Developing a SDSS for multi-criteria flood susceptibility mapping in Malaysia

by

Shanker Chandrasegaran
18843

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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Universiti Tcknologi PETRONAS

Bandar Seri Iskandar

32610 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

____

(Dr Abdul - Lateef Babatunde Balogun)

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2017

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.

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SHANKER CHANDRASEGARAN

ABSTRACT

Flood are the natural disaster occurred which causes socio-economic consequences by devastating economic and social losses. The aim of this study is to propose a GIS multi-criteria methodology to produce a reliable hazard zone mapping and prediction of flood-prone areas. Flood mapping has been used widely in many countries nowadays as a method to encounter this natural hazard phenomenon. Understanding the surface and subsurface condition can tremendously improve an accurate flood susceptibility map for effective flood catastrophe management. In this study, Spatial Decision Support System (SDSS) method which has combined application of Geographical Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) based on expert`s opinion was adopted. Establishing a flood susceptibility map based on the significance of the flood causing factors is the main objective of this study. Eight factors that are relevant to the hazard of flooding was considered in the methodology, such as stream power index (SPI), land use, slope angle, topographic wetness index (TWI), geology, runoff, elevation, and distance from drainage network. The study was demonstrated in Perlis state, Malaysia. Perlis was known as one of the states that has been repeatedly devastated by extreme flood events in Malaysia for the last few decades. By adopting GIS-based Analytical Hierarchy Process (AHP), flood susceptibility zone map was simulated. The final flood hazard map was compared with the historical inundation data for the validation process. The result proves a satisfactory agreement between the flood susceptibility zones and the spatial distribution of historical flood that happened in the study area. The proposed SDSS methodology and the results prove that food generation in the study area highly relies on the surface and subsurface condition of the study area as the key catalyst.

ACKNOWLEDGEMENT

This project has taken about eight months of planning and working processes in order to fulfil the requirements of Final Year Project subject. In this duration, many people have been involved directly and indirectly who contributed in various ways to make this project in order to make it a success. Without help from them, this would not be achieved. Thus, it is a pleasure for me to convey my heartfelt gratitude to them all in this humble acknowledgement.

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Certainly, on the list of peoples to be thank of are all friends from all around and to those people that not be mentioned here. Your names may slip of my mind at this moment, but your actions and helps stay in my mind forever.

Finally, grateful gratitude to the almighty God that has made all things possible.

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LIST OF ABBREVIATIONS

GIS	Geographical Information System
SSDS	Spatial Decision Support System
MCDA	Multi-Criteria Decision Analysis
DSS	Decision Support System
DMS	Database Management System
WLC	Weighted Linear Combination
AHP	Analytical Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio
TWI	Topographic Wetness Index
SPI	Stream Power Index
FHI	Flood Hazard Index (FHI)

CHAPTER 1

INTRODUCTION

1.1 Background

Floods can have most devastating consequences and can have effects on the economy, environment and people. Flooding is a common disaster that destroys properties and claiming more than 20,000 lives per year and adversely affects around 75 million people worldwide (Smith, 1996). Floods can also affect victims and their families for a long period of time. The loss of friends and family has profound effects, particularly on kids. The loss of one's home, loss of property and interruption to business and get-togethers may proceed with stress. For a few people, the mental effects can be enduring.

Flood is a natural disaster which normally occurs due to the accumulation of too much of water rainfall in a specific region. However, it can also be caused by other natural disasters, particularly at coastal area where immersion can be caused by a tempest surge related to a tropical cyclone, tsunami, or a high tide. It is a major disaster in Malaysia.

Huge funds were used to implementing the flood control project and reconstruct the flood affected area. Government always try to minimise the flood damage by identifying factors that cause flooding. Flood estimation must be done well for relative flood hazard and risk management which will be useful for mitigation (Patel, D.P and Srivastava, P.K, 2013). Thus, there is the need for further studies to generate effective plans that can overcome the problem. Predicting the area that is most likely to be affected by flood by using Spatial Decision Support System (SDSS) is one of the methods to overcome the problem.

1.1.1 Spatial Decision Support System (SDSS)

Spatial Decision Support System (SDSS) has been widely used in flood mapping studies since its multi useful purposes to help the spatial organizer with guidance in making land utilize choices. SDSS is a computer-based system which used to assist in decision making to solve the semi-structures spatial problem. It is intended to help the spatial organizer with guidance in making land use decisions. A framework which model choices could be utilized to help recognize the best choice.

SDSS is also known as a policy support system. It comprises a Geographical Information System (GIS) and a Decision Support System (DSS). This entails use of a database management system (DMS), which analyse geographical data.

