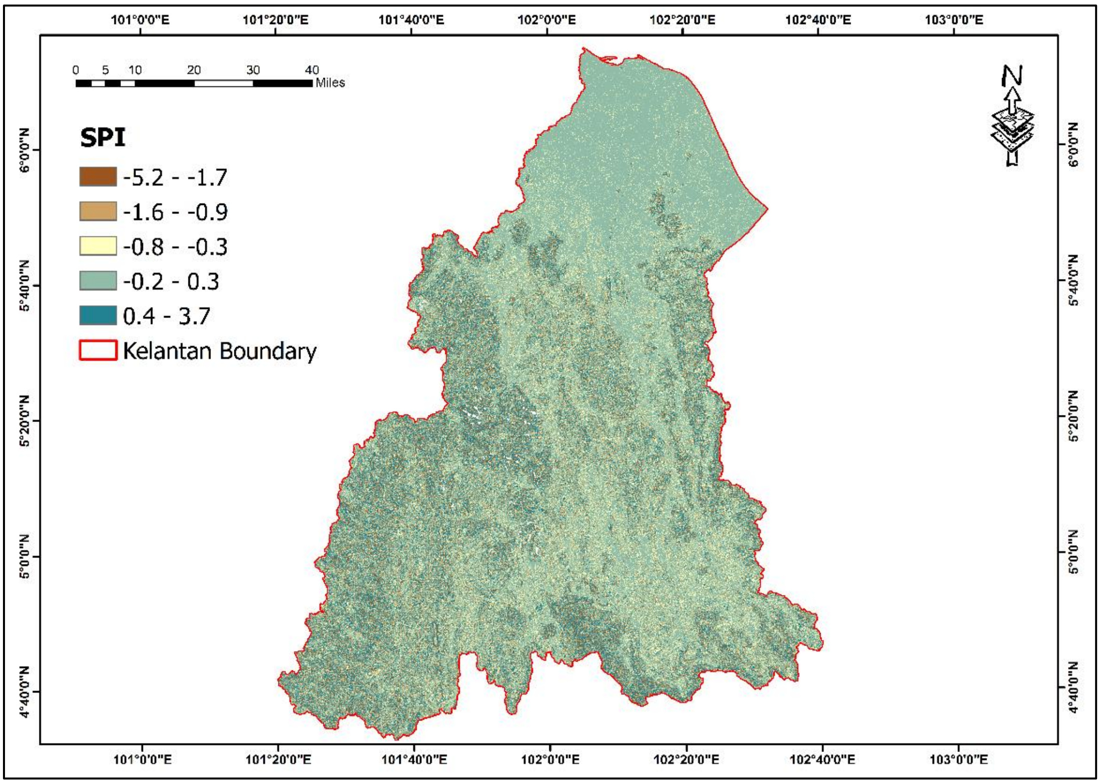


FIGURE 3.9. SPI map of Kelantan

3.3.7 Slope

The possibility of a flood increment as the slope of an area declines (Das et al., 2021). Slope influences the path and volume of runoff water that reaches a site. A flat surface can make runoff to flow quickly which leading the vulnerability of the area to be flooded. However, a rough surface can make the runoff move slower and delay flooding. The slope map was computed from DEM through ArcGIS software using spatial analyst tool. **Figure 3.10** demonstrates the map of slope in Kelantan. The value of slope is in the unit of degree. The values ranked from lowest (0 - 6.8) to the highest (32.6 – 75.3). The north part of Kelantan indicates that the slope is very low to be compared to slope in west part of Gua Musang.

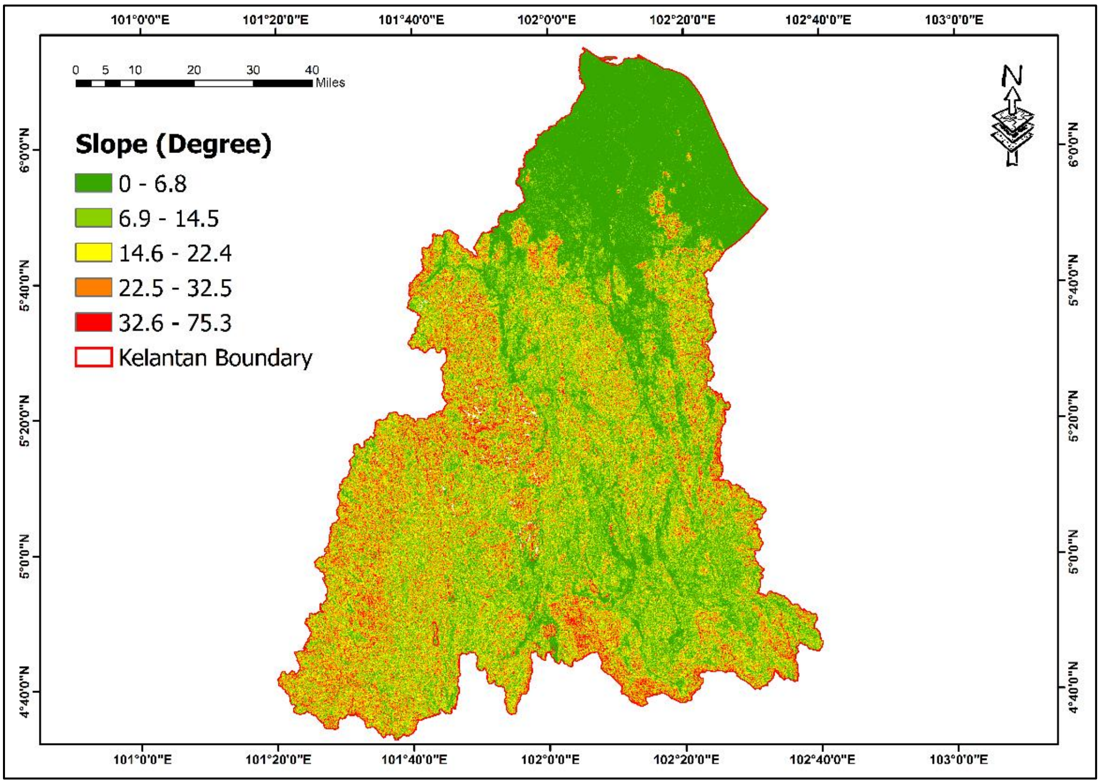


FIGURE 3.10. Slope map of Kelantan

3.3.8 Land Use/Land Cover (LULC) and Normalized Differential Vegetation Index (NDVI)

Land use and land cover are important in flood mapping as it is related to soil stability and infiltration. The presence of dense vegetation on the surface slows the water's travels from the sky to the ground, reducing runoff (Ouma & Tateishi, 2014). Moreover, impermeable surface such as concrete cannot absorb most of the water and lead to the increment of surface runoff. The LULC map was computed from 2020 Landsat 8 OLI imagery received from the United States Geological Survey (USGS) website. **Figure 3.11** presents the land use-land cover map of Kelantan. From the LULC map obtained, 35% of Kelantan is consists of forest, 53% for agricultural activities, 13% of settlements and <1% for water body.

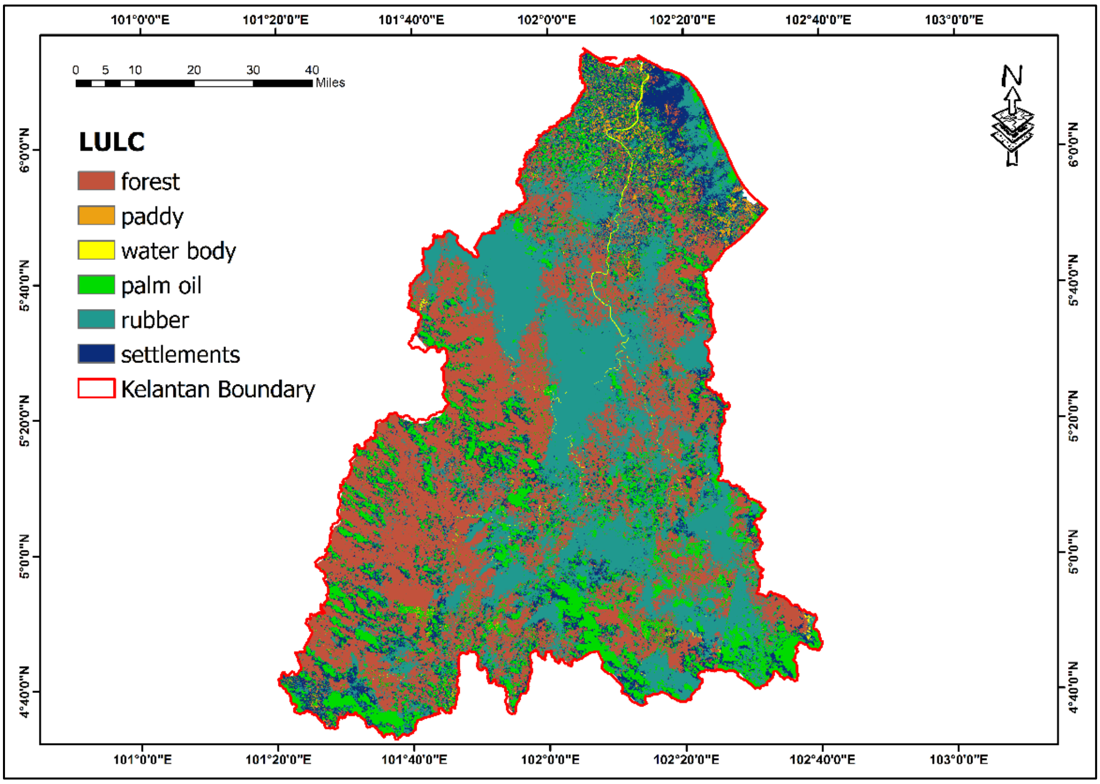


FIGURE 3.11. Land Use/ Land Cover map of Kelantan

3.3.9 Normalized Differential Vegetation Index (NDVI)

The normalized differential vegetation index is frequently used to measure vegetation as a flood defense factor because it reduces runoff and serves as a barrier (NDVI) (Tehrany et al., 2014). In Singh et al., (2016)'s paper, NDVI is used to evaluate the change in land use/land cover in India. The NDVI is a ground surface reflectance-based index. Moreover, NDVI scale runs from -1 to +1. A greater NDVI value indicates the existence of healthy vegetation cover, whereas a smaller value indicates sparse vegetation. The NDVI map is produced from Landsat 8 OLI imagery using **Equation 3.3** for Landsat 8. NDVI is traditionally measured as the ratio of red (R) and near infrared (NIR) values. **Figure 3.12** illustrates the NDVI map of Kelantan which ranges from -0.6 to 0.8. The north part of Kelantan is observed to have lower value of NDVI which indicates the presence of sparse vegetation in the area.

$$NDVI = (Band\ 5 - Band\ 4) / (Band\ 5 + Band\ 4). \qquad \text{Equation 3.3}$$

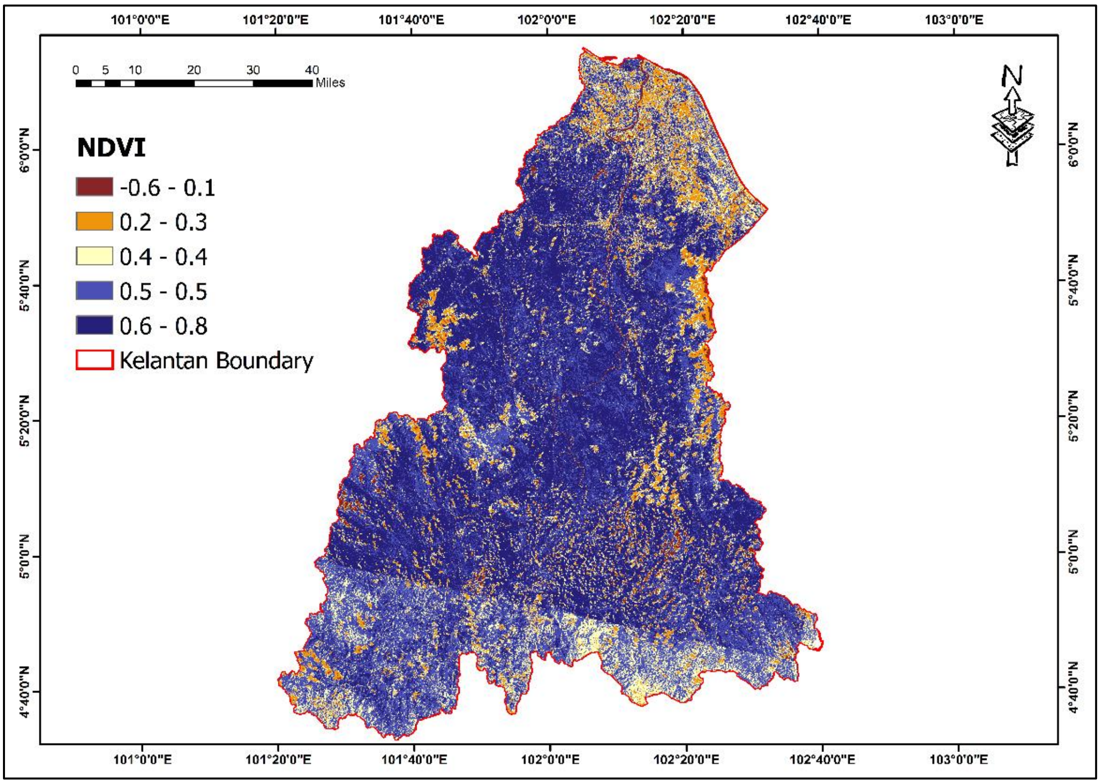


FIGURE 3.12. NDVI map of Kelantan

3.3.10 Geology

The geological characteristic of a region impacts infiltration and runoff generation directly or indirectly, based on the permeability and porosity of soil and rocks (Rahmati et al., 2016). Regions on resistant rock have lower drainage densities and consequently lower risk of flooding (Celik et al., 2012). **Figure 3.13** demonstrates the geology map of Kelantan. The geology map was obtained from Department of Minerals and Geoscience of Malaysia in 2018. From the figure, the study area is divided into five categories of geological which are Quaternary (clay, silt, sand, peat and minor gravel), Triassic (shale, siltstone, sandstone and limestone), Permian (phyllite, slate, sandstone and limestone), Intrusive rock (undifferentiated acid intrusive) and Silurian-Ordovician (schist, phyllite and slate).

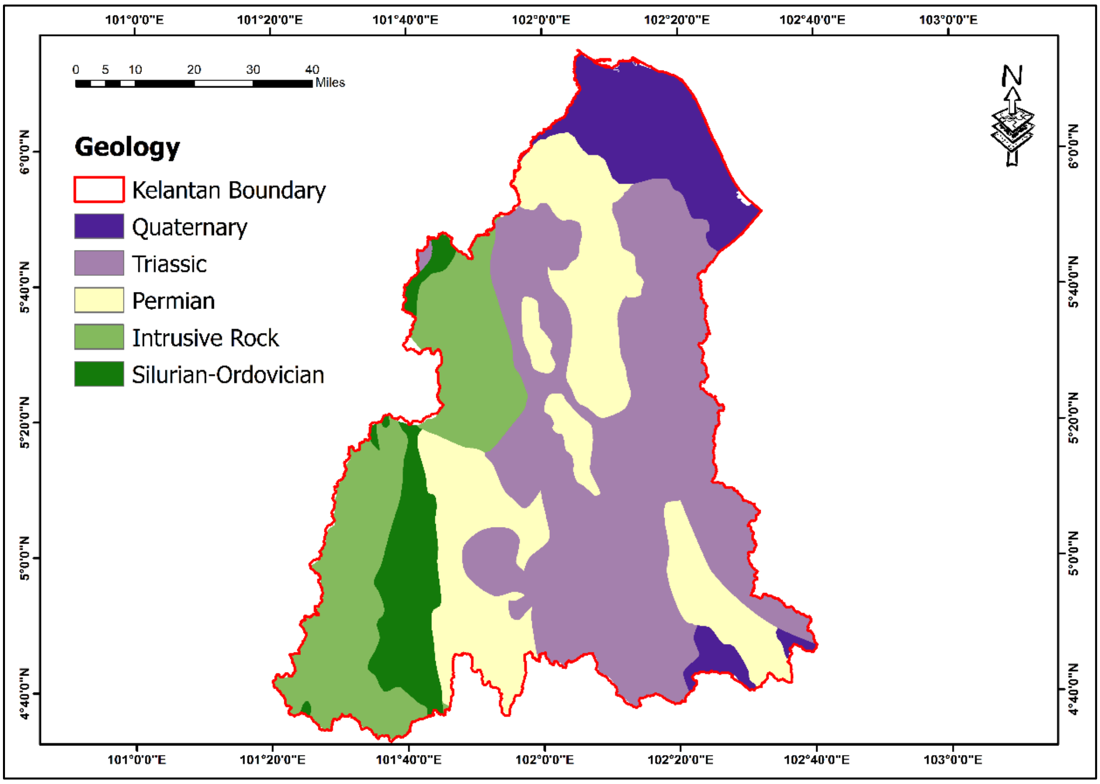


FIGURE 3.13. Geology map of Kelantan

3.4 Weight Linear Combination Technique (WLC)

The major components in using the weighted linear combination approach were to identify the relevance of each criterion (factor) and their corresponding weights (Vojtek et al., 2019). The WLC in AHP procedure was divided into five steps: (a) enumerate the unit factors; (b) assigned the unit factors in hierarchical order; (c) assigned numerical values based on their importance; (d) a comparison matrix was produced; (e) computed the normalized eigenvector that determined the weights of each unit factor. When assigned numerical values, expert judgement and a literature review were used to estimate criteria scores and relative weights on a nine-point continuous scale (Saaty, 1980) based on the relative importance of the various components (**Table 3.1).** The consistency ratio (CR) is used in the study to measure the reliability of the pairwise comparison matrix. This can be obtained by calculating Consistency Index (CI) using **Equation 3.4 .**

$$CI = \frac{\lambda max - n}{n - 1} \qquad \text{Equation 3.4}$$

Where λmax is principal eigenvalue of the matrix and n is number of the criteria. To assess whether the pairwise comparison matrix is consistent or not, the consistency ratio (CR) is calculated using **Equation 3.5.**

$$CR = \frac{CI}{RI} \qquad \text{Equation 3.5}$$

Where RI is a function factor of the matrix order in pairwise matrix dependent on the sample size (Ibrahim et al., 2020). If the consistency ratio value is less than or equal to 10%, it is acceptable. However, if the CR value is greater than 10%, the subjective assessment should be reconsidered.

TABLE 3.1. Criteria Weight of Pairwise Comparison Matrix Scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the goal.
3	Moderate importance	Slightly favor one element over another.
5	Strong Importance	Strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another
9	Extreme importance	The evidence in favor of one element over another is of the greatest overall order of confirmation.
2,4,6,8 can be used to express intermediate values		

CHAPTER 4 :
RESULT AND DISCUSSION

4.1 Overview

This chapter will discuss the final results of this study according to the objectives of the study. Therefore, food susceptibility map for Kelantan is produced by utilizing GIS and AHP method. The result of weighted criteria using AHP will be discuss in this chapter as well as the final map of flood susceptibility map. The chapter will further discuss the validation method findings that have been obtained in this study.

4.2 Flood Susceptibility Map

This section will be divided into two parts where the weighted criteria is obtained by using pairwise comparison matrix in AHP. The next part is where the flood susceptibility map is produced using weighted overlay method in GIS.

4.2.1 Weight Linear Combination Technique (WLC)

After appointed relative weights on a nine-point continuous scale (Saaty, 1980) based on the relative significance of the various components, a comparison matrix was produced with the diagonal components equal to 1. For instance, the first row which is rainfall will be of equal importance to rainfall. Thus, in the next row when NDVI is compare with NDVI, it will give equal importance and so on. Next, the sum of each value in the same column is calculated **(Table 4.1).**

Afterwards, normalized pairwise matrix is calculated by dividing all the components of the column with sum of the column in comparison matrix. The criteria weights are calculated by dividing the sum of the components in the row with the number of criteria **(Table 4.2).** The greater the weight of a criterion, the greater its importance in the overall calculations (Malczewski, 1999). In this case, rainfall is the most significance in contributing flooding because it has the highest weight criteria which is 26.2 % and the least significance is SPI with 2.95%. From the weight criteria obtained, the top three influencing factors of flood occurrence are rainfall, distance from drainage and drainage density.

TABLE 4.1. Pair-Wise Comparison Matrix

Parameters	Rainfall	NDVI	TWI	SPI	Slope	Land Use	Geology	Elevation	Drainage Density	Distance to river
Rainfall	1	5	5	5	5	5	5	3	3	1
NDVI	1/5	1	3	3	1/2	3	2	1	1/3	1/3
TWI	1/5	1/3	1	1	1/3	1/3	1/3	1/5	1/2	1/2
SPI	1/5	1/3	1	1	1/3	1/3	1/3	1/5	1/3	1/3
Slope	1/5	2	3	3	1	3	3	1	1/3	1/3
Land Use	1/5	1/3	3	3	1/3	1	2	1	1/3	1/3
Geology	1/5	1/2	3	3	1/3	1/2	1	2	1/2	1/2
Elevation	1/3	1	5	5	1	1	1/2	1	1	1
Drainage Density	1/3	3	2	3	3	3	2	1	1	1
Distance to river	1	3	2	3	3	3	2	1	1	1
Col Sum	4	16.50	28	30	14.83	20.17	18.17	11.40	8.33	6.33

TABLE 4.2. Normalized Pairwise Matrix and Final Weights (Wc)

Parameters	Rainfall	NDVI	TWI	SPI	Slope	Land Use	Geology	Elevation	Drainage Density	Distance to river	Weight (Wc)
Rainfall	0.26	0.30	0.18	0.17	0.34	0.25	0.28	0.26	0.36	0.16	26.23%
NDVI	0.05	0.06	0.11	0.10	0.03	0.15	0.11	0.09	0.04	0.05	7.86%
TWI	0.05	0.02	0.04	0.03	0.02	0.02	0.02	0.02	0.06	0.08	3.37%
SPI	0.05	0.02	0.04	0.03	0.02	0.02	0.02	0.02	0.04	0.05	2.95%
Slope	0.05	0.12	0.11	0.10	0.07	0.15	0.17	0.09	0.04	0.05	9.60%
Land Use	0.05	0.02	0.11	0.10	0.02	0.05	0.11	0.09	0.04	0.05	6.14%
Geology	0.05	0.03	0.11	0.10	0.02	0.02	0.06	0.18	0.06	0.08	6.64%
Elevation	0.09	0.06	0.18	0.17	0.07	0.05	0.03	0.09	0.12	0.16	9.41%
Drainage Density	0.09	0.18	0.07	0.10	0.20	0.15	0.11	0.09	0.12	0.16	13.11%
Distance to river	0.26	0.18	0.07	0.10	0.20	0.15	0.11	0.09	0.12	0.16	14.69%

Figure 4.1 illustrates the graph of weighted criteria percentage. Based on the figure, rainfall is classified for 26% which indicates high significance to be compared with other factors. Other than that, distance from drainage and drainage density recorded 15% and 13% significance, respectively. Elevation and slope factors obtained for 9% and 10% respectively. These two factors have close value of weighted criteria as they are very related to each other. Besides, NDVI, land use and geology are classified as 8%, 6% and 7% respectively. These three parameters are very close to each other as they can influence each other outcome. For instance, when an area is consisted of settlement, the value of NDVI will be lower as the health of vegetation are badly affected by land use. This may create surface runoff to flow on top of impermeable surfaces. Lastly, both SPI and TWI are 3% significance to be compare with other factors.

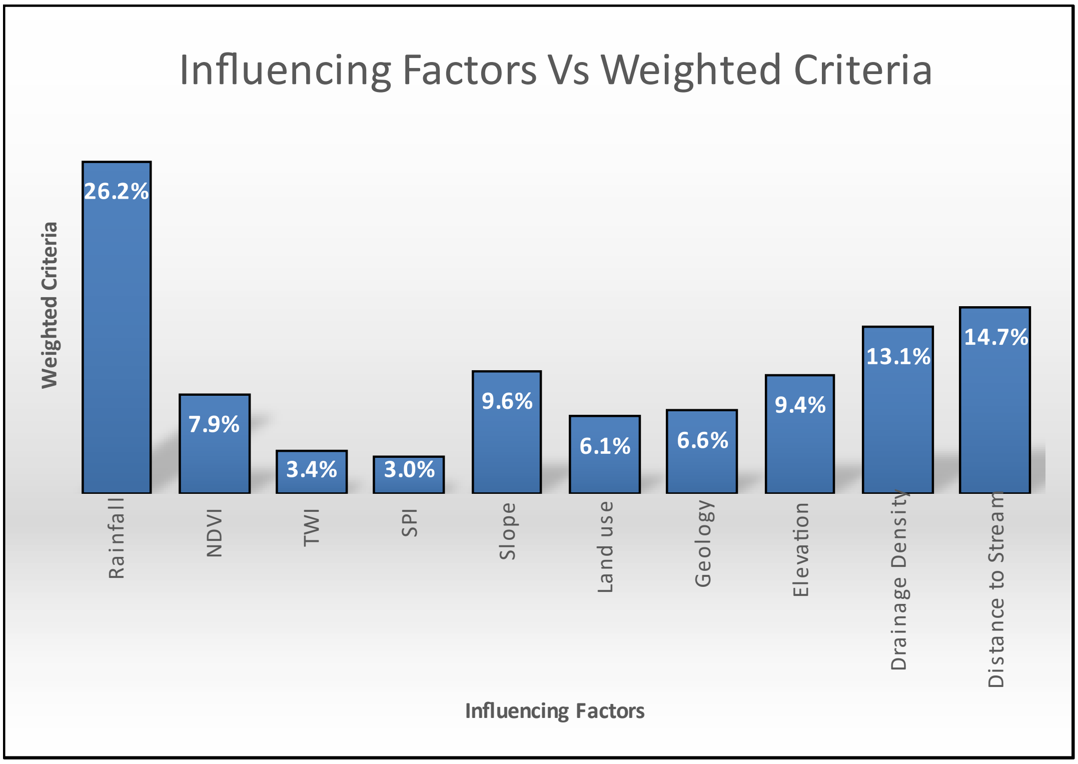
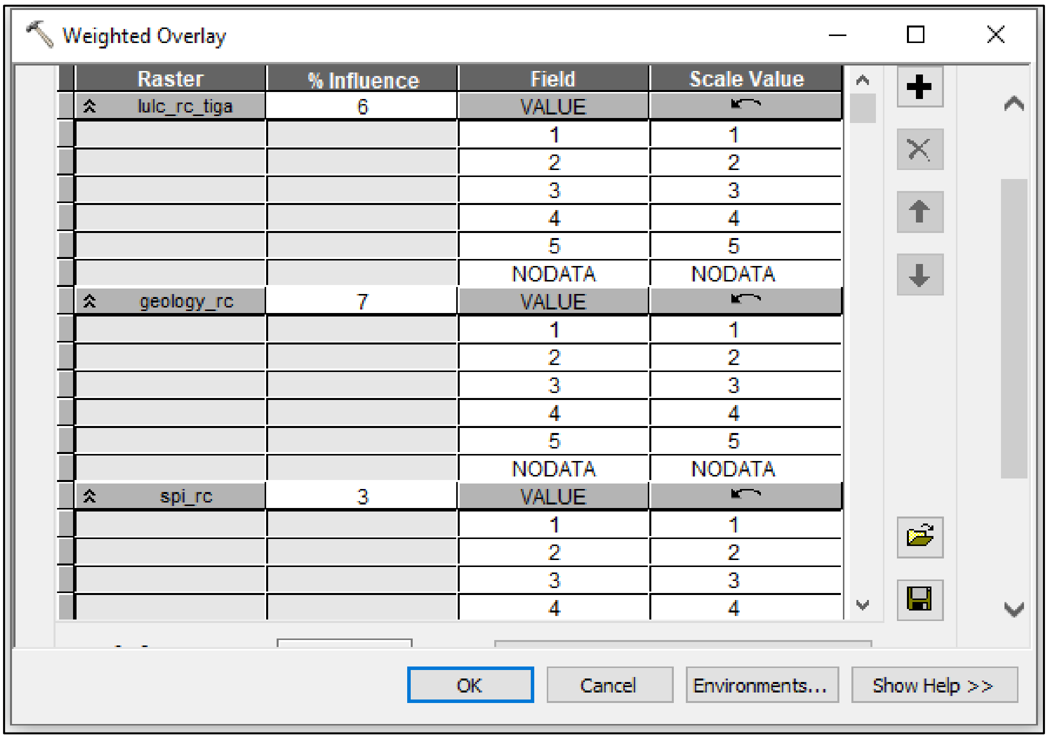


FIGURE 4.1. Normalized Weight Percentage of Each Influencing Factors

Moreover, using **Equation 3.4** and **Equation 3.5,** the consistency ratio (CR) was calculated to evaluate the consistency of the produced ratings. The calculated CR for this study is 0.08, verifying the reliability of the ratings used. The value of CR is considered as acceptable because the obtained value is less than 0.1 or 10%. When the CR ratio is greater than 0.1, the set of evaluations may be too incompatible to be rely on. (Elkhrachy, 2015).

4.2.2 Integration of GIS

After obtaining the weights of the criteria, the susceptibility map is generated using weighted overlay tool in ArcGIS. In order to use this tool, each raster parameters needed to reclassify according to its susceptibility class ratings. Next, the cell attributes are multiplied by their percentage influence and the resulting raster is summed **(Figure 4.2).** Therefore, final map of flood susceptibility was produced after the calculation of weighted overlay. The final flood susceptibility map was classified into five classes of grading method which are very high risk, high risk, moderate, low risk and very low risk **(Figure 4.3)**. **Table 4.1** shows the determined area of flood susceptibility regions as well as the percentage of the individual risked area.



Raster	% Influence	Field	Scale Value
lulc_rc_tiga	6	VALUE	
		1	1
		2	2
		3	3
		4	4
		5	5
		NODATA	NODATA
geology_rc	7	VALUE	
		1	1
		2	2
		3	3
		4	4
		5	5
		NODATA	NODATA
spi_rc	3	VALUE	
		1	1
		2	2
		3	3
		4	4

FIGURE 4.2. Weighted Overlay Method in ArcGIS

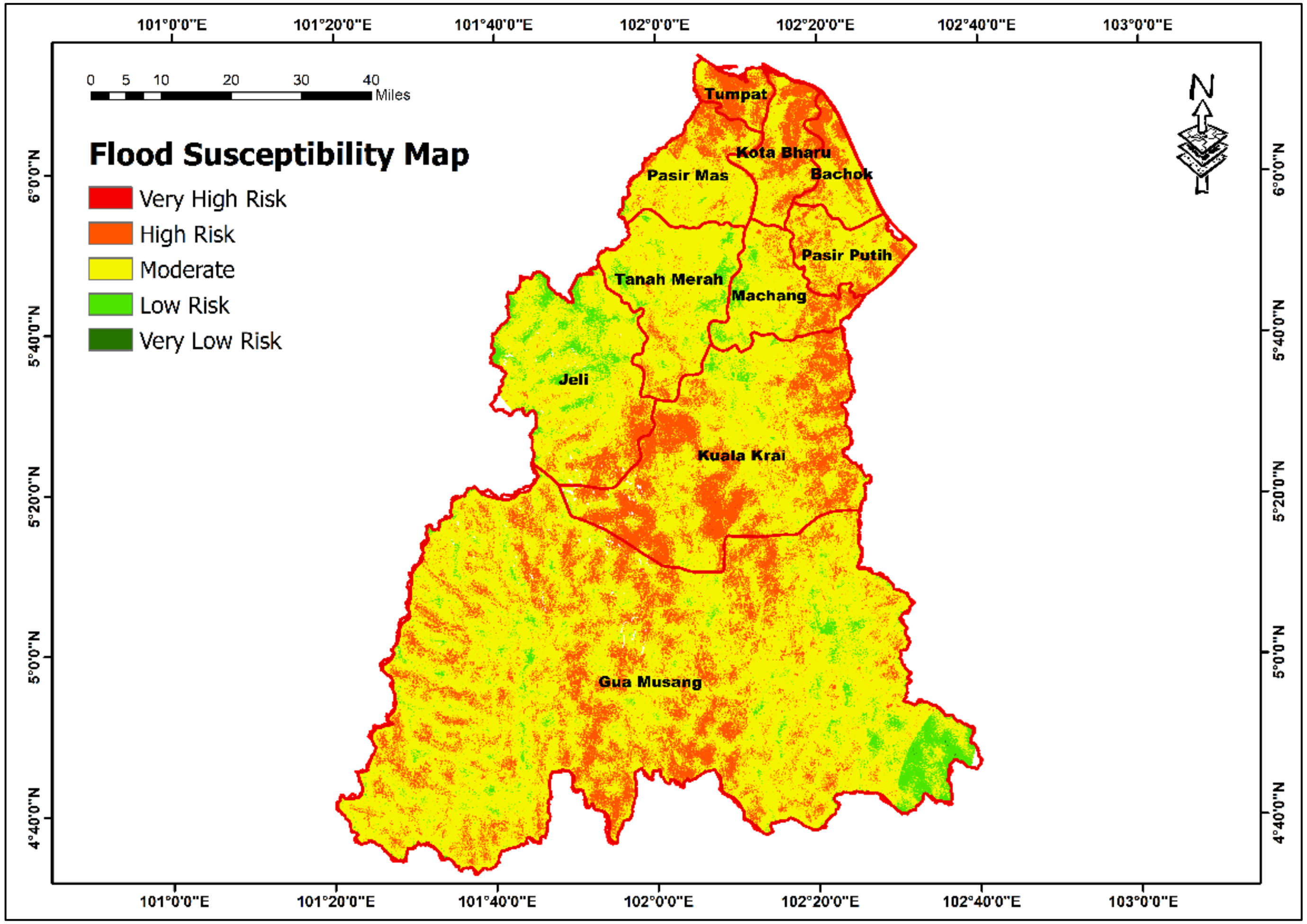


FIGURE 4.3. Flood Susceptibility of Kelantan

TABLE 4.3. Area of flood Susceptibility in km^2 and Percentage

Flood Susceptibility	Area (km^2)	Area (%)
Very High	0.4941	0%
High	3187.0323	21%
Moderate	11036.6667	74%
Low	688.1481	5%
Very Low	0.8442	0%

Moderate flood susceptibility recorded as the highest percentage of area with a value of 74%. Besides, the high flood susceptibility class has 21 % of area, meanwhile, low flood susceptibility class has 5% of Kelantan area. It can be observed that the percentage of high flood susceptibility area is higher than low flood susceptibility area with a difference of 16%. Both Very high and very low flood susceptibility were recorded for 0% of risk. However, because of the percentage of moderate is greater, there is a possibility for it to change into high susceptibility and very high susceptibility if no proper flood management is taken.

High susceptibility flood in Kelantan can be explained by looking at top weight criteria produced through AHP. High susceptibility areas are occupied with settlements such as residentials and agricultures. Besides, it also occupied with paddy, palm oil and rubber **(Figure 3.11).** The reducing vegetation areas make the soil porosity, infiltration rate and evapotranspiration rate become lower. Northern part of Kelantan such as Pasir Mas may have high susceptibility to flood because the distance from river to populated area are close to the Kelantan River. Moreover, in **(Figure 3.7)** it shows that Kuala Krai and the center area of Gua Musang have high density drainage. Even though they have high drainage density, the water capacity especially in Kuala Krai is very high. This is because Kuala Krai is the biggest intersection of river between Sungai Kelantan, Sungai Lebir and Sungai Galas.

Other reason that may cause high susceptibility of flood is because most of the areas have very low elevation. It can be seen that the upper part of Kelantan has low slope as well as low elevation **(Figure 3.4 & Figure 3.10)** This may make the movement of water became quickly to flow and flooded the area. The intensity of rainfall over the area of Kelantan are dominated by Jeli. This may explain the high risk of flood at the bottom part of Jeli as it both have low elevation high intensity of rainfall. Finally, most of low susceptibility flood area are occupied with forest and have a lot of vegetation land.

4.3 Validation of Flood Susceptibility Map

The area under the curve (AUC) based on historical flood events is a powerful tool for verifying such MCDM models due to its simplified nature, thoroughness, and rational correlation with the prediction (Tehrany et al., 2013). AUC measures how well a model can distinctive true positive events from false positive events (Bhalla, 2015). The AUC was calculated using the cumulative percentage of areas with varying levels of flood vulnerability and the cumulative percentage of flood events in the various risk areas (Msabi et al., 2021). According to **Table 4.4** the value of 1.0 is the most excellent accuracy.

TABLE 4.4. AUC classification level (Irawan, 2018)

AUC Range	Classification Level
0.9 - 1.0	Excellent
0.8 - 0.9	Good
0.7 - 0.8	Fair
0.6 - 0.7	Poor
0.5 - 0.6	Failure

The AUC graph is obtained by using ArcSDM tool through ArcGIS. Through the final map of flood susceptibility map and flood inventory data, the graph of AUC is generated. The flood inventory data is the historical flood events in Kelantan from 2019. **Figure 4.3** implies the correlation between inventory points and areas that laid on high and very high susceptibility of flooding. Referring to the graph in **Figure 4.4,** the obtained AUC is 0.711 and considered as fair or acceptable result.

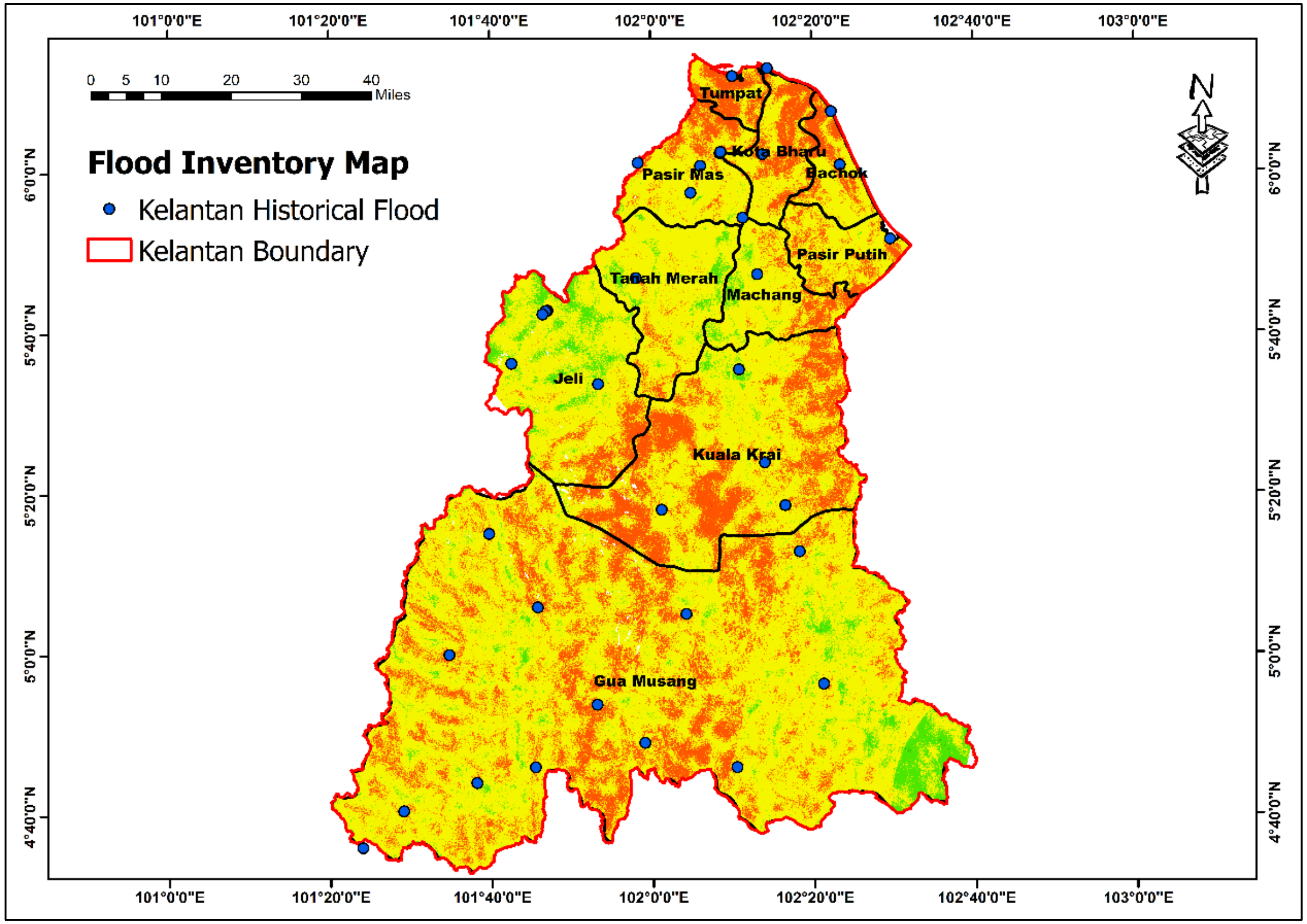


FIGURE 4.4. Flood Inventory Map of Kelantan in 2019

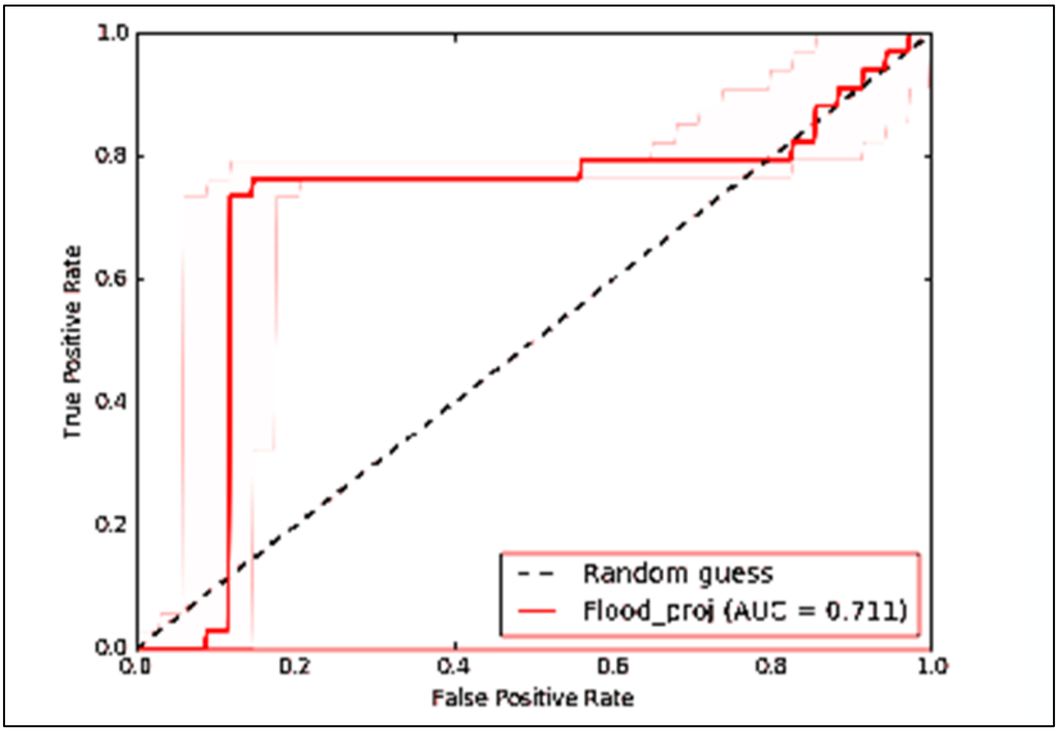


FIGURE 4.5. Area Under the Curve (AUC) Graph for Validation

The less accuracy of the map may be because of the lack judgement in determining the weight criteria of the parameters. The weight criteria of distance from river and drainage density may be too higher than other factors such as land use and elevation. In contrast, drainage density and distance from river may be less contributing to flooding rather than land use and elevation. Other than that, the lack of accuracy may be due to the lack of judgement in classify the susceptibility class rating when reclassifying during the process of weighted overlay method calculation.

CHAPTER 5 :
CONCLUSION & RECOMMENDATION

Kelantan is extremely vulnerable to floods, particularly during the northeast monsoon seasons, which cause infrastructure destruction and casualties. The goal of this study was to create a flood susceptibility map for the entire state of Kelantan using GIS and AHP. To generate the flood map, a total of ten influencing factors were used in GIS using the AHP technique. The final map was classified into five classes of grading method. With a value of 74%, moderate flood susceptibility was recorded as the highest percentage of area. Furthermore, the high flood susceptibility class accounts for 21% of Kelantan's land area, while the low flood susceptibility class accounts for 5% of Kelantan's land area. Moreover, the moderate susceptibility will not stay as moderate forever if the government did not take a proper management on maintaining river and drainage. It could change to high risk and very high risk in a matter of time as the climate change is getting severe days by days. Therefore, this meets the first objective of this study. The final result is further validated by using area under the curve (AUC) method. This method needed the flood susceptibility map and historical flood inventory data of Kelantan to produce AUC graph. The result of AUC for validate the result is 0.7 which considered as acceptable. Thus, this supported the second objective of this study.

Having more judgements from experts and a better literature review in rating scores and relative weight can generate more stable and accurate weight criteria in AHP. Other than that, input data such as flood inventory map should be updated regularly. Concisely, this study supported a fairly accurate flood susceptibility using AHP method for Kelantan area in Malaysia. A high-resolution flood susceptibility map can assist authorities in estimating the location of appropriate flood mitigation structures. The findings of this study may be useful to engineers or governments in preserving Kelantan and preventing flooding in the area of study. The utilization of

AHP in this study to identify flood susceptibility of an area can be implemented to other region as it delivers considerable accurate results. The critical evaluation of the factors used in this study is essential because it can provide detailed and accurate results in flood susceptibility mapping.

REFERENCES

Adger, N.W. (2006). Vulnerability. *Glob. Environ. Chang*. 16, 268–281

Althuwaynee, O. F., Pradhan, B., Park, H. J., & Lee, J. H. (2014). A novel ensemble bivariate statistical evidential belief function with knowledge-based analytical hierarchy process and multivariate statistical logistic regression for landslide susceptibility mapping. *CATENA*, 114, 21–36. https://doi.org/10.1016/j.catena.2013.10.011

Astro Awani. (2021). [INFOGRAFIK] Statistik mangsa banjir (sehingga 6 Januari, 7 petang). astroawani.com. Retrieved from https://www.astroawani.com/video-malaysia/infografik-statistik-mangsa-banjir-sehingga-6-januari-7-petang-1884452

Bates, P.D. (2012). Integrating remote sensing data with flood inundation models: how far have we got? *Hydrol. Proc*. 26 (16), 2515–2521.

Berita Harian. (2021, January 5). Banjir di 6 negeri, lebih 20,000 mangsa dipindahkan. Retrieved from https://www.bharian.com.my/berita/nasional/2021/01/772072/banjir-di-6-negeri-lebih-20000-mangsa-dipindahkan

Beven, K., Kirkby, M., Schofield, N., & Tagg, A. (1984). Testing a physically-based flood forecasting model (TOPMODEL) for three U.K. catchments. *Journal of Hydrology*, *69*(1–4), 119–143. https://doi.org/10.1016/0022-1694(84)90159-8

Bhalla, D. (2015). *A Complete Guide to Area Under Curve (AUC)*. ListenData. https://www.listendata.com/2014/08/learn-area-under-curve-auc.html#comment-form

Butler, R. (2015, January 19). High deforestation rates in Malaysian states hit by flooding. Mongabay Environmental News. Retrieved from https://news.mongabay.com/2015/01/high-deforestation-rates-in-malaysian-states-hit-by-flooding/

Çelik, H.E., Coskun, G., Cigizoglu, H.K. *et al.* (2012). The analysis of 2004 flood on Kozdere Stream in Istanbul. *Nat Hazards* **63,** 461–477. https://doi.org/10.1007/s11069-012-0165-x

Chandio, I.A., Matori, A.N.B., WanYusof, K.B. (2013). GIS-based analytic hierarchy process as a multicriteria decision analysis instrument: a review. *Arab J Geosci* 6, 3059–3066. https://doi.org/10.1007/s12517-012-0568-8

Cinque, P., Crowe, P., and Davies, K. (2003). The role of spatial information and GIS in the management of flood emergencies. Available at: http://www.ses.nsw.gov.au/content/documents/pdf/research-papers/42916/The_role_of_spatial_information_and_GIS_in_the_management_of_floo d_emergencies.pdf

Dahri, N., & Abida, H. (2017). Monte Carlo simulation-aided analytical hierarchy process (AHP) for flood susceptibility mapping in Gabes Basin (southeastern Tunisia). *Environmental Earth Sciences*, *76*(7). https://doi.org/10.1007/s12665-017-6619-4

Dano, U., Lawal, M., Abdul, N. H., Ahmad, M., Chandio, I. A., Sabri, S., Balogun, A. L., and Abba, H. A. (2011). Geographic Information System and Remote Sensing Applications in Flood Hazards Management*: A Review*. 3(9): 933-947.

Danumah, J.H., Odai, S.N., Saley, B.M., Szarzynski, J., Thiel, M., Kwaku, A., Kouame, F.K. and Akpa, L.Y. (2016), “Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques, (cote d’ivoire)”, Geoenvironmental Disasters, Vol. 3 No. 1

Darwin, Kombaitan, B., Yudoko, G., & Purboyo, H. (2018). Application of GIS on determination of flood prone areas and critical arterial road network by using chaid method in Bandung area. *MATEC Web of Conferences*, 147, 02007. https://doi.org/10.1051/matecconf/201814702007

Das, S. (2019). Geospatial mapping of flood susceptibility and hydro-geomorphic response to the floods in Ulhas basin, India. *Remote Sensing Applications: Society and Environment, 14,* 60–74. https://doi.org/10.1016/j.rsase.2019.02.006

Das, S. (2020). Flood susceptibility mapping of the Western Ghat coastal belt using multi-source geospatial data and analytical hierarchy process (AHP). Remote Sensing Applications: *Society and Environment*, 20, 100379. https://doi.org/10.1016/j.rsase.2020.100379

Das, S., & Gupta, A. (2021). Multi-criteria decision based geospatial mapping of flood susceptibility and temporal hydro-geomorphic changes in the Subarnarekha basin, India. *Geoscience Frontiers*, *12*(5), 101206. https://doi.org/10.1016/j.gsf.2021.101206

De Brito, M. M., & Evers, M. (2016). Multi-criteria decision-making for flood risk management: a survey of the current state of the art. *Natural Hazards and Earth System Sciences*, 16(4), 1019–1033. https://doi.org/10.5194/nhess-16-1019-2016

Department of Irrigation and Drainage Malaysia. (2009). DID Manual: Volume 1 - *Flood Management* (Kuala Lumpur: Jabatan Pengairan dan Saliran), 1.1-13.8.

Dou, X., Song, J., Wang, L., Tang, B., Xu, S., Kong, F., Jiang, X. (2017). Flood risk assessment and mapping based on a modified multi-parameter flood hazard index model in the Guanzhong Urban Area, China. *Stochastic Environmental Research and Risk Assessment*, (), –. doi:10.1007/s00477-017-1429-5

Elkhrachy, I. (2015). Flash Flood Hazard Mapping Using Satellite Images and GIS Tools: A case study of Najran City, Kingdom of Saudi Arabia (KSA). *The Egyptian Journal of Remote Sensing and Space Science*, 18(2), 261–278. https://doi.org/10.1016/j.ejrs.2015.06.007

Ghani, A. A., Zakaria, N. A., & Falconer, R. A. (2009). Editorial: River modelling and flood mitigation; Malaysian perspectives. *Proceedings of the Institution of Civil Engineers - Water Management*, *162*(1), 1–2. https://doi.org/10.1680/wama.2009.162.1.1

Gigović, Ljubomir; Pamučar, Dragan; Bajić, Zoran; Drobnjak, Siniša (2017). Application of GIS-Interval Rough AHP Methodology for Flood Hazard Mapping in Urban Areas. *Water*, 9(6), 360–. doi:10.3390/w9060360

Hanifah, R., Isnanto, R. R., & Christyono, Y. (2012). Simulasi Sistem Informasi Geografis (SIG) Pemantauan Posisi Kendaraan Via SMS Gateway. *Transmisi: Jurnal Ilmiah Teknik Elektro*, 12(2), 45-49. https://doi.org/10.12777/transmisi.12.2.45-49

Hareez, A.M. (2020). *Spatial Modelling Of Flood Susceptibility In Kelantan Using Gis And Random Forest Machine Learning* (Dissertation submitted in partial fulfilment of the requirements for the Bachelor of Engineering (Hons)). Universiti Teknologi Petronas, Perak Darul Ridzuan, Malaysia.

Hasni, N. A. M. (2014). *The Peninsular Malaysia Flooding - a Spatio-temporal Analysis of Precipitation Records*. UMP.

Hirabayashi, Y., Mahendran, R., Koirala, S. (2013). Global flood risk under climate change. *Nature Clim Change* 3, 816–821. https://doi.org/10.1038/nclimate1911

Hong, H., Tsangaratos, P., Ilia, I., Liu, J., Zhu, A.-X., & Chen, W. (2017). Application of fuzzy weight of evidence and data mining techniques in construction of flood susceptibility map of Poyang County, China. *Science of The Total Environment*, 625(0048–9697), 575–588. https://doi.org/10.1016/j.scitotenv.2017.12.256

Hwang, C.L. and Yoon, K. (1981). Multiple Attribute Decision Making: Methods and Applications. *Springer-Verlag*, New York. https://doi.org/10.1007/978-3-642-48318-9

Ibbitt, R., Takara, K., Mohd. Desa, M.N. & Pawitan, H., (2002). Catalogue of Rivers for Southeast Asia and the Pacific – *Volume IV*. UNESCO-IHP, Jakarta.

Ibrahim, M. B., Harahap, I. S. H., Balogun, A. L. B., & Usman, A. (2020). The use of geospatial data from GIS in the quantitative analysis of landslides. *IOP Conference*

Series: Earth and Environmental Science, *540*(1), 012048. https://doi.org/10.1088/1755-1315/540/1/012048

Irawan, F. (2018). A Comparative Assessment of Random Forest and SVM Algorithms, Using Combination of Principal Component Analysis and SMOTE For Accounts Receivable Seamless Prediction.

Jacinto, R., Grosso, N., Reis, E., Dias, L., Santos, F. D., and Garrett, P. (2015).Continental Portuguese Territory Flood Susceptibility Index – contribution to a vulnerability index, Nat. *Hazards Earth Syst*. Sci., 15, 1907–1919, https://doi.org/10.5194/nhess-15-1907-2015

Jebur, M. N., Pradhan, B., & Tehrany, M. S. (2014). Optimization of landslide conditioning factors using very high-resolution airborne laser scanning (LiDAR) data at catchment scale. *Remote Sensing of Environment*, *152*, 150–165. https://doi.org/10.1016/j.rse.2014.05.013

Kafle. S. K. (2014). *Flood Early Warning Systems in Nepal*: A Gendered Perspective. 10.13140/2.1.5057.6167.

Khalid, M. S., Mustaffa, C. S., Marzuki, M. N., Sakdan, M. F., Sipon, S., Ariffin, M. T., & Shafiai. S. (2015). Failure to React Positively to Flood Early Warning Systems: Lessons Learned by Flood Victims from Flash Flood Disasters: *The Malaysia Experience*. https://doi.org/10.5281/zenodo.1100585

Khan H, Haider S, Saeed K, Ali N. (2008). Assessment of potable water quality of Kohat division and its impact on health. J Chem Soc Pak 30:246–250

Khan, A., Govil, H., Khan, H. H., Kumar Thakur, P., Yunus, A. P., & Pani, P. (2021). Channel responses to flooding of Ganga River, Bihar India, 2019 using SAR and optical remote sensing. *Advances in Space Research.* Published. https://doi.org/10.1016/j.asr.2021.08.039

Khosravi, K., Nohani, E., Maroufinia, E., Pourghasemi, H. R. (2016). A GIS-based flood susceptibility assessment and its mapping in Iran: a comparison between frequency ratio and weights-of-evidence bivariate statistical models with multi-criteria decision-making technique. *Natural Hazards,* 83(2), 947–987. doi:10.1007/s11069-016-2357-2

Khosravi, K., Shahabi, H., Pham, B.T., Adamowski, J., Shirzadi, A., Pradhan, B., Dou, J., Ly, H.B., Grof, ́ G., Ho, H.L., Hong, H., Chapi, K., Prakash, I., (2019). A comparative assessment of flood susceptibility modeling using Multi-Criteria Decision-Making Analysis and Machine Learning Methods. J. Hydrol. 573, 311–323. https://doi.org/ 10.1016/j.jhydrol.2019.03.073

Kittipongvises, S., Phetrak, A., Rattanapun, P., Brundiers, K., Buizer, J. L., & Melnick, R. (2020). AHP-GIS analysis for flood hazard assessment of the communities nearby the world heritage site on Ayutthaya Island, Thailand. *International Journal of Disaster Risk Reduction*, *48*, 101612. https://doi.org/10.1016/j.ijdrr.2020.101612

Koem, C., & Tantanee, S. (2020). Flash flood hazard mapping based on AHP with GIS and satellite information in Kampong Speu Province, Cambodia. *International Journal of Disaster Resilience in the Built Environment*, *12*(5), 457–470. https://doi.org/10.1108/ijdrbe-09-2020-0099

Kumar, P. K. D., Gopinath, G., & Seralathan, P. (2007). Application of remote sensing and GIS for the demarcation of groundwater potential zones of a river basin in Kerala, southwest coast of India. *International Journal of Remote Sensing*, *28*(24), 5583–5601. https://doi.org/10.1080/01431160601086050

Lyu, H. M., Shen, S. L., Zhou, A., & Yang, J. (2019). Perspectives for flood risk assessment and management for mega-city metro system. *Tunnelling and Underground Space Technology*, *84*, 31–44. https://doi.org/10.1016/j.tust.2018.10.019

Mahmoud, S.H., Gan, T.Y., (2018). Multi-criteria approach to develop flood susceptibility maps in arid regions of Middle East. J. Clean. Prod. 196, 216–229. https://doi.org/ 10.1016/j.jclepro.2018.06.047.

Malczewski, J. (1999). GIS and Multicriteria Decision Analysis. John Wiley & Sons.

Malczewski, J. (2007). GIS-based multicriteria decision analysis: a survey of the literature. *Int. J. Geogr*. Inf. Sci. ISSN 20 (7), 703–726. https://doi.org/10.1080/ 13658810600661508.

Mann Kendall Test: A Case Study In Pahang And Kelantan River Basins. *Jurnal Teknologi*, *78*(9–4). https://doi.org/10.11113/jt.v78.9696

Martinez-Taboada, F., & Redondo, J. I. (2020). Variable importance plot (mean decrease accuracy and mean decrease Gini). (Version 1). PLOS ONE. https://doi.org/10.1371/journal.pone.0230799.g002 ([])

Matori, A. N., Lawal, D. U., Yusof, K. W., Hashim, M. A., & Balogun, A. L. (2014). Spatial Analytic Hierarchy Process Model for Flood Forecasting: An Integrated Approach. IOP Conference Series: *Earth and Environmental Science*, 20, 012029. https://doi.org/10.1088/1755-1315/20/1/012029

Menon, J., Edward, J. (2017, April 4). Poor drain maintenance causing floods in the city. Malaysia | Malay Mail. Retrieved from https://www.malaymail.com/news/malaysia/2017/04/04/poor-drain-maintenance-causing-floods-in-the-city/1348775

Mojaddadi, H., Pradhan, B., Nampak, H., Ahmad, N., & Ghazali, A. H. B. (2017). Ensemble machine-learning-based geospatial approach for flood risk assessment using multi-sensor remote-sensing data and GIS. *Geomatics, Natural Hazards and Risk*, *8*(2), 1080–1102. https://doi.org/10.1080/19475705.2017.1294113

Moore ID, Grayson RB, Ladson AR (1991) Digital terrain modelling: a review of hydrological, geomorphological, and biological applications. Hydrol Process 5:3–30

Msabi, M. M., & Makonyo, M. (2021). Flood susceptibility mapping using GIS and multi-criteria decision analysis: A case of Dodoma region, central Tanzania. *Remote Sensing Applications: Society and Environment*, *21*, 100445. https://doi.org/10.1016/j.rsase.2020.100445

Nashwan, M. S., Ismail, T., & Ahmed, K. (2018). Flood susceptibility assessment in Kelantan river basin using copula. *International Journal of Engineering & Technology*, 7(2), 584. https://doi.org/10.14419/ijet.v7i2.10447

NOAA National Severe Storms Laboratory. (2020). Flood Basics. Retrieved from https://www.nssl.noaa.gov/education/svrwx101/floods/

Nsangou, D., Kpoumié, A., Mfonka, Z., Ngouh, A. N., Fossi, D. H., Jourdan, C., Mbele, H. Z., Mouncherou, O. F., Vandervaere, J. P., & Ndam Ngoupayou, J. R. (2022). Urban flood susceptibility modelling using AHP and GIS approach: case of the Mfoundi watershed at Yaoundé in the South-Cameroon plateau. *Scientific African*, *15*, e01043. https://doi.org/10.1016/j.sciaf.2021.e01043

Nurul Ashikin, A., Nor Diana, M. I., Siwar, C., Alam, M. M., & Yasar, M. (2021). Community Preparation and Vulnerability Indices for Floods in Pahang State of Malaysia. *Land*, 10(2), 198. https://doi.org/10.3390/land10020198

Othman, M. A., Zakaria, N. A., Ab. Ghani, A., Chang, C. K., & Chan, N. W. (2016b). ANALYSIS OF TRENDS OF EXTREME RAINFALL EVENTS USING

Ouma, Y., & Tateishi, R. (2014). Urban Flood Vulnerability and Risk Mapping Using Integrated Multi-Parametric AHP and GIS: Methodological Overview and Case Study Assessment. *Water*, *6*(6), 1515–1545. https://doi.org/10.3390/w6061515

Patel, M., Bhatt, B & Vashi, M. (2017). SMART-Multi-criteria decision-making technique for use in planning activities.

Pavan, M., Todeschini, R. (2009). Multicriteria Decision-Making Methods. In: Comprehensive Chemometrics. Elsevier, pp. 585–615. https://doi.org/10.1016/ B978-0-444-64165-6.04035-0

Pourghasemi HR, Moradi HR, Aghda SMF, Gokceoglu C, Pradhan B. (2014). GIS-based landslide susceptibility mapping with probabilistic likelihood ratio and spatial multi-criteria evaluation models (North of Tehran, Iran). *Arab J Geosci* 7(5):1857–1878

Pradhan, B. (2009). Flood susceptible mapping and risk area delineation using logistic regression, GIS and remote sensing. J. Spatial Hydrol. 9 (2), 1–18.

Qi, S., Brown, D. G., Tian, Q., Jiang, L., Zhao, T., and Bergen, K. M. (2009). Inundation extent and flood frequency mapping using LANDSAT imagery and digital elevation models, GISci. *Remote Sens*., 46, 101–127, doi:10.2747/1548-1603.46.1.101.

Rahmati, O., Pourghasemi, H. R., & Zeinivand, H. (2015). Flood susceptibility mapping using frequency ratio and weights-of-evidence models in the Golastan Province, Iran. *Geocarto International*, *31*(1), 42–70. https://doi.org/10.1080/10106049.2015.1041559

Rincón, D., Khan, U., & Armenakis, C. (2018). Flood Risk Mapping Using GIS and Multi-Criteria Analysis: A Greater Toronto Area Case Study. *Geosciences*, 8(8), 275. MDPI AG. Retrieved from http://dx.doi.org/10.3390/geosciences8080275

Rudini, Matori, A. N., Ab Talib, J., & Balogun, A. L. (2018). Application of Geographic Information System (GIS) to Model the Hydrocarbon Migration: Case Study from North-East Malay Basin, Malaysia. *E3S Web of Conferences*, 34, 02027. https://doi.org/10.1051/e3sconf/20183402027

Saaty, T.L., (1980). *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill Book Co*, New York, p. 287.

Saaty, Thomas. (2008). Decision making with the analytic hierarchy process. *Int J Serv Sci. International Journal of Services Sciences*. 1. 83-98.

Saha AK, Gupta RP, Sarkar I, Arora KM, Csaplovics E. (2005). An approach for GIS-based statistical landslide susceptibility zonation with a case study in the Himalayas. *Landslides* 2(1):61–69

Samanta, S., Pal, D. K., & Palsamanta, B. (2018). Flood susceptibility analysis through remote sensing, GIS and frequency ratio model. *Applied Water Science*, 8(2). https://doi.org/10.1007/s13201-018-0710-1

Sánchez-Lozano, J. M., Teruel-Solano, J., Soto-Elvira, P. L., & Socorro García-Cascales, M. (2013). Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain. *Renewable and Sustainable Energy Reviews*, 24, 544–556. https://doi.org/10.1016/j.rser.2013.03.019

Schoenherr, T., Tummala, R., Harrison, T. P. (2008). Assessing supply chain risks with the analytic hierarchy process: *Providing decision support for the offshoring decision by a US manufacturing company.* , 14(2), 100–111. doi:10.1016/j.pursup.2008.01.008

Selamat, M.H., Selamat, A., Othman, M.S., Shamsuddin, N.H., Zukepli, N.I., & Yusuf, L.M. (2012). A review on application of geographical information system in town planning in Malaysia.

Shah, M. F. (2022, January 1). *Focus on disaster early warning systems*. The Star. Retrieved from https://www.thestar.com.my/news/focus/2022/01/02/focus-on-disaster-early-warningsystems#:%7E:text=Although%20Malaysia%20has%20an%20early,recent%20floods%20in%20Kuala%20Lumpur

Siddayao, G. P., Valdez, S. E., & Fernandez, P. L. (2014). Analytic Hierarchy Process (AHP) in Spatial Modeling for Floodplain Risk Assessment. *International Journal of*

Machine Learning and Computing, *4*(5), 450–457. https://doi.org/10.7763/ijmlc.2014.v4.453

Singh, R. P., Singh, N., Singh, S., & Mukherjee, S. (2016). Normalized Difference Vegetation Index (NDVI) Based Classification to Assess the Change in Land Use/Land Cover (LULC) in Lower Assam, India. *International Journal of Advanced Remote Sensing and GIS*, *5*(1), 1963–1970. https://doi.org/10.23953/cloud.ijarsg.74

Sofia, G., Roder, G., Dalla Fontana, G. (2017). Flood dynamics in urbanised landscapes: 100 years of climate and humans' interaction. Sci Rep 7, 40527. https://doi.org/10.1038/srep40527

Sun, R., Gong, Z., Gao, G., & Shah, A. A. (2020). Comparative analysis of Multi-Criteria Decision-Making methods for flood disaster risk in the Yangtze River Delta. *International Journal of Disaster Risk Reduction*, 51, 101768. https://doi.org/10.1016/j.ijdrr.2020.101768

Syed Hussain, T. P. R., Md Nor, A. R., & Ismail, H. (2014). The Level of Satisfaction towards Flood Management System in Kelantan, Malaysia. *Pertanika Journal of Social Sciences & Humanities*, *22*(1), 257–269

Tam, Abd Rahman, Harun, Hanapi, & Kaoje. (2019). Application of Satellite Rainfall Products for Flood Inundation Modelling in Kelantan River Basin, Malaysia. *Hydrology*, 6(4), 95. https://doi.org/10.3390/hydrology6040095

Tehrany, M. S., Pradhan, B., & Jebur, M. N. (2014). Flood susceptibility mapping using a novel ensemble weights-of-evidence and support vector machine models in GIS. *Journal of Hydrology*, *512*, 332–343. https://doi.org/10.1016/j.jhydrol.2014.03.008

Tehrany MS, Pradhan B, Jebur MN. (2015). Flood susceptibility analysis and its verifcation using a novel ensemble support vector machine and frequency ratio method. *Stoch Environ Res Risk Assess* 29:1149–1165. https://doi.org/10.1007/s00477-015-1021-9

Tehrany, M.S., Pradhan, B., Jebur, M.N. (2014). Flood susceptibility mapping using a novel ensemble weights-of-evidence and support vector machine models in GIS. J. Hydrol. 512, 332–343.

Usman Kaoje, Ismail & Ibrahim, Ishiaku. (2017). URBAN FLOOD VULNERABILITY MAPPING OF LAGOS, NIGERIA. MATTER: *International Journal of Science and Technology*. 3. 224-236. 10.20319/mijst.2017.s31.224236.

Vilasan, R. T., & Kapse, V. S. (2022). Evaluation of the prediction capability of AHP and F-AHP methods in flood susceptibility mapping of Ernakulam district (India). *Natural Hazards*. https://doi.org/10.1007/s11069-022-05248-4

Vojtek, M., & Vojteková, J. (2019). Flood Susceptibility Mapping on a National Scale in Slovakia Using the Analytical Hierarchy Process. *Water*, 11(2), 364. https://doi.org/10.3390/w11020364

Wang HB, Wu SR, Shi JS, Li B. (2013). Qualitative hazard and risk assessment of landslides: a practical framework for a case study in China. *Nat Hazard* 69(3):1281–1294

Wong, C., Liew, J., Yusop, Z., Ismail, T., Venneker, R., & Uhlenbrook, S. (2016). Rainfall Characteristics and Regionalization in Peninsular Malaysia Based on a High Resolution Gridded Data Set. *Water*, 8(11), 500. https://doi.org/10.3390/w8110500

World Health Organization. (2019, November 8). Floods. Retrieved from https://www.who.int/health-topics/floods#tab=tab_1

Yahaya, N. S., Lim C. S., Jamaluddin, U. A., Pereira, J. J. (2016). The December 2014 flood in Kelantan: A post-event perspective. *Warta Geologi*. 41.

Yusoff, A., Din, N. M., Yussof, S., & Khan, S. U. (2015). Big data analytics for Flood Information Management in Kelantan, Malaysia. *2015 IEEE Student Conference on Research and Development (SCOReD)*. https://doi.org/10.1109/scored.2015.7449346

Zaharia, L., Costache, R., Praˇvaˇlie, R., Ioana-Toroimac, G., (2017). Mapping flood and flooding potential indices: a methodological approach to identifying areas susceptible to flood and flooding risk. *Case study: the Prahova catchment (Romania). Front. Earth Sci*. 11 (2), 229-247.

Zambrano, A. M., Calderón, X., Jaramillo, S., Zambrano, O. M., Esteve, M., & Palau, C. (2017). Community Early Warning Systems. *Wireless Public Safety Networks 3*, 39–66. https://doi.org/10.1016/b978-1-78548-053-9.50003-2