FLOOD SUSCEPTIBILITY MAPPING USING GIS AND FUZZY AHP

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CIVIL ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS
JANUARY 2022

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by

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17003149

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Civil Engineering)

JANUARY 2022

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CERTIFICATION OF APPROVAL

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Approved by,

____
AP Dr Muhammad Raza Ul Mustafa

Date : 23 MARCH 2022

UNIVERSITI TEKNOLOGI PETRONAS
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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.

NOR ZAFATINAH BINTI ZAIROL AFFENDI

Date : 22 MARCH 2022

ACKNOWLEDGEMENT

Bismillahirahmanirahim..

Foremost, I would like to take this opportunity to thank Allah S.W.T., the Almighty, for providing me with this golden opportunity to complete the dissertation for my Final Year Project. This journey fulifilled the objective of the Final Year Project which is to develop a framework, in which will enhance students' skills in the process of applying knowledge, expanding thoughts, solving problems independently and presenting findings through minimum guidance and supervision.

I want to express my most profound appreciation to my previous and current advisors, Dr Abdul-Lateef Babatunde Balogun and AP Dr Muhammad Raza Ul Mustafa for their enlightening guidance and supervision throughout my final year project journey.

Not to forget Mr Abdulwaheed Adelekan Tella for all the supports and knowledge shared with me regarding my project. Then, grateful acknowledgement to my project partner, Ms Nurul Najihah binti Khairul Anuar who have given such a good cooperation throughout the completion of the project.

Also, much-obliged to Universiti Teknologi PETRONAS (UTP) and Civil Engineering and Environmental Department for equipping students with essential skills and excellent theoretical as well as practical work throughout the study period. Therefore, I consider myself a fortunate individual as I had been given a chance to be a part of it. Last but not least, I thanked my parents, Mr. Zairol Affendi and Mrs. Nor Azura, family and friends whom I am greatly indebted for their unwavering support and advice.

Thank you.

ABSTRACT

Kelantan Darul Naim, one of Malaysia's northeast corner states, experiences recurrent flood hazards. Floods are natural calamities that strike Malaysia and the rest of the world every year. It results in infrastructural damage as well as fatalities. Flood susceptibility mapping is one of the early warning systems that can monitor the flood level and alert people to the catastrophe. Existing flood mapping systems may include flaws such as inconsistencies and inaccuracies. Therefore, this study aims to showcase the potential for flood susceptibility mapping using Geographic Information System (GIS) and Fuzzy Analytic Hierarchy Process (Fuzzy AHP) methodologies in Kelantan, Malaysia. For flood mapping, several GIS analyses using spatial analysis were performed using ArcGIS and combined with Fuzzy AHP. The Spatial Analyst module of the ArcGIS software is used to carry out algebraic mapping methods and map flood danger factors, while the Fuzzy AHP is utilised to calculate the weights of criteria based on expert opinions. The Fuzzy AHP models were used to assess ten flood-causative elements. Rainfall, distance to stream, and drainage density were the most crucial flood-causing elements, with Fuzzy AHP weights of 27%, 14%, and 13%, respectively. By overlaying the Fuzzy AHP map with previous flood occurrences in the research area, the models' accuracy was verified. The FAHP model's higher accuracy and usefulness for flood susceptibility mapping in Kelantan was demonstrated when the Fuzzy AHP map was fully aligned with historical flood locations. As a result of merging GIS and Fuzzy AHP, a better understanding of flood impacting factors and decision-making to manage future flood occurrences will be achievable. To supplement the findings of this study, combining GIS with new machine learning techniques might be helpful for future research. A comparison of MCDM and machine learning models will disclose each model's strengths and limitations, allowing the optimal model for future flood susceptibility assessment to be chosen.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background

A flood (**Figure 1.1**) occurs when water overflows and submerges normally dry terrain. Floods can come in many types and sizes, ranging from a few inches to many feet of water. They might also appear suddenly or gradually. Climate change, unplanned rapid urbanization, changes in land-use patterns, and inadequate watershed management caused flooding events to become more frequent and devastating (Blistanova et al. 2016; Commission et al. 2010; Sangati 2009; Villordon 2015). Floods are the most common and widespread natural disasters caused by weather (NOAA National Severe Storms Laboratory, 2020).

FIGURE 1.1: Flash Flood in Kuala Lumpur

Source: The Straits Times (2022)

According to the Organization for Economic Cooperation and Development (2016), floods cause damages of more than 40 billion US dollars annually worldwide. Flooded places are frequently buried with silt and muck when the floodwaters recede. Sharp debris, pesticides, gasoline, and untreated sewage are examples of hazardous pollutants that can contaminate water and the environment. Potentially dangerous mold blooms can quickly overwhelm water-soaked structures. Flooded areas may lose power and access to safe drinking water, resulting in outbreaks of deadly waterborne diseases such as typhoid, hepatitis A, and cholera (Nunez, 2016).

There are three types of floods: flash floods, which are caused by heavy rain and cause water levels to rise quickly, potentially overtaking rivers, streams, channels, or roads; river floods, which occur when a river's capacity is exceeded by constant rain or thawing; and coastal floods, which are caused by storm surges associated with tropical cyclones and tsunamis (World Health Organization, 2019).

Malaysia has a tropical climate with low temperatures and significant humidity. The southwest and northeast monsoons have an impact on the country's climate. The previous monsoon, which lasted from November to February, brought torrential rains to Peninsular Malaysia's east coast and Sabah and Sarawak, with rainfall totalling up to 600 mm in 24 hours in extreme hours cases. Rainy winds accompany the southwest monsoon, but rain is often less than during the northeast monsoon. In addition, during the monsoons, there are two transition periods (inter-monsoons) during which convectional thunderstorms are common (Ministry of Environment and Water Malaysia, 2017).

Numerous floods have hit Malaysia over the years. Massive floods hit Johor, Malaysia, in December 2006 (19th to 31st December) and January 2007 (12th to 17th January). Two waves slammed through the country, causing natural disasters. The water level reached a new high of 2.75 meters in the impacted districts, the highest since 1950. The fatality rate was 18 percent, and more than 100,000 people were evacuated during the disaster (Shah et al., 2017). In 2008, floods devastated Johor again, killing 28 people and causing damage estimated at $21.1 million.

Severe floods struck Malaysia in 2010, wreaking havoc on various states, particularly the economy and society. Malaysia's average annual rainfall for all states is around 2,500 mm, making it one of the world's wettest countries (Khalid and Shafiai, 2015). Peninsular Malaysia receives 2420 mm of yearly rainfall, Sabah 2630 mm, and Sarawak 3830 mm, with Peninsular Malaysia's east coast and Sabah and Sarawak's coastal regions receiving the highest.

In recent decades, Malaysia has experienced various extreme meteorological and climatic phenomena, including La Nina in 2011 and 2012 (which resulted in flooding). Also, unusual thunderstorms almost every year (which resulted in wind damage, flash floods, and landslides), and monsoonal floods (which resulted in many casualties, including loss of life in many parts of the country exposed to monsoon winds) (The Star, 2011, as cited in Chan, N. W., 2012).

According to another study, Malaysia was hit by 39 catastrophes between 1968 and 2004. Major natural catastrophes struck 19 times (49%), resulting in 1460 deaths and 821 injuries. Natural disasters were counted as 18 cases (46%) that resulted in 282 deaths and 1892 injuries, whereas the following calamities (forest fires and fog) were calculated as 2 cases (5%) that resulted in no deaths or property damage. Floods were identified as the most prevalent calamity, with six occurrences (Shah et al., 2017).

Generally, flood management measures are classified as structural or non-structural. By managing water flow both outside and inside settlements, the structural norms aim to limit the risk of floods. They work with non-structural solutions such as better development planning and control to protect people from flooding. Non-structural and structural approaches are not mutually exclusive, and combining the two is the most effective strategy. Existing development planning and management policies and practices should link a comprehensive and integrated strategy.

Understanding the scale and characteristics of current risk and the likelihood of future changes in hazard is particularly critical for balancing long-term and short-term investments in flood risk management. However, as urbanisation and climate change increase, it may become necessary to shift away from what is now commonly referred to as an over-reliance on well-designed defences and toward more adaptive and incremental non-structural solutions. Flood mapping is one of the non-structural alternatives (S.F. Zakaria et al., 2017). According to the Royal Town Planning Institute, geographic information systems (GIS) could provide various advantages to urban planning, including better mapping and analysis, faster and more immersive access, more efficient information retrieval, and higher service quality. GIS software can create detailed maps using a lot of data. As a result, this research combines GIS capabilities with expert judgment to assess and map current and future flood events in Malaysia, with the Kelantan region as a case study. The Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is a multi-criteria decision-making tool for evaluating and ranking expert opinion on the importance of various elements that cause flooding and potential mitigation solutions.

1.2 Problem Statement

Flood mapping, which is usually done with the help of a Geographic Information System (GIS) and other tools, is an important part of flood risk management. Many of the methods, however, have drawbacks. Flood mapping done in various ways will yield diverse findings, posing accuracy and consistency issues.

We will employ flood hazard maps as a way to solve flooding issues in this study. Some of the flood hazard maps operating in other flood mapping researches use Analytical Hierarchy Process (AHP) integrated with Geographic Information System (GIS). However, using GIS or AHP alone does not provide accurate study results.

The AHP technique has some faults due to subjectivity in determining the value of the indicator weighting from arbitrary expert assessments (Papaioannou et al., 2015). The author proposed integrating GIS with Fuzzy AHP to increase flood mapping accuracy and consistency to address this issue.

1.3 Objectives & Scope of Study

1.3.1 Objectives

1. To identify the factors causing flooding.
2. To produce flood susceptibility map using GIS and Fuzzy AHP.
3. To validate the accuracy of the flood map.

1.3.2 Scope of Study

1. To do literature review of past research on flood susceptibility mapping to understand the topic better.
2. To develop a flood susceptibility map using GIS and Fuzzy AHP as the multi-criteria decision-making (MCDM) technique to address flood hazards in Kelantan, Malaysia.
3. To produce a flood susceptibility map using ArcGIS desktop to map the flood in the area of Kelantan.

CHAPTER 2

LITERATURE REVIEW

2.1 Flood

Flooding and drought are two water-related disasters that have wreaked havoc on human populations in recent decades. If not properly handled, these natural extremes, strongly linked to climate change-induced risks, could result in more anthropogenic disasters (Fasihi,S. et al., 2021). Flood is one of the most significant contributors to global death, as seen in **Figure 2.1**, illustrating the number of deaths caused by natural disasters from 1901 to 2018 (Hannah Ritchie and Max Roser, 2019). Floods are very difficult to predict, which means states must be prepared to respond at all times.

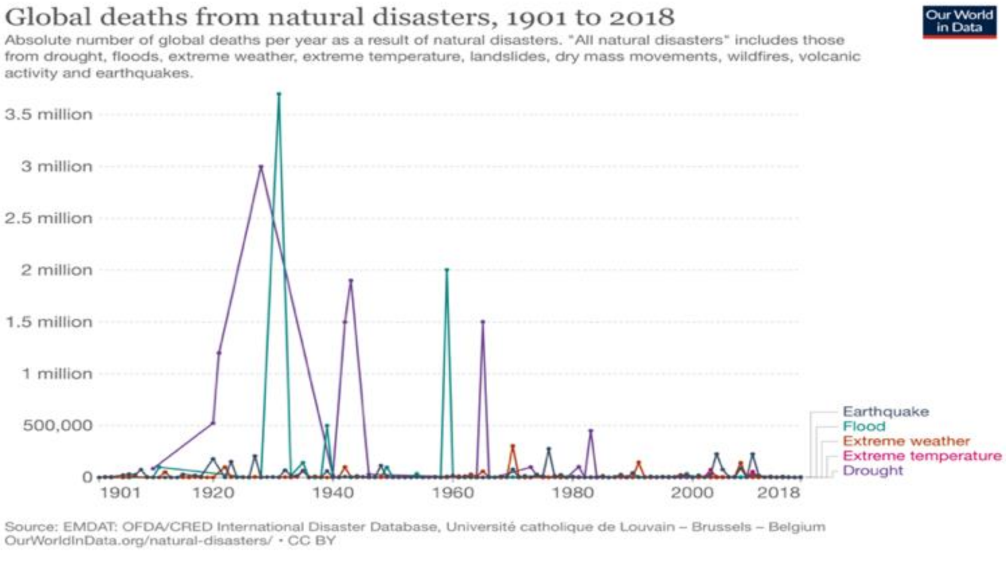


FIGURE 2.1: Global Death by Type of Natural Disaster

Source: Our World in Data (2019)

2.2 Flood Mitigation Measures

There are two types of flood mitigation measures: structural and non-structural. Structural forms of mitigation lessen the risk of floods by limiting water flow both outside and inside settlements. Flood walls/seawalls, floodgates, levees, and evacuation routes are all examples. Non-structural methods, on the other hand, limit the damage by relocating people and property from high-risk regions. Elevated structures, land purchases, permanent moves, zoning, subdivision, and building codes are just a few examples. Due to the breakdown of ancient dams and floodgates, structural solutions have lost favour over time (DuBois, G., & Tyrrell, K., 2019). Flood mapping is one of the non-structural measures in flood management.

2.3 Introduction to Geographic Information System (GIS)

In research from Teixeira et al. (2021), a Geographical Information System (GIS) can be defined as a decision support system framework that is designed to acquire, organize, manage, analyze, and visualize geographical and alphanumeric data, (Duckham et al., 2003; Goodchild, 2009b, 2010).

A geographic information system (GIS) is a system that creates, manages, analyses, and maps all forms of data, according to the Environmental Systems Research Institute (ESRI, 2020). By combining location data (where things are) with other types of descriptive data, GIS ties data to a map (what things are like there). This establishes the foundation for mapping and analysis in science and almost every field. GIS allows users to understand better patterns, linkages, and the context of their location. Benefits include improved communication and efficiency and better management and decision-making.

The one that looks at the disposition of its data sets in layers (**Figure 2.2**) is a more complete and simple way to define GIS. "A collection of maps covering the same area of the country in which a specific location has the same coordinates across all maps in the system." It is possible to analyse its thematic and spatial aspects to have a deeper understanding of the zone.

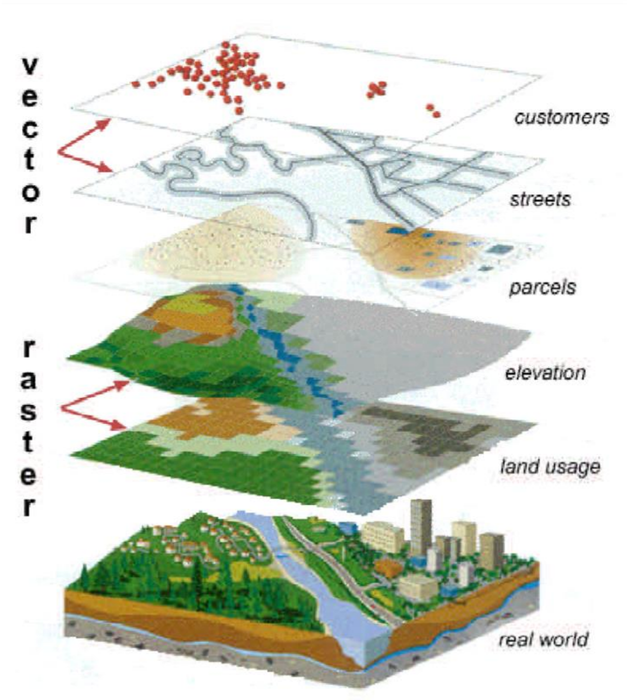


FIGURE 2.2: The Concept of Layers

Source: ESRI (2010)

The Geographic Information System (GIS) was used to collect past flood data and create spatial prediction mapping for hazard-prone locations. After the validation and training process, a flood spatial prediction map is generated between each model. GIS was unique in that it could merge spatial data with other current data services, frequently found in Database Management Systems (DBMS).

2.3.1 Geographic Information System (GIS) Application

Mapping locations: Geographic information systems (GIS) can map locations. GIS enables the generation of maps through automated mapping, data collecting, and analytic surveying tools.

Quantity mapping: People use quantity mapping to identify places that fulfil their criteria and take action and see the links between locations. This adds to the information provided by merely mapping the positions of features.

Mapping densities: While it is possible to detect concentrations by simply mapping the locations of features, it might be challenging to determine which areas receive more attention than others in areas with several qualities. This map allows us to count the number of features using a conventional unit of measurements, such as acres or square miles, to see how the distribution is done.

Finding distances: GIS can be used to see what is going on within a certain radius of a feature.

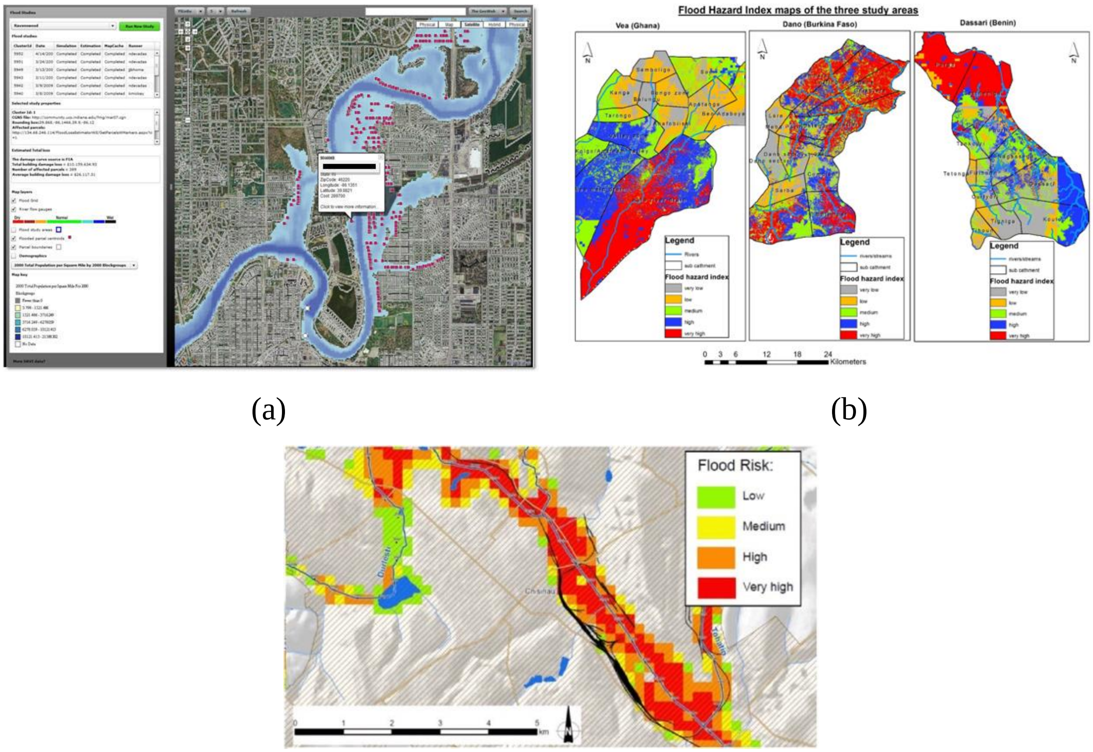
Mapping and monitoring change: GIS can be used to map changes in a region to forecast future conditions, select a course of action, or evaluate the results of a policy or activity.

2.4 Flood Mapping

Flood mapping is an essential part of flood risk mitigation. **Figure 2.3** shows three types of flood maps: flood inundation maps, flood hazard maps, and flood risk maps (Ismail Mohamad et al., 2017). With the use of satellite pictures, flood inundation maps can be constructed in near-real-time. The interpreted flood boundary can then be used to measure flood water levels later.

According to the Finnish Environment Institute (2015), A flood risk map indicates the potential effects of floods. An equation defines risk: Risk is Probability multiplied by Consequences, where Consequences equal Hazard multiplied by Vulnerability (potential number of people at risk of being flooded, fundamental operations, the buildings that are difficult to evacuate, possible economic damages, and adverse environmental impacts).

When mapping floodplains, it's essential to make sure the sources are precise and credible. Historical flood maps are based on observations and are thus trustworthy, mainly if the observed floodplain is generated from particular aerial or satellite photography or field markers. However, as previously indicated, there are often no sources of information accessible, or the practical flood extent does not correspond to the flood magnitude specified. The flooded region must be modelled in this situation. Flood scenarios can be simulated for a variety of return durations using flood modelling. The degree of risk, such as the depth of the water or the speed of the flow, can be determined (Finnish Environment Institute, 2015).



(a) (b)

(c)

FIGURE 2.3: (a) Flood Inundation, (b) Flood Hazard, (c) Flood Risk Map

Source: S.F Zakaria et al. (2017)

A flood hazard map is a crucial tool for determining the level of risk in a given location. The hazard map is required for centrally planning development operations and can be utilised as a decision support system (DSS). As a result, it should be straightforward to comprehend, with the goal of creating a hazard map that both technical and non-technical people can read and understand. According to S.F. Zakaria et al. (2017), there is a need to create maps based on user-specific user requirements, whether for personal or institutional use. Flood hazard maps are classified by the type of flood, the depth of the flood, the velocity of the flood, the extent of the water flow, and the flooding direction.

Generally, GIS software provides publicly accessible information with restricted information, which displays the size of the flood and the protective measures performed. Local governments will need more precise information to make decisions, such as municipality-level maps containing real estate data. Professional bodies can get maps with more precise additional data, down to individual household plot levels if needed. Field information (for example, large building projects or road construction that dramatically modify the landscape), as well as other pertinent data, such as any changes in peak recorded, flows from gauging stations following extreme occurrences, must be updated regularly (S.F Zakaria et al., 2017).

2.4.1 Flood Mapping using GIS

A geographic information system (GIS) is a computer system for recording, storing, verifying, and displaying data on Earth's surface positions, according to C. Sue (2017) of the National Geographic Society. GIS may help individuals and businesses better understand geographical patterns and relationships by integrating seemingly disparate data.

GIS has evolved into an appealing and effective tool for managing flood hazards and determining risk zones based on specific geographic areas (D.U. Lawal, 2011). As a result, its significant capabilities made it possible to create a flood risk map by outlining the actual flood-prone zones. In a GIS, geographic information is kept in a database, queried, and graphically displayed for analysis. By overlapping or intersecting distinct geographical layers, flood risk zones can be recognized and employed explicitly for mitigation or more stringent floodplain management measures.

Segamat, in the northern section of Johor state, was chosen as the research location for flood mapping and analysis (Safie, M. et al., 2006). The study's data was initially created by the Directorate of National Mapping Malaysia (JUPEM) as topographic maps series L7030 on a scale of 1:50 000 with 20-meter contour intervals. On the other hand, this strategy allows for the detection of flooded areas only after the flood, when the second satellite passes, rather than during the first (Nirupama and S.P. Simonovic, 2002, as cited in D. U. Lawal et al., 2014).

Next, (Nguyen et al., 2020) conducted empirical research to assess flood hazards along Vietnam's South-Central Coast using a combination of the fuzzy analytic hierarchy process (AHP), the fuzzy technique for the order of preferences according to similarity to the ideal solution (TOPSIS), and a geographic information system (GIS). There were a total of 12 flood factor maps made. The findings suggest that the key parameters impacting flood dangers are elevation, stream bottom terrains, flood-induced floodplain, and distance to the water body. The results demonstrate that using a hybrid strategy based on GIS and FAHP–TOPSIS allows decision-makers to interact with the factors influencing floods.

2.4.2 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a mathematical and psychological method for organising and analysing complicated choices. It was created in the 1970s by Thomas L. Saaty and has since been improved upon. It is divided into three sections:

- The overarching goal or issue you're attempting to resolve.
- All conceivable solutions are referred to as alternatives.
- The criteria by which the alternatives will be judged.

By quantifying its metrics and alternative alternatives and tying these parts to the broader purpose, AHP provides a coherent foundation for a necessary decision (Hummel et al., 2014). AHP is a multi-criteria decision-making (MCDM) model commonly used to rank factors (Kordi and Brandt, 2012; Beskese et al., 2014). It can be used to solve decision-making problems that need the examination of both quantifiable and non-quantifiable measures simultaneously. It is widely accepted because of its simplicity, ease of use, and versatility (Ho, 2008).

Indeed, researchers, practitioners, and decision-makers have praised AHP for its use in assessing flood and landslide risk, slope failure (Althuwaynee, O.F. et al., 2016), groundwater vulnerability (Neshat, A. et al., 2014), and urban seismic vulnerability (Alizadeh, M. et al., 2018). The AHP approach, on the other hand, has flaws, particularly in the early and intermediate stages of discovery. For example, criteria and alternatives are supposed to be independent in a hierarchical or top-down decision-making model, which is rarely the case in real-life settings (Neaupane, K.M. et al., 2006 as cited in D. U. Lawal et al., 2019). Moreover, there may be distortions if the criteria and sub-criteria are correlated with each other. (D. U. Lawal et al., 2019).

2.4.3 Fuzzy Analytical Hierarchy Process (Fuzzy AHP)

The Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is a fuzzy logic-based Analytic Hierarchy Process (AHP). AHP practise is similar to the Fuzzy AHP approach. The Fuzzy AHP approach places the AHP scale into the fuzzy triangle scale to be accessed first (Putra et al., 2018). In their research, (Chou and Yu, 2013) suggest a hybrid Fuzzy AHP cope with decision-making difficulties in an uncertain and multi-criteria environment. Fuzzy AHP is a reasonably complicated methodology requiring more numerical calculations in evaluating compound priorities than regular AHP, increasing the effort. Fuzzy AHP has a substantial benefit over standard AHP, according to (Rabia Arikan, 2016): decision-makers have higher confidence when making interval assessments than fixed value judgments. Fuzzy AHP will perform better when we use survey results or subjective observations of people. Traditional

AHP is ineffective at assessing subjective values, whereas Fuzzy AHP seeks to reduce ambiguity.

This work extends the Fuzzy AHP method to flood mapping based on its successful application in many sectors. The result obtained indicates the best balance of performance record for criteria of several categories such as physicochemical properties and elements of safety, environmental, and health in the journal (J. Ooi et al., 2018).

2.4.4 Flood Mapping Using GIS and Fuzzy AHP

The use of a combination of spatial analysis and mathematical models to assess flood risks is well-known worldwide. Flood-prone areas were mapped, and reliable flood hazard maps were created using a geographical information system (GIS) (M.M. Islam et al.,2000, as cited in Nguyen et al., 2020). To analyse flood risks, a commercial relational database management system was integrated to a GIS-based decision support system. Multiple-criteria decision-making (MCDM) has made it possible to define optimal specifications for assessing the factors that determine flood risk. Flood danger has been thoroughly examined using a Fuzzy AHP. The Fuzzy AHP was used in conjunction with GIS to map flood risks and evaluate flood danger based on natural and manmade causes. Each method has the advantage of assessing the flood's impact components (Nguyen et al., 2020).

Based on the Bang Rakam Model 60 project, a study in Thailand focuses on flood hazard assessment utilising Fuzzy AHP integrated with GIS. When studying complex decision-making situations, the Fuzzy AHP involves tedious calculations, but it can capture the judgement of human uncertainty (Erensal et al., 2006). To assign a weight to the element determining flood hazard, eight factors were analysed. Flow accumulation, elevation, and soil water infiltration were all found to have the same weight in the results. (Aphittha Yodying et al., 2019).

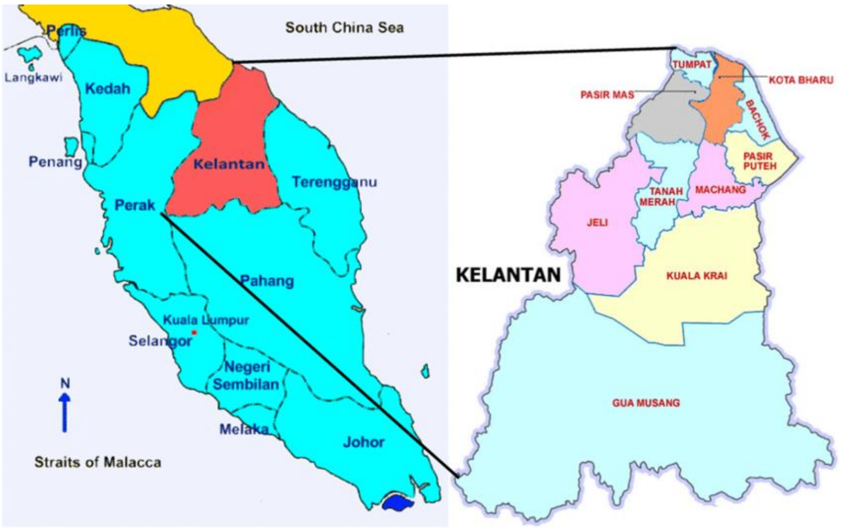
Flood risk assessment can provide crucial information about reducing disaster risk by integrating social, economic, and environmental strategies. This research can also assist in establishing the groundwork for catastrophe and risk management by allowing people to estimate the number of damages and losses that will occur in the future. The author of this study will go over flood susceptibility mapping with GIS and Fuzzy AHP and the benefits of adopting these methods.

CHAPTER 3

METHODOLOGY

3.1 Study Area

Kelantan, also known as Kelantan Darul Naim, is a Malaysian state located in the northeast corner of the peninsula. It was chosen as the research region because Kelantan is one of the most inundated states on the peninsula. **Figure 3.1(a)** depicts the map of Peninsular Malaysia and **Figure 3.1(b)** shows the map of Kelantan state. Kelantan is located at 5°15′N 102°0′E in terms of latitude and longitude. It is subjected to the North-East Monsoon from November to March each year due to its geographical location. Almost every year, between late November and early January, monsoons poured torrential rainfall over a lengthy time, creating floods (Jabatan Perairan dan Saliran, 2006, as cited in N. S. Ahmad Sobri, 2012).



(a) (b)

FIGURE 3.1: (a) Map of Peninsular Malaysia, (b) Map of Kelantan State

3.2 Project Methodology

The methodology flowchart in **Figure 3.2** below explains the steps and processes for creating a Kelantan flood susceptibility map using ArcGIS and Fuzzy AHP.

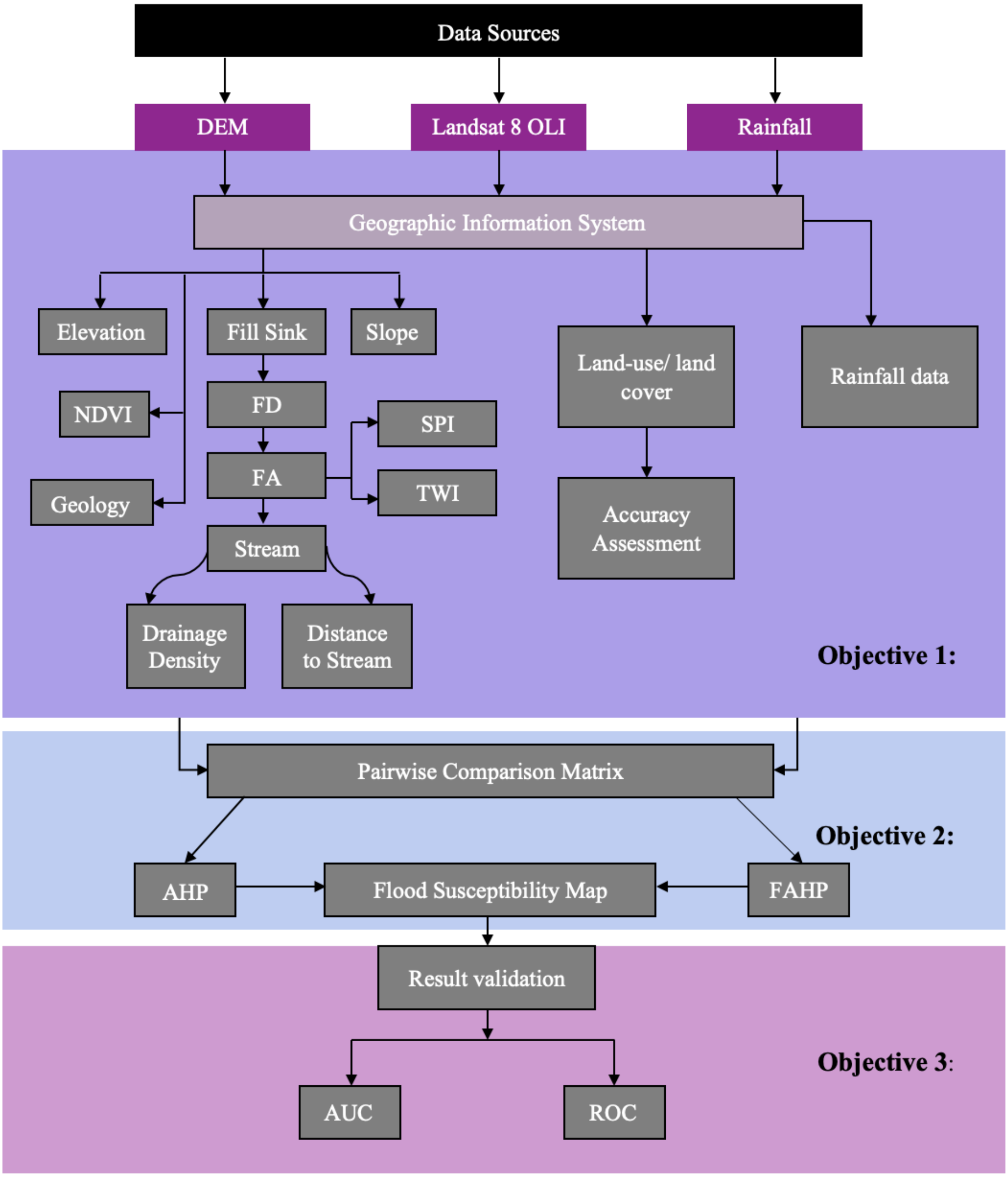


FIGURE 3.2: Project Methodology

3.3 Geospatial Data Sources and Causative Factors

The causative factors and location of flood need to be defined to determine the study region's flooding. As mentioned in the methodology flowchart in **Figure 3.2**, we gathered related data from various sources (**Table 3.1**). Several factors, such as slope, geology, and elevation, are considered while estimating a flood occurrence. However, rainfall, drainage density, and distance to stream are essential elements in determining the flooding rate. Rainfall (RF), Normalized Difference Vegetation Index (NDVI), Topographic Wetness Index (TWI), Stream Power Index (SPI), slope (S), Land Use/ Land Cover (LULC), geology (G), elevation (E), drainage density (DD), and distance to stream (DS) are all causative factors in this research region. The flood susceptibility factors were then separated into Very low susceptibility, Low susceptibility, Moderate susceptibility, High susceptibility, and Very high susceptibility based on the relevance of the criteria The numerous components and their ranks in the flood susceptibility mapping are listed in **Table 3.2**. The categorization criterion is based on flood susceptibility levels defined in a prior study (Pradhan, 2010, as cited in Dano et al., 2019).

TABLE 3.1: Data Sources

Primary Data	Format	Year	Source	Extracted Data
DEM	Raster	2020	Earth Explorer https://earthexplorer.usgs.gov/	Topographic Wetness Index (TWI), Stream Power Index (SPI), slope, elevation, drainage density and distance to stream
Landsat 8 OLI Imagery	Raster	2020	Earth Explorer https://earthexplorer.usgs.gov/	Normalized Difference Vegetation Index (NDVI), Land use/land cover (LULC)
Rainfall data	Raster	2020	Climate Research Unit Data https://www.uea.ac.uk/groups-and-centres/climatic-research-unit	Rainfall
Geology data	Spreadsheet file	2020	Kelantan Department of Mineral & Geoscience https://www.jmg.gov.my/	Geology

TABLE 3.2: Causative Factors Classes and Ranking

Number	**Causative Factors**	**Classes**	**Ranking**
1	Rainfall (RF)	2,485.0 – 3,183.6	1
		3,183.6 – 3,592.2	2
		3,592.2 – 4,132.6	3
		4,132.6 – 4,936.6	4
		4,936.6 – 5,846.1	5
2	Normalized Difference Vegetation Index (NDVI)	-0.60 – 0.07	1
		0.07 – 0.26	2
		0.26 – 0.38	3
		0.38 – 0.47	4
		0.47 – 0.78	5
3	Topographic Wetness Index (TWI)	2.07 – 5.19	1
		5.19 –6.44	2
		6.44 –7.90	3
		7.90 – 9.77	4
		9.77 – 19.75	5
4	SPI	-5.20 – -1.74	1
		-1.74 – -0.94	2
		-0.94 – -0.28	3
		-0.28 – 0.28	4
		0.28 – 3.70	5
5	Slope (S)	0 – 7	5
		7 – 14	4
		14 – 22	3
		22 – 32	2
		32 – 75	1
6	LULC	Forest	1
		Palm Oil	6
		River Stream	7
		Mixed Agriculture	4
		Cleared Land	5
		Rubber	2
		Paddy	3

TABLE 3.3: (continued)

Number	Causative Factors	Classes	Ranking
7	Geology	Quaternary	4
		Jurassic to Cretaceous	7
		Triassic	1
		Permian	2
		Cretaceous	5
		Triassic to Jurassic	3
		Devonian	8
		Silurian to Devonian	9
		Ordovician to Silurian	6
8	Elevation	-25 – 190	5
		190 – 440	4
		440 – 776	3
		776 – 1,194	2
		1,194 – 2,183	1
9	Drainage Density	0 – 0.29	1
		0.29 – 0.52	2
		0.52 – 0.79	3
		0.79 – 1.09	4
		1.09 – 1.81	5
10	Distance to stream	0 – 549	5
		549 – 1,157	4
		1,157 – 1,804	3
		1,804 – 2,549	2
		2,549 – 5,000	1

3.4 A Multi-Criteria Decision Making (MCDM) Using Fuzzy AHP

According to Chang's extension analysis, the calculation and analysis are done by combining the AHP approach with fuzzy triangular numbers (TFNs) in **Table 3.3**, utilizing the pair-wise comparison method of AHP. (Aphittha Yodying, 2019, citing Chang, 1996). TFN properties are depicted in **Figure 3.3**.

TABLE 3.4: Triangular Fuzzy Numbers

Linguistic Scale	Intensity of importance on an absolute scale (AHP method)	Triangular Fuzzy Numbers (l,m,u)
Equally Important	1	(1,1,1)
Moderately More Important	3	(2,3,4)
Strongly More Important	5	(4,5,6)
Very Strongly More Important	7	(6,7,8)
Extremely More Important	9	(9,9,9)
Intermediate Value	2	(1,2,3)
Intermediate Value	4	(3,4,5)
Intermediate Value	6	(5,6,7)
Intermediate Value	8	(7,8,9)

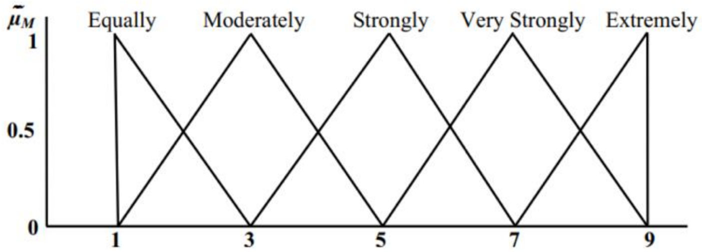


FIGURE 3.3: Linguistic Variables for the Inportant Weight of Each Criterion

Source: Kabir, G., & Hasin, M. A. A. (2011)

Assume a group of 1 decision-makers (DMt, t = 1,..., l) is tasked with assessing n interventions (Ai, I = 1,..., n) using m criteria (Cj, j = 1,..., m). The criterion's weights are represented as linguistic variables and rendered as fuzzy triangular numbers, and they are used to assess treatments (Saaty, T.L., 2008). Ayhan, (2013) stated that the AHP priorities were fuzzified by converting the crisp numeric AHP values to fuzzy numbers after evaluating and averaging the decision-maker's preferences. **Table 3.4** shows the fuzzification approach employed in this experiment.

TABLE 3.5: Decision Matrix of the Criteria of Fuzzy AHP

Criterion	**RF**	**NDVI**	**TWI**	**SPI**	**S**	**LULC**	**G**	**EL**	**DD**	**DS**
RF	1,1,1	4,5,6	4,5,6	4,5,6	4,5,6	4,5,6	4,5,6	4,5,6	2,3,4	1,1,1
NDVI	0.17,0.2,0.25	1,1,1	4,5,6	2,3,4	0.33,0.5,1	2,3,4	1,2,3	1,1,1	0.25,0.33,0.5	0.25,0.33,0.5
TWI	0.17,0.2,0.25	0.25,0.33,0.5	1,1,1	1,1,1	0.33,0.5,1	0.25,0.33,0.5	0.25,0.33,0.5	0.17,0.20,0.25	0.33,0.5,1	0.33,0.5,1
SPI	0.17,0.2,0.25	0.25,0.33,0.5	1,1,1	1,1,1	0.25,0.33,0.5	0.25,0.33,0.5	0.25,0.33,0.5	0.25,0.33,0.5	0.25,0.33,0.5	0.25,0.33,0.5
S	0.17,0.2,0.25	1,2,3	2,3,4	2,3,4	1,1,1	2,3,4	2,3,4	1,1,1	0.25,0.33,0.5	0.25,0.33,0.5
LULC	0.17,0.2,0.25	0.25,0.33,0.5	2,3,4	2,3,4	0.33,0.5,1	1,1,1	1,2,3	1,1,1	0.25,0.33,0.5	0.25,0.33,0.5
G	0.25,0.33,0.5	0.25,0.33,0.5	2,3,4	2,3,4	0.33,0.5,1	0.33,0.5,1	1,1,1	1,2,3	1,1,1	0.33,0.5,1
EL	0.25,0.33,0.5	1,1,1	4,5,6	4,5,6	1,1,1	1,1,1	0.33,0.5,1	1,1,1	1,1,1	1,1,1
DD	0.25,0.33,0.5	2,3,4	1,2,3	2,3,4	2,3,4	2,3,4	1,2,3	1,1,1	1,1,1	1,1,1
DS	1,1,1	2,3,4	1,2,3	2,3,4	2,3,4	2,3,4	1,2,3	1,1,1	1,1,1	1,1,1

The relative relevance of the criterion was then calculated using the geometric mean. The geometric mean was calculated using Buckley's (1985) Equations (3.1) and (3.2) shown in **Table 3.5**.

$$A_1\, x\, A_2\, x\, A_n = (l_1, m_1, u_1)\, x\, (l_2, m_2, u_2) \ldots x\, (l_n, m_n, u_n) \;=\; (l_1 l_2 l_n, m_1 m_2 m_n, u_1 u_2 u_n) \tag{3.1}$$

$$\text{Geometric Mean} = (l_1 l_2 l_n, m_1 m_2 m_n, u_1 u_2 u_n)^{-n} \tag{3.2}$$

where the conditioning factors are A1, A2, and An, while each criterion's lowest, middle and biggest member values are l, m, and u, respectively.

$$w_i \;=\; r_i\, x\, (r_1 \;+\; r_2 \;+\; r_3) \;=\; (lw_i, mw_i, uw_i) \tag{3.3}$$

Based on Equation (3.3), here w_i is the relative fuzzy weight and r_i is the geometric mean. To produce the average weight (Aw) indicated in **Table 3.6**, Equation (3.4) was utilized for defuzzification (Tella, A., Balogun, AL, 2020).

$$\mathrm{A_w} = \frac{lwi + mwi + uwi}{3} \tag{3.4}$$

The normalized average weight (Ni) was calculated from the defuzzied data (average weight) using Equation (3.5), as shown in **Table 3.6**.

$$\mathrm{Ni} = \frac{Aw}{\sum_{i=1}^{n} Aw} \tag{3.5}$$

TABLE 3.6: Fuzzy Matrix Geometric Mean

Conditioning Factors	ri		
	l	m	u
Rainfall	0.184	0.283	0.429
NDVI	0.049	0.082	0.142
TWI	0.022	0.035	0.066
SPI	0.021	0.032	0.057
Slope	0.055	0.093	0.157
LULC	0.037	0.063	0.106
Geology	0.041	0.071	0.137
Elevation	0.067	0.095	0.142
Drainage Density	0.075	0.131	0.215
Distance to Stream	0.086	0.147	0.231
Reciprocal of Total	0.103	0.080	0.063
Ascending Order	0.063	0.080	0.103

TABLE 3.7: Weight of the Criteria (Fuzzy)

Conditioning Factors	Wi			**Average Weight (Aw)**	**Normalized Weight (Ni)**	**Weight (%)**
	l	m	u			
Rainfall	0.184	0.283	0.429	0.299	0.266	27
NDVI	0.049	0.082	0.142	0.091	0.081	8
TWI	0.022	0.035	0.066	0.041	0.036	4
SPI	0.021	0.032	0.057	0.037	0.032	3
Slope	0.055	0.093	0.157	0.102	0.090	9
LULC	0.037	0.063	0.106	0.069	0.061	6
Geology	0.041	0.071	0.137	0.083	0.074	7
Elevation	0.067	0.095	0.142	0.101	0.090	9
Drainage Density	0.075	0.131	0.215	0.141	0.125	13
Distance to Stream	0.086	0.147	0.231	0.154	0.138	14

3.4.1 Reclassification Process

The spatial analyst extension fuzzy membership function tool for Fuzzy AHP in ArcMap was utilized to reclassify all of the parameters used in this investigation. Reclassification converts input raster data to integer values for subsequent analysis (Mahmoud and Gan 2018, as cited in Feloni et al. 2020). In ArcGIS, the fuzzy logic was characterized using the fuzzy membership, which ranges from 0 to 1 as defined by Zadeh (1965). The integer 1 denotes full fuzzy membership, whereas the integer 0 denotes no fuzzy membership (Roy and Saha, 2019). Following that, we created the map using a raster calculator, similar to the method employed by Feloni et al. (2020).

3.4.2 Combining Fuzzy AHP and GIS

Using aggregated values of inputs that match their weights is a valuable strategy for measuring flood risk. The benefits of combining MCDM and GIS in hazard risk assessment have been established (Nyimbili, P.H. et al., 2018). The Fuzzy AHP hybrid approach provides a logical and systematic quantitative framework for identifying critical problems, assigning relative priorities to these issues, choosing the best-compromise alternatives, and finally establishing communication in the direction of universal acceptance. In fuzzy geographical decision-making, the fuzzy AHP is integrated with GIS. The Fuzzy AHP is used to weight stated criteria using expert opinions in a structured questionnaire. GIS is used to execute the Map Algebra technique to map flood hazard factors using ArcGIS software's Spatial Analyst module (Raster Calculator).

CHAPTER 4

RESULT AND DISCUSSION

4.1 Flood Conditioning Factor Processing In GIS

The flood susceptibility map of Kelantan was created using fuzzy AHP models based on ten conditioning factors which are rainfall, NDVI, TWI, SPI, slope, LULC, geology, elevation, drainage density, and distance to stream. According to the models, rainfall, drainage density, and distance to stream have the greatest impact on flood incidence in the state.

4.1.1 Rainfall (RF)

Rainfall has an impact on flooding (Zhao et al., 2018). Flooding becomes worse when rain intensity and frequency increase. Flash floods can cause water levels to rise drastically in a short period. The rainfall map (**Figure 4.1**) was constructed by interpolating the point features of the rainfall data using the ArcGIS spatial analyst inverse distance weight function. The rainfall levels were classified into five classes using Natural Breaks (Jenks) in ArcGIS software. They were then divided into five categories, with 2,485 mm being the lowest and 5,846 mm as the highest.

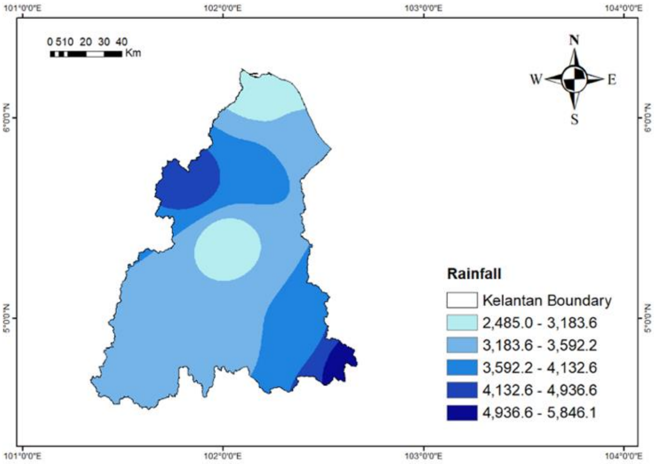


FIGURE 4.1: Rainfall Map

4.1.2 Normalized Different Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) measures the difference between near-infrared (which vegetation strongly reflects) and red light to quantify vegetation (which vegetation absorbs). A mean value of the NDVI across all pixels for the given periods is estimated to assess the variations in the NDVI for pre-monsoon and post-monsoon. Anomalies in NDVI estimates are used on an average scale to understand the impact of the flood during the stated season (Ghosh, S., Kumar, D. & Kumari, R., 2022). The research area's normalized distinct vegetation index ranges from -0.60 to 0.78 as shown in **Figure 4.2**.

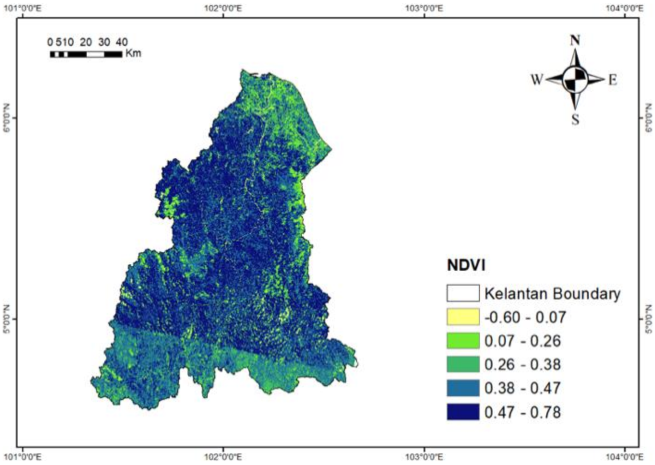


FIGURE 4.2: NDVI Map

4.1.3 Topographic Wetness Index (TWI)

Among topographic features, the topographic Wetness index is a practical and widely used instrument for describing humidity conditions on a basin size. The highest number on the TWI map corresponds to locations with a higher TWI, typically floodplain areas, and lower values correspond to sites with a lower TWI index. TWI is a quantitative measure of the impact of geomorphology on floods that combines the measurement of upstream and slope (Kanani Sadat et al., 2019). As a result, floods are susceptible to the topographic area's excessive wetness. The TWI was estimated using a raster calculator in ArcGIS utilizing DEM data and Equation (4.1). The research area's topographic wetness index ranges from 5.11 to 23.24 is shown in **Figure 4.3**.

$$\mathrm{TWI} = \mathrm{In}\ \left(\frac{As}{\tan\beta}\right) \qquad (4.1)$$

where, As = local upslope area ($m^2\ m^{-1}$), tan β = local slope gradient

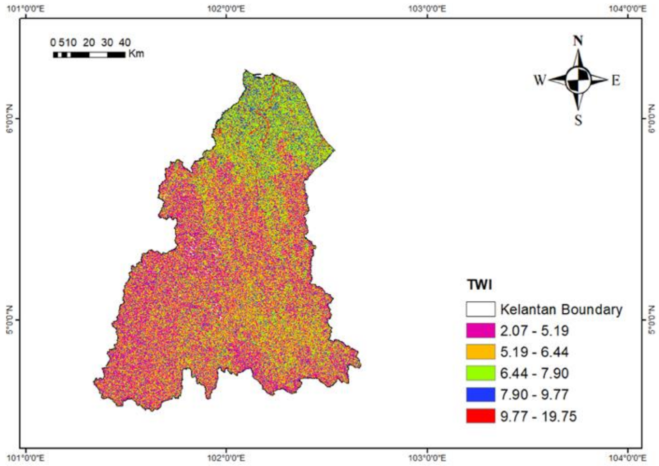


FIGURE 4.3: TWI Map

4.1.4 Stream Power Index (SPI)

The study of the fluvial environment necessitates the use of SPI (Knighton, 1999). Because it describes the damaged stream channel and sediment flow at a place on the terrain surface, SPI is an important metric to consider in flood susceptibility models (Das, 2019). The power of a stream determines the scale of a flood's potential devastation. Due to a significant increase in the slope and area of the watershed, the SPI value rises as the rate of water flow increases (Lee et al., 2018). The SPI map is shown as **Figure 4.4** below. Moore et al. (1991) proposed Equation (4.2) for calculating the SPI:

$$\text{SPI} = C_a \times \tan s \tag{4.2}$$

where, C_a=catchment area, tan s = slope

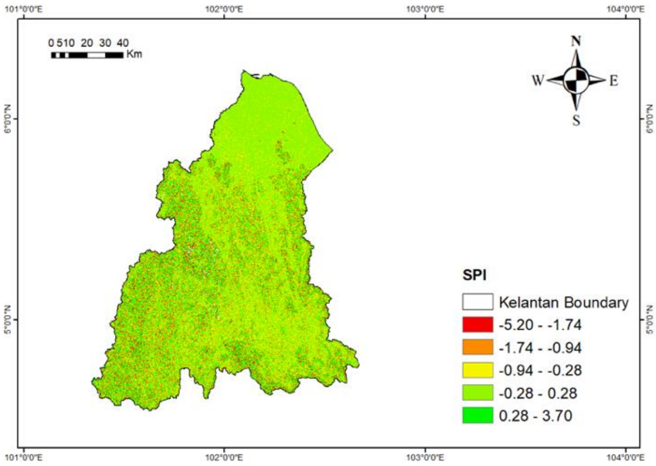


FIGURE 4.4: SPI Map

4.1.5 Slope (S)

Runoff, which regulates water flow, is linked to the slope. On steep slopes, runoff is increased, whereas water gathers on intermediate slopes. Locations with mild or flat slopes, according to Li et al., have a greater sensitivity to floods due to the static arrangement of water (2012). This study computed the slope using ArcGIS software and DEM data and the map is shown in **Figure 4.5**.

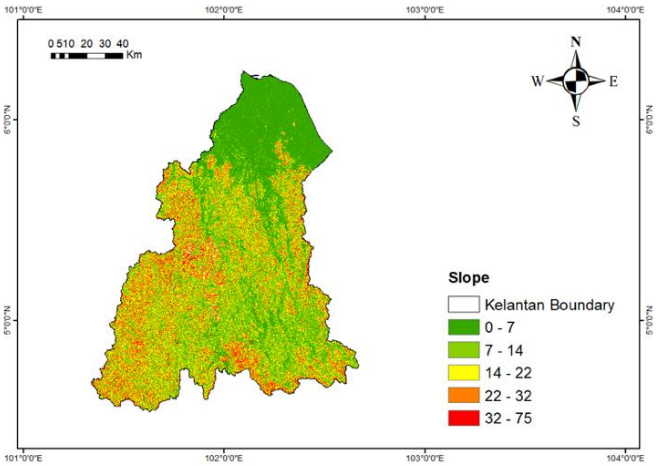


FIGURE 4.5: Slope Map

4.1.6 Land use/ land cover (LULC)

The rate of water infiltration in a given area is determined by land use/ land cover. Due to low percolation and heavy runoff, vegetated areas have intense infiltration, which helps to minimize flooding, whereas bare soil or sparsely vegetated areas are more likely to flood (Tehrany et al., 2014 as cited in Mahmoud and Gan, 2018). The LULC map was created from 2020 Landsat 8 OLI photographs from the USGS Earth Explorer (https://earthexplorer.usgs.gov/). ArcGIS was used to pick training sites using Landsat images and high-resolution satellite photography. A metropolitan area, vegetation, water bodies, desolate terrain, and agricultural land were all developed. The map of the LULC is shown in **Figure 4.6**.

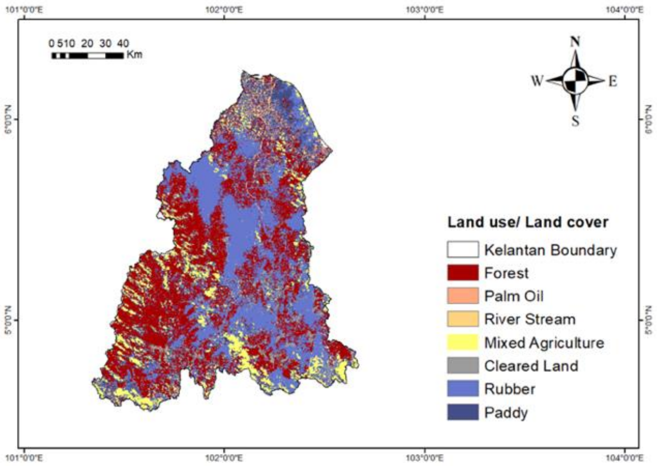


FIGURE 4.6: LULC Map

4.1.7 Geology (G)

A GIS user can analyze flood-prone locations with geological data by understanding the background of permeable and impermeable soil layers. Water can enter porous soil, whereas impermeable soil inhibits water from infiltrating, resulting in the formation of water bodies on the soil surface (2017, Chandrasegaran). The geology map is shown in **Figure 4.7**.

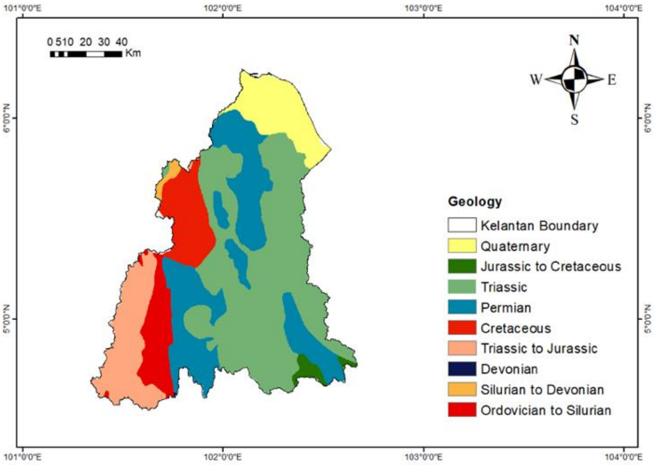


FIGURE 4.7: Geology Map

4.1.8 Elevation (EL)

Base Flood Height is defined by the Federal Emergency Management Agency (FEMA) as "the elevation of surface water resulting from a flood that has a 1% chance of equaling or exceeding that level in any given year." The higher the flood danger, the lower the building/property is below the Base Flood Elevation. The elevation map was constructed using the digital elevation model in ArcGIS software and classed by natural breaking after the sink had been filled to maintain flow continuity. The elevation (**Figure 4.8**) is measured in meters and ranges from -25 to 2,183.

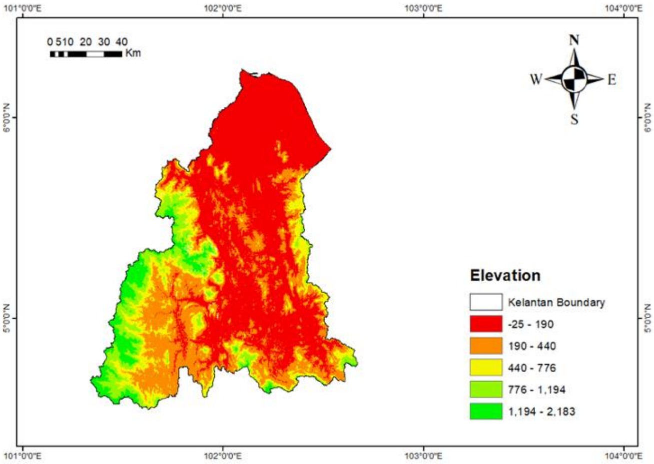


FIGURE 4.8: Elevation Map

4.1.9 Drainage Density (DD)

Excessive drainage density creates surface runoff, which causes flooding (Dinesh Kumar et al., 2007 as cited in Das, 2019). According to Kumar et al., high drainage density sites are more prone to floods than low drainage density regions because drainage density is critical in runoff generation (2007). (Bhattacharya and Srivastava, 2006). The stream network was used to build a drainage density map, then divided into five classes using ArcGIS software's spatial analyst capabilities. In the research area (**Figure 4.9**), susceptibility values range from the highest drainage density (1.09 – 1.81) to the lowest drainage density (0 – 0.29).

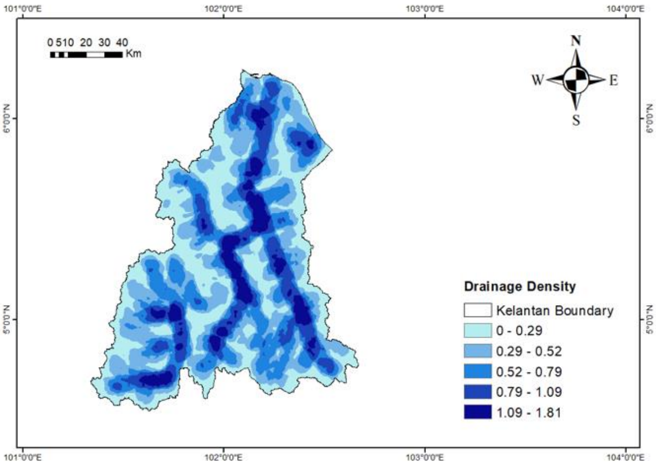


FIGURE 4.9: Drainage Density Map

4.1.10 Distance to Stream (DS)

Flooding is more likely in places nearest the stream and main channel, whereas areas farther away are less at risk. Floods have a much greater impact in areas near rivers than in areas farther away from drains. Areas within 90 meters of the drainage are more susceptible, according to Pradhan (2010). According to recent studies, floods are less likely to occur at distances greater than 2000 meters from a drainage system (Samanta et al., 2016). As a result, ArcGIS was utilized to define a safer region up to 2500 meters from the drainage, whereas floodplain areas were classified between 0 and 1500 meters from the stream (**Figure 4.10**).

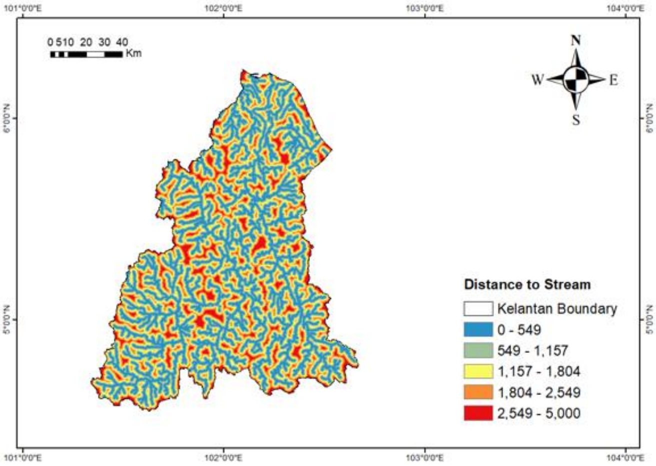


FIGURE 4.10: Distance to Stream Map

4.2 Flood Susceptibility Mapping

All ten conditioning factors were used as a questionnaire to create this flood susceptibility map. The questionnaire's results were based on expert opinion, and the Fuzzy AHP was used to weigh the reported causal elements. The weighted percentage of the causative components, as given in **Table 3.6**, is inserted and used to determine flood susceptibility map using ArcGIS software's Spatial Analyst module (Raster Calculator). Equation (4.3) shows the formula used to calculate all of the raster factors data in ArcGIS.

$$\text{Flood map} = \sum(Causative\ Factors\ X\ Weight\ Percentage\ ) \qquad (4.3)$$

After inserting all the data into formula given in Equation (4.3), the flood susceptibility map is produced as shown in **Figure 4.11**.

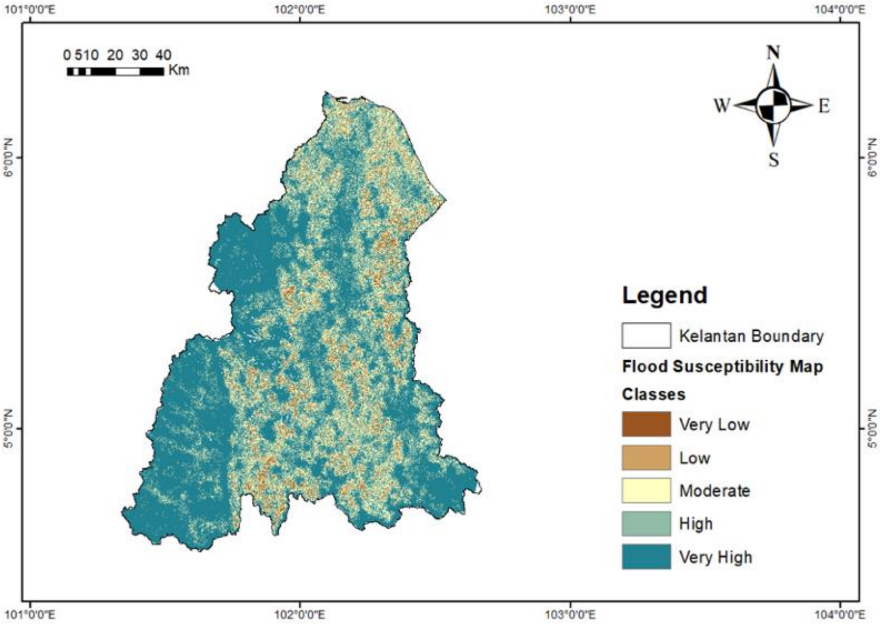


FIGURE 4.11: Flood Susceptibility Map

TABLE 4.1: Flood Susceptibility Statistics of Fuzzy AHP Model

Flood Susceptibility Classes	Area covered in km^2	Area covered (%)
Very Low	231.51	1.90
Low	878.56	6.29
Moderate	2031.54	14.02
High	3696.56	25.19
Very High	7802.27	52.72

The flood susceptibility map was divided into five groups, ranging from very low to very high (**Figure 4.11**). **Table 4.1** shows the statistical analysis of the outcome. Because of the low flood sensitivity, the likelihood of flooding was low, making it safer to inhabit. When a flood susceptibility was extremely high, it signified that the probability of a flood was highly high, necessitating the need for preventative measures to avoid any accidents. The FAHP model's output reveals that the very highly susceptible, highly susceptible, and moderately susceptible areas are 7802.27 km^2 (52.72%), 3696.56 km^2 (25.19%), and 2031.54 km^2 (14.02%), respectively.

4.3 Validation of Fuzzy AHP Model

The receiver operating characteristic (ROC) approach, the most extensively used method for evaluating the accuracy of susceptibility mapping data, is utilized to validate the model in this study. The ROC technique has been widely used in predictive mapping research (Althuwaynee et al. 2014; Khosravi et al. 2016a; Lee & Pradhan 2007; Tehrany et al. 2019b). The model has been validated quantitatively using the ROC curve approach, with true and false values as the assessment foundation (Tien Bui et al., 2012). To analyze the AUC values, Equation (4.4) can be utilized.

$$\text{AUC} = \frac{(\sum TP + \sum TN)}{(P+N)} \tag{4.4}$$

Where TP (true positive) denotes correctly classified flash flood pixels, TN (true negative) denotes correctly classified non-flash flood pixels, P is the total number of flash flood pixels, and N is the total number of non-flash flood pixels, P is the total number of flash flood pixels, and N is the total number of non-flash flood pixels.

The AUC ranges from 0.5 to 1.0, with 1.0 representing the highest precision, indicating that the model was entirely satisfied in its ability to predict the existence of a calamity without bias (Pradhan and Lee, 2010). As a result, the closer the AUC value is to 1.0, the more precise and authentic the model is. In **Table 4.2**, the AUC range is shown.

TABLE 4.2: AUC Range

AUC values	Test quality
0.9 – 1.0	Excellent
0.8 – 0.9	Very Good
0.7 – 0.8	Good
0.6 – 0.7	Satisfactory
0.5 – 0.6	Unsatisfactory

Figure 4.12 shows the receiver operating characteristic (ROC) curve of Fuzzy AHP method. The result showed that the area under the curve (AUC) for the training dataset was 1.0, corresponding to 100 percent accuracy for the datasets.

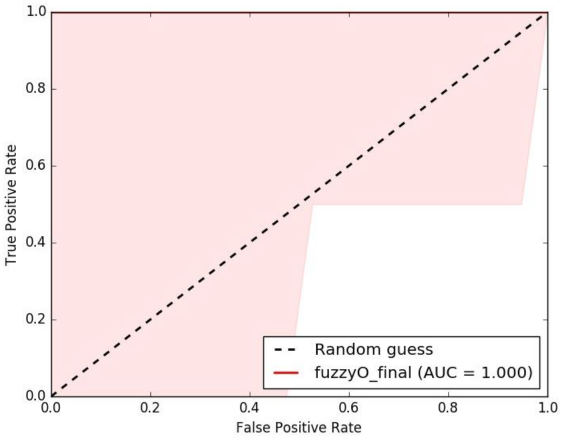


FIGURE 4.12: ROC Curve Using The Past Flood Dataset

This research was carried out to pinpoint the flood-prone area. As a result, it is critical to compare the flood susceptibility mapping developed with real-life situations for the flood susceptibility mapping to be accurate. The GIS was used to plot all of the flood spots. Based on the findings of the overlay flood events in 2019 of Kelantan state, the produced flood susceptibility map matched the historical flood occurrences. According to the Fuzzy AHP validation technique, the high to very high classes on the flood map are highly correlated with the actual scenario in Fuzzy AHP, as shown in **Figure 4.13**. As a result, it may be inferred that the flood susceptibility map developed is accurate.

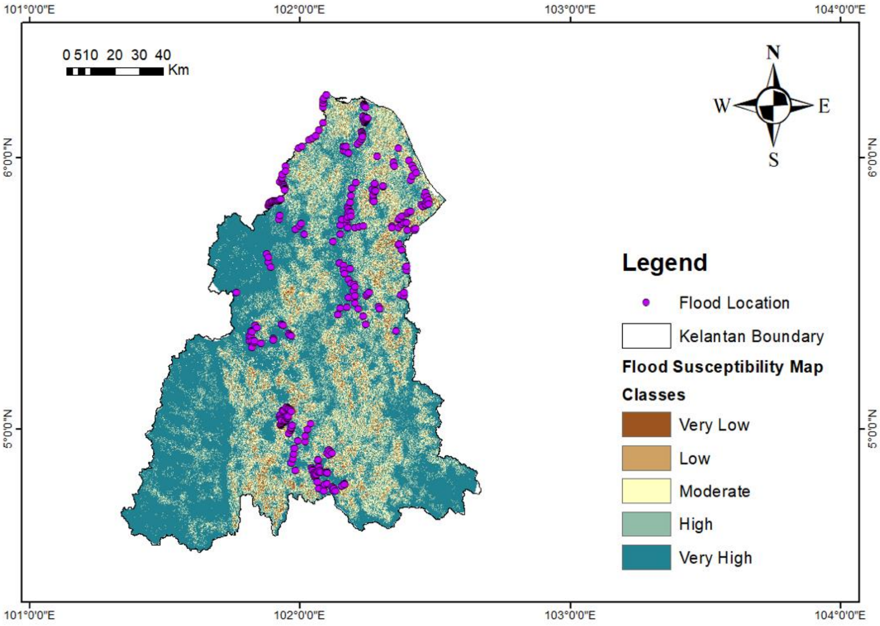


FIGURE 4.13: Flood Location in Previous Flood Event

CHAPTER 5

CONCLUSION AND RECOMMENDATION

By combining MCDM approaches (Fuzzy AHP) with GIS, this work explored the causes of floods in Kelantan state and built a regional flood susceptibility model. The monsoons routinely provide high rainfall over a lengthy period, resulting in floods in Kelantan practically every year between late November and early January (Jabatan Perairan dan Saliran, 2006, as cited in N. S. Ahmad Sobri, 2012). This work aims to improve flood mapping accuracy and consistency by combining GIS with Fuzzy AHP. This study used a geographical fuzzy decision-making methodology to predict the high-risk locations of flood hazards in Kelantan, taking into account various potential components and expert opinions.

Ten causative factors were chosen because of their link to floods in the study area. The Fuzzy AHP model's results show that rainfall, drainage density, and distance to streams significantly impact flood occurrences. The research area's southern, northern, and central sections have high and highly vulnerable flood hazard zones.

The models were validated by overlaying sites of historical flood episodes on the resulting map. Finally, an integrated Fuzzy AHP and GIS allowed decision-makers to connect with the factors influencing floods. This research could aid Malaysian authorities in controlling floods and developing an early warning system to alert citizens to flood dangers.

To supplement the findings of this study, combining GIS with new machine learning techniques might be helpful for future research. A comparison of MCDM and machine learning models will disclose each model's strengths and limitations, allowing the optimal model for future flood susceptibility assessment to be chosen.

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