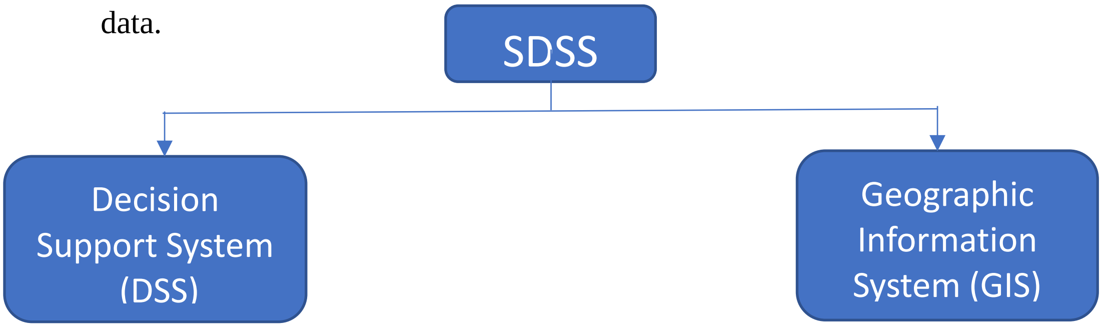


Figure 1: Components of SDSS

1.1.2 Decision Support System (DSS)

Decision Support System (DSS) is a decision-making system use at work type of sorting, ranking or choosing from alternate factors that will cause flood in the study area. The core of DSS in this project is Multi-Criteria Decision Analysis (MCDA) (Ljubomir Gigovic, et al., 2017). There are various methods of MCDA that can be used in evaluating multiple conflicting criteria in decision making, such as Weighted sum model (WSM), Analytic Hierarchy Process (AHP) and many more.

In this project, we mainly focus on Analytic Hierarchy Process (AHP) to determine the significance of flood-causing factors.

Figure 2: Components of DSS

1.1.3 Geographic Information System (GIS)

Geographic Information System is a computer-based system for capturing, storing, querying, analysing, and displaying geospatial data. In this study, geospatial data refers to the location and spatial feature of the study area. GIS technologies can handle and process location and attribute data of spatial features. GIS helps to analyse current situation, modelling and stimulating the different scenario for future prediction. GIS can be used as a smart map, together with a qualified user could assist with manipulation, analysis, and presentation of information tied to different locations (Sina Khatami and Bahram Khazaei, 2014). There are five components of GIS,

Figure 3: Components of GIS

1.1.4 GIS-MCDA

In this study, GIS and MCDA will be related together to combine and transform value judgement and geographical data for decision-making purposes. The decision needs to be done to identify the seriousness of each flood causing factors to be evaluated when doing flood mapping using GIS-based technologies.

GIS	MCDA
These techniques & procedures are recognized as a decision support system involving the integration of spatially referenced data in a problem-solving environment.	It provides a rich collection of techniques and procedures for: • Structuring decision problems • Designing, evaluating and prioritizing alternative decisions.

Table 1: GIS-MCDA

1.2 Problem statement

Malaysia has experienced many major floods that had resulted in a loss of several billion in cost and thousands of lives. Late urbanization amplifies the cost of damage to roads, bridges, infrastructures, residential properties, agribusinesses and private plugs. There are different factors that can contribute to flooding such as slope angle, topographic wetness index, low humid clay soil composition and many more.

Tragically, the developers are not considering those factors nowadays and developments continued in those areas as of late. Many developers are mainly focused on money making by utilizing all those space while failing to consider the hazard and conceivable outcomes of flood to happen in their developing area. At that point, when the natural disaster happens, there will be many damages occurs which might cost a lot of money.

Even civilians or communities are not aware of the surrounding geographical and meteorological before getting committed to the area. Therefore, by doing this study a method in identifying floods using flood modelling and GIS mapping could be very helpful to the communities.

1.3 Objective

The objective of the study are as follows:

- To determine the significance of multiple flood causing factors using AHP
- To produce a flood susceptibility map using SDSS

1.4 Scope of study

Decision Support System will be used in making decisions and ranking the factors in order of importance and sensitivity in this study. The core of DSS in this project is Multi-Criteria Decision Analysis (MCDA). MCDA can be used in many ways in multi-criteria flood susceptibility mopping. More accurate flood hazard zone mapping can be produced by adopting more than one type of MCDA in the study.

For this study, only one method of MCDA, which is Saaty`s Analytical Hierarchical Process (AHP), is used. This is because AHP is one of the straightforward, convenient and most popular analytical methods in flood modelling. It has a mature system that is accepted as an industry standard. AHP uses a systematic approach to make proper decisions for criteria weighing. AHP also was known as a system with simple method using pair-wise comparison among experts. The consistency of the evaluation also can be maintained by calculating the consistency index and consistency ratio in this system.

1.5 Study Area

The study area for this project chosen is Perlis, located in northern part of the west coast of Peninsular Malaysia. It is located in between Thailand and Kedah, Malaysia. The total area of Perlis is 821 Km^2. The total population is 246,000 and the density is 300/Km^2. It is located about 485.7 km kilometres from Kuala Lumpur. It is geologically located at latitude 6.4449° N and longitude of 100.2048° E.

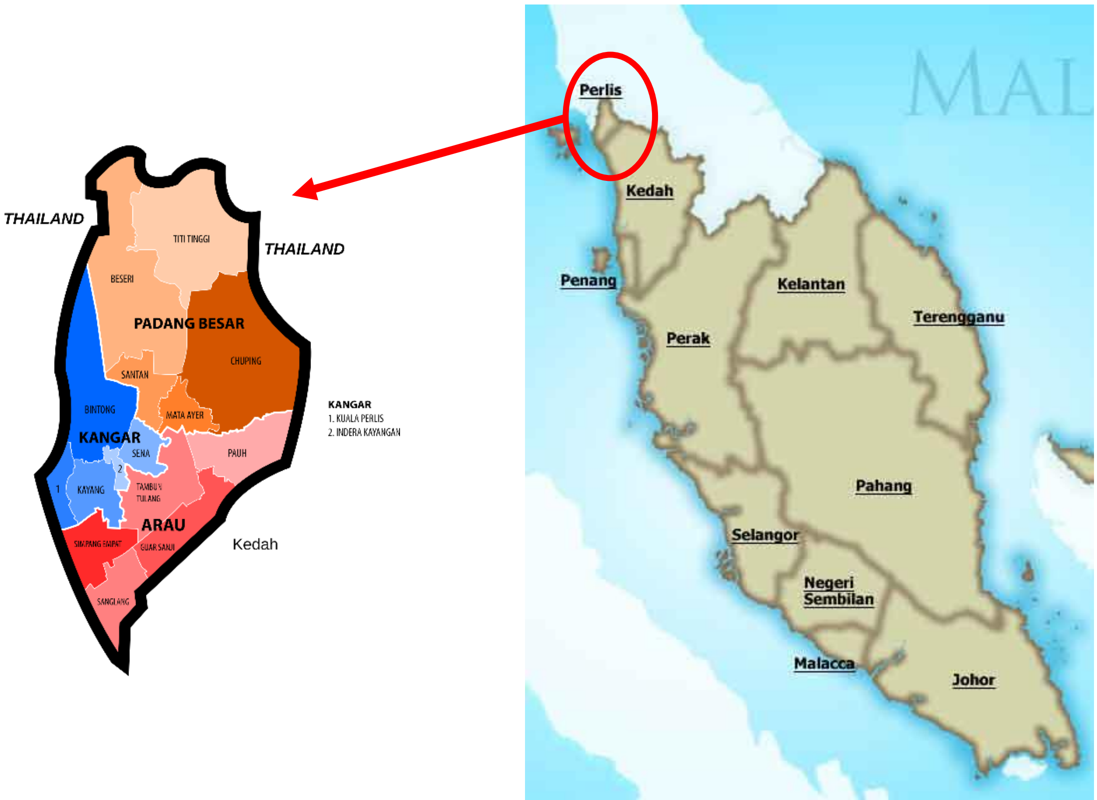


Figure 4: Study area, Perlis

Perlis has a tropical climate, which is normally having tropical wet climate or a tropical monsoon and trade-wind littoral climate. The area usually has significant rainfall and only short dry season. This type of climate is corresponding to Köppen climate classification category "Am".

Perlis also have a man-made reservoir with dam named Timah Tasoh located at Kangar, Perlis. It serves as a water catchment and storage to supply water to the people of Perlis as well as prevent any occurrence of flood in the state of Perlis. The capacity of the lake is 35.3 million litres of water with the water level of 27m in the dam.

The study area mainly consists of flat surface and high mountains at the edge towards the Thailand border. It includes various land use activities including residential, urban and agricultural as well as road and drainage networks. Due to high elevation difference and high rainfall, the chances of this area getting flood is high. So, the flood susceptibility map should be produced to this area to identify the flood hazard area.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the literature review of how this study has done by using SSDS as a tool. Besides that, this chapter also consists of reviews of the factors causing a flood susceptibility.

2.1 Flood Mapping

Flood maps are easily-read, rapidly-accessible charts and maps which facilitate the identification of areas at risk of flooding, quantification of what is at risk of being flooded and helps prioritise mitigation and response efforts. Considering that, flood susceptibility maps will be used as a valuable source for planning the future development of the city to identify flood susceptibility area.

Through this easily-read flood map, it is easy to make local communities to be aware in advance of an emergency, which can promote the implementation of flood-proofing measures. Flood zoning for specific area normally involves multiple factor or criteria that geographically related to each other (Rezafahmi, 2010).

Flood mapping has been widely used in many countries for years. Existing flood map must be updated every 20 years due to change and additional information available about peak flows and floodplain elevations. Besides, completing restudy in flood mapping consume much time and cost.

Within the last decades, mappings start to generate by combining computers graphics and database to produce Graphical Information System (GIS). With help of Geographic Information System (GIS) automated process, the studies are faster and even accurate in mapping the flood inundation area (Rezafahmi, 2010).

All those factors will be analysed using Geographic Information System (GIS). Many studies have been conducted to produce flood susceptibility mapping and flood analysis using GIS (Rahmati, Zeinivand, & Besharat, 2015).

2.2 Geographical Information System (GIS)

Geographical Information System (GIS) allows multiple layers of information to be displayed on a single map. Moreover, GIS enables the user to conduct interactive queries, analyse the data, edit data on the map, and display the outcome. The user can compare each location in term of coordinates, connectivity, proximity and geodesy. Using GIS, locations can be expressed in different ways such as coordinates, address, and zip codes.

In general, we can say that a GIS has the following components (Mohd Khusyairi bin Kusmaniirat, 2008):

i. User interface;
ii. Data input and integration;
iii. Graph and image processing functions;
iv. Visualization and plotting;
v. Data storage and retrieval (organized in the form of a geographic database).

In previous studies, GIS has been used for addressing different water resources issues such as water quality, ground water movement, ground water contamination, river restoration, hydrological modelling and management, and etc (Nur Nadrah Binti Roslan, 2015).

Several case studies of GIS-based flood modelling are presented to explain the modelling procedure and its benefits or challenges in detail (Sina Khatami and Bahram Khazaei, 2014):

i. Save cost and time.
ii. Modification and updating of the model parameters (data sets) would be easy and straight forward. User is not dealing with equations but the visualized results that could enhance the perception and understanding of different plausible scenarios

iii. Can combine different layers of geographic data and create new integrated information which is quite useful for creating dependent or independent hydrological variables
iv. Can provide a spatial element that other hydrologic models lack. This could be done with the analysis of variables such as slope, aspect and watershed or catchment area.
v. Can compare each location in term of coordinates, connectivity, proximity and geodesy
vi. Locations can be expressed in different ways such as coordinates, address, and zip code

2.2.1 Data in GIS

Data in GIS was obtained from various way either in map (for road and rivers), digitalized (from satellite images), or table format (Rainfall value). Different data need to be overlaid on top of one another on a single map. All the maps that have been obtained in form of hardcopy need to be scanned to be in digital format. Data obtained for each factor will be based on conditions.

Geographical data can be obtained in various forms such as spatial, and non-spatial data. (Rezafahmi, 2010)

i. Spatial Data
   Spatial Data is a geographical data which have locations in terms of coordinates. Spatial data comes with ‘Where’ as the component. Spatial data and geographical reference can provide location with two or three-dimensional space where users use to identify the location and spatial relations. Examples of spatial data are, river, paper maps, drawing plans, digital maps and more.
ii. Non-spatial data
   Also known as attribute data which mainly consist of numbers and data. This data won’t provide locations. Attribute data normally provide additional information and characteristics of features which can be tied to spatial data. ‘What’ is the component of attribute data. Examples of non-spatial data are names, email addresses, phone numbers and others.

2.2.2 GIS maps

GIS map will be produced when all data combined to form a map and it will consist layers of information. For instance, in this study flood mapping should consist many flooding factors such as Stream Power Index (SPI), land use, slope angle, Topographic Wetness Index (TWI), geology, surface runoff, elevation and distance from drainage network. GIS maps also can be used to show information about location and intensity of each factor. Using this GIS software, new data can be added in GIS maps easily compared to traditional method. GIS map makes updating maps much easier (Rezafahmi, 2010).

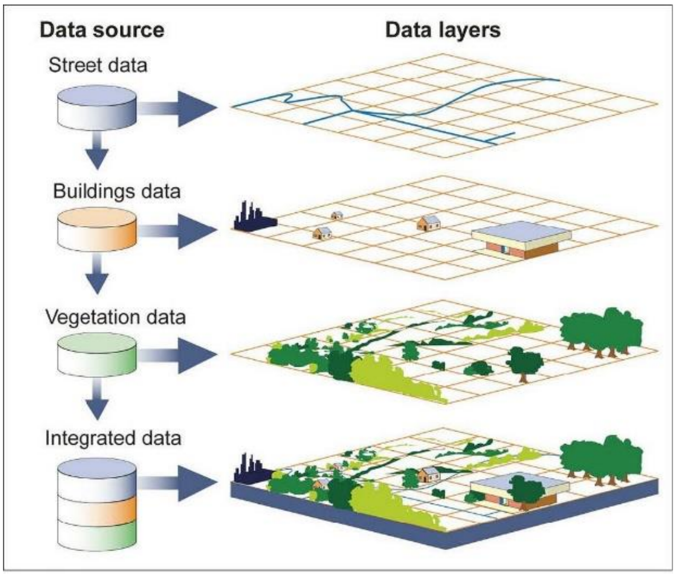


Figure 5: GIS layers

2.2.3 GIS Application in Flood susceptibility

GIS has been used for capturing, managing, analysing, and displaying all kinds of geographical information. It integrates hardware, software and data (Sheryl Lin Kuok Tyng, 2014).

2.3 Decision Support System (DSS)

In this current world, flood-related issues need to be handled in more proper manner. Holistic flood management vision can be realized through the application of Decision Support System (DSS) (Nur Nadrah binti Roslan, 2015). This system is intended to help the spatial organiser with guidance in making land use decisions. DSS helps people to make decisions on problems that keep changing and hard to predict in advance such as natural disasters. It also can be used as a tool to facilitate organizational process. This system can be fully computerized, human-powered or combination of both.

2.3.1 Multiple Criteria Decision Analysis (MCDA)

Multiple Criteria Decision Analysis (MCDA) is a core of Decision Support System (DSS) that have been used in this study. MCDA has been used since the sixties in the last century. This system is an assortment of methods and techniques to compare and rank up multiple existing alternatives by incorporating opposing criteria in a proper decision-making process (Rahmati et al., 2015).

MCDA has undergone many improvements until today, and it has been established methodology with various books, applications, scientific journals and introduced in university courses. It is verified all-time in both theoretical analysis and practical applications.

In our daily life, we might face many situations that will make us weigh multiple criteria implicitly and we might feel comfortable to make decisions based on our intuition. On the other site, it is also important to well organize the problem and professionally weigh multiple criteria. In weighing and rank each factor causing flood there are not only very sophisticated matters involving multiple criteria, but there are also various parties will be deeply overwhelmed by the consequences.

This method can be used in many aspects in life ranging from environmental planning, water resources management, forestry, fisheries management, nuclear emergency management, climate policies until life-cycle analysis (Nur Nadrah binti Roslan, 2015). Since the scope of the method covers environmental planning, it is suitable to apply in this flood-related project. The system requires critical decision making to handle, involves many experts related to this study with objective such as rank the factors according to priority and severity.

There are few steps in an MCDA to be approached:

i. Problem structuring

   Initiates with analysing the objectives and identify all the possible factors that might cause flood. Followed by coming up with decision options and obtaining performance measures.

ii. Analysis

   a. Criteria weighing

      Process of acquiring data from decision makers about the relative significance of criteria. Weights might be communicated at either an ordinal or cardinal estimation level.

   b. Criteria transforming

      As the data or criteria obtained are in different units, they need to be converted to commensurate units prior to aggregation in the ranking or scoring function.

   c. Option ranking and/or scoring

      The transformed performance measures and weighs need to be combined to identify overall performance for each option, relative to other options.

iii. Sensitivity analysis and decision making

   At last, sensitivity analysis is performed to analyse the heartiness of the ranking outcome. Variety of MCDA methods, execution measures, and weights produce various outcome with own sensitivity. The final product of the MCDA procedure is a proposal comprising both best-positioned option or gathering of choices. The decision will be made based on the outcome.

There are a lot of methods can be used in flood modelling project to attain final ranking of the decision making such as, Frequency Ratio (FR), Weights-of-Evidence (WofE), Analytical Hierarchy Process (AHP), Weighted Sum Model

(WSM), and few ensembles of different type of MCDA such as ensemble of Frequency Ratio with AHP (FR-AHP).

Based on previous studies, few comparisons have been made between the types of MCDA methods (Khabat Khosravi et al, 2016).

Frequency Ratio (FR)	Weights-of-Evidence (WofE)	Analytical Hierarchy Process (AHP)	Ensemble of Frequency Ratio with AHP (FR-AHP)	Weighted sum model (WSM)
• It can be simply implemented and its result is completely easy to comprehend • Used for evaluation of the impact of each affecting factor on flood occurrences • Flood susceptibility index (FSI) is computed	• Describes a relationship between the flood event and the conditioning factors to obtain probability of flooding • Mathematical relationships and equations are given by Bonham-Carter (1991, 1994) • Calculates the weight of classes for each conditioning factor (A) are based on '+'ve & '-'ve	• Allow map layers to be weighted in order to reflect their relative influences • Enables the user to achieve scale advantages drawn from a set of alternatives (Saaty 1980) • Using Questionnaire method to obtain the weight of each factor from experts • Based on pair-wise comparison that makes judgments and calculations easy	• There are some limitations due to statistical assumptions (Althuwaynee et al. 2014) • The weights obtained from the frequency ratio model were applied as the input data for paired analysis instead of experts opinions (Ghosh et al. 2011; Althuwaynee et al. 2014) • Prediction Rate(PR) - Consistency Index(CI)	• It is applicable only when all the data are expressed in exactly the same unit • Defined on *m* alternatives and *n* decision criteria • Suppose that w_j denotes the relative weight of importance of the criterion C_j and a_{ij} is the performance value of alternative *A* • *Calculates* $A_i^{WSM\text{-}score}$

Table 2: Comparisons between types of MCDA

2.3.2 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is one of the MCDA structural method used for analysing organising complex decisions based on psychological and mathematical method. It was developed by Thomas L. Saaty in the 1970s. Rather than finding the correct decision for the user, AHP also helps to identify the best suits their goal by providing a comprehensive and rational framework for evaluating alternative solutions (AHP, 2017). This method needs a number of decision makers to systematically evaluate its various elements by their own to each other. This is carried out through a structured comparison of all possible paired combinations of criteria using a cross-tabulation matrix. Results for AHP will be based on every criterion to find the suitable alternative (Dano Umar Lawal et al., 2012).

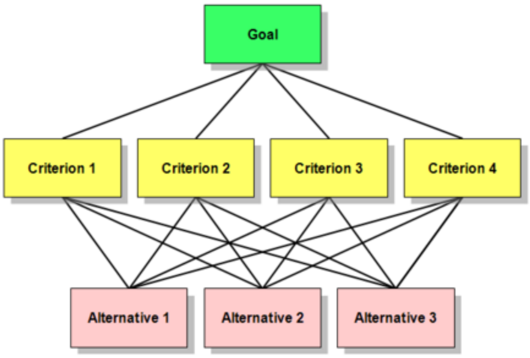


Figure 6: Methodology of AHP

Firstly, few questionnaires will be distributed among decision makes which comprises a number of experts who know well about flooding and their factors. In making the comparisons, the decision makers can use concrete data about the elements, but they typically use their judgments about the elements' relative meaning and importance. AHP will help to convert evaluations to a numerical value for easier comparison made using pairwise comparison. Every decision makers will rank every element based on Saaty`s Scale of Relative Importance of one criterion compared to other, starting from the most important element as 9 until least important element as 2. For equal important elements will be rank as 1 for both. Numerical priorities will be calculated for each decision alternatives and final decision will be made based on it to achieve the decision goal (Rahmati et al., 2015).

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective(s)
3	Weak importance	Experience and judgement strongly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	Where compromise is needed
Reciprocals of the nonzero	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

Table 3: Scales of relative importance according to Saaty (1980)

CHAPTER 3

METHODOLOGY

To achieve the objectives of the project, few methods have been handled. The workflow of the study can be divided into two types, primary and secondary method. Primary is about how the problem will be handled to obtain correct data and analyse it within the provided time frame. The secondary method shows the structural steps will be conducted during research phases.

3.1 Primary work flow

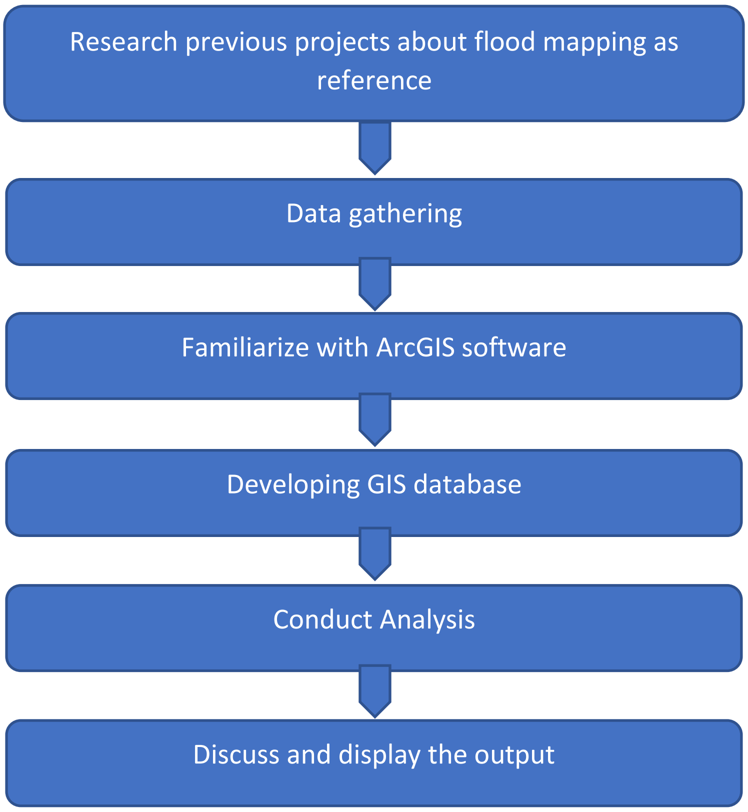


Figure 7: Primary work flow

3.2 Secondary work flow

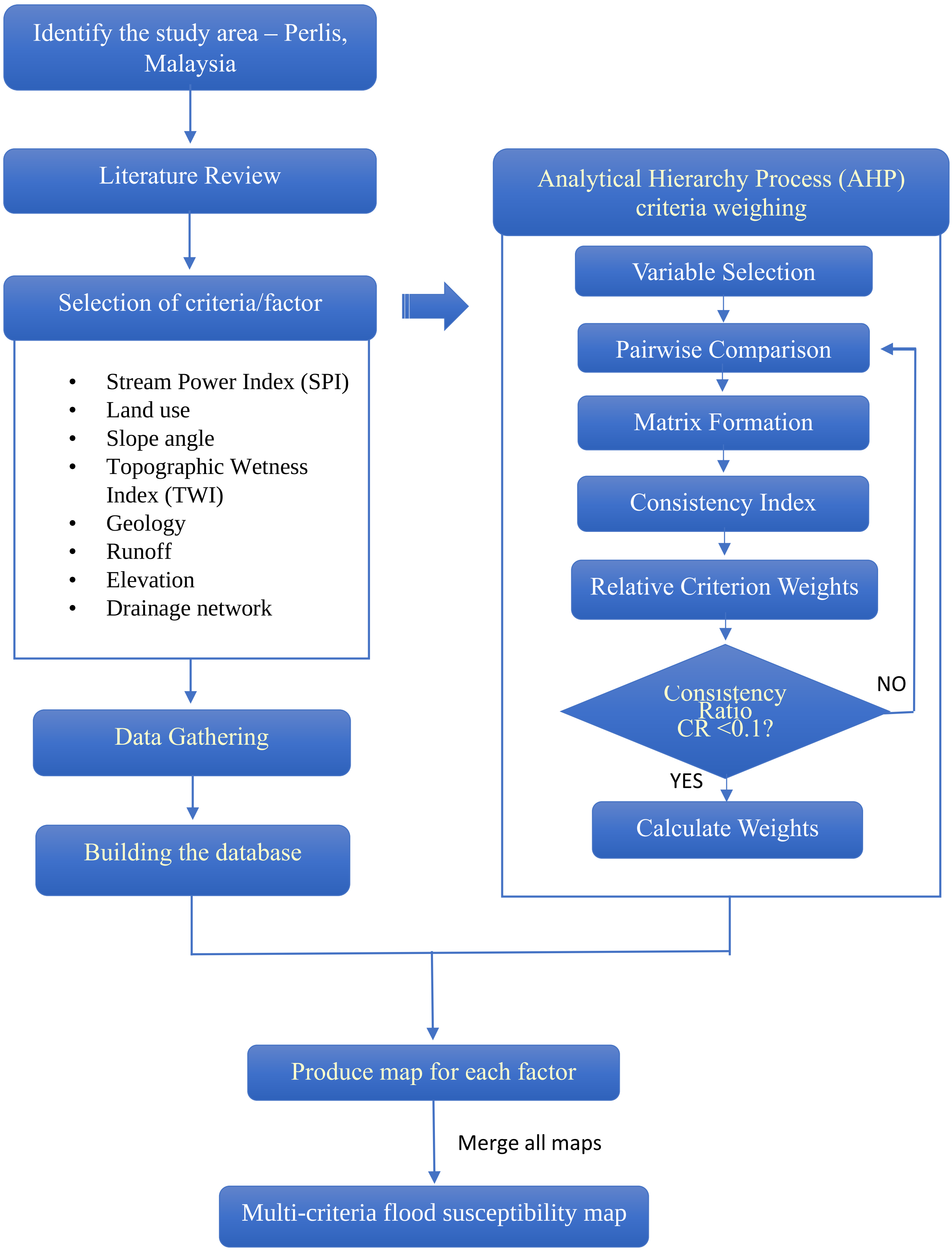


Figure 8: Secondary work flow

3.3 Identify the study area

Perlis, Malaysia has been used as the study area in this project. The location, rainfall, existing manmade and natural structures and also relative components of the study area that might affect flood occurring details was collected.

3.4 Literature review

Literature review helped in providing more idea on how previous studies have been made in previous projects, this helped me to choose the type of study and methodology need to be done to achieve the objective. Several journals, articles, maps, newspapers, expert`s advice and other online sources have been revised in the making of this project.

3.5 Selection of criteria/factor

No exact agreement exists on which factors should be applied in flood susceptibility assessments. In this study, some factors influencing natural flood was considered. Those are:

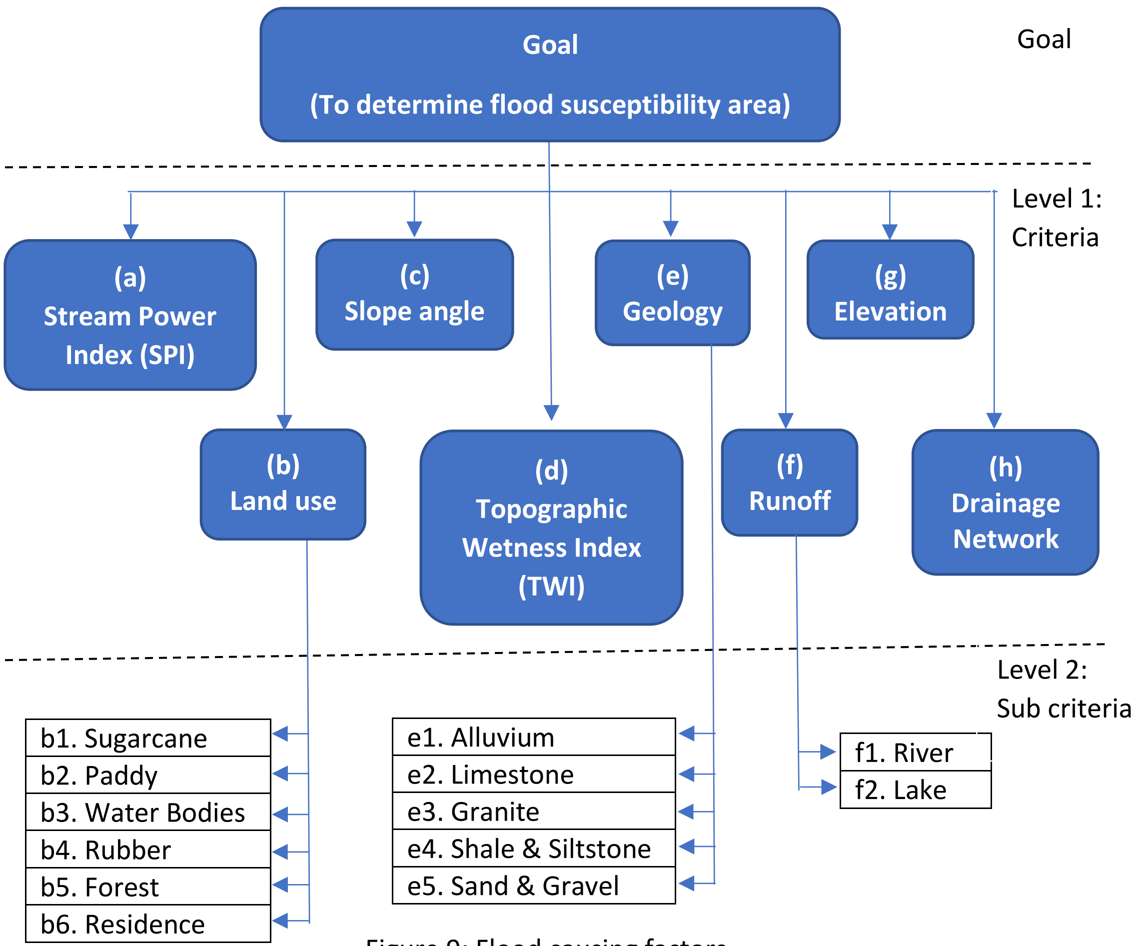


Figure 9: Flood causing factors

a. Stream Power Index (SPI)

Stream Power Index is a measurement of the erosive power of flowing water. It can be used to describe potential flow erosion at the given point of the topographic surface. As the gradient of the slope increase, the velocity and amount of water contributed by upslope will increase, hence stream power index increases (Abdulkadir T. Sholagberu, et al., 2016).

b. Land use

Land use also is one of the factors to be considered in flood susceptibility, because it varies in type surface types. Vegetated areas have a low potential for flooding due to the negative relationship between flooding and vegetation density. Where else, residential areas, roads, industrial areas and other constructed area which mostly made of impervious surface and bare lands will cause surface runoff. The water cannot be absorbed by the soil underneath easily and will be stored on the surface which will act as a water storage. This also will cause flooding. So, the area needs to be classified based on types of land use.

c. Slope angle

Slope angle can be considered as slope indicator for flood susceptibility. This factor plays an important role in flood susceptibility since it influences surface runoff velocity and vertical percolation. It can determine rate and duration of water flow. In the flat surface, water will move slowly and late to distribute or evaporate. This will cause the water to accumulate easily, so these areas are riskier with respect to occurrence of flood compared to steeper surfaces GIS (Rahmati, Zeinivand, & Besharat, 2015).

d. Topographic Wetness Index (TWI)

Topographic Wetness Index is a steady state wetness index. TWI indicates the amount of water accumulation at a point in watershed and trend of water to flow downslope by gravity (Jaafari et al., 2013).

e. Geology

Geological maps can show why flooding will not necessarily occur in every part of a valley floor. The capacity of water can absorb by the soil is related to underlying geology. Some of the soil can allow water to infiltrate, called as permeable soil, On the other hand, there are also nonporous or impermeable soil such as clay and shale which prevent the water to infiltrate.

Porosity or permeability of a soil varies depends on the shape and grain size of the soil. If they are mixed, the porosity will be lowered, because the smaller particles fill the voids between the larger ones. The wider the range in grain sizes, the lower the resulting porosity.

f. Runoff

Streams are fed by runoff from rainfall and snowmelt moving as overland or subsurface flow. Floods occur when large volumes of runoff flow quickly into streams and rivers.

g. Elevation

Changes in elevation will change the direction of runoff. Water runs downhill. When water drains from the soil on local topographic highs, it drains into the low areas of the landscape.

h. Drainage network

Drainage will help to transport water to prevent flooding in any area. The nearer the area from the drainage, the lower the chance of the area getting flooded. This is because the water accumulated in the area which located near drainage will be transported to other place or water bodies easily.

The factors are believed to be causing natural flood to occur. Therefore, the following steps were adhered in coming up with the data layers factors.

3.6 Data Gathering

Data can be obtained in a various way in term of spatial and non-spatial data. Getting the map into the computer is a critical first step in GIS. To create the map, data from a different kind of format will be obtained such as AutoCAD, JPEG image, and many more. For example, an outline map may be available as an AutoCAD DXF format file. The GIS should at minimum be capable of absorbing the DXF fine without further modification. Several data need to be gathered from few departments, such as rainfall data was obtained from Department of Irrigation and Drainage (DID) and Digital Elevation Model, (DEM) was obtained from United States Geological Survey (USGS). In some cases, the data will be in excel or text file which was then imported to ArcGIS software to analyse the factor. To increase the accuracy, more than one data need to gather.

For making a suitable decision and proper study, the effects of involving factors for flooding selected was considered. Details for each factor was collected in form of spatial and non-spatial form. Data are often available from different public agencies and organizations, and usually in different coordinate systems, spatial references, at different scales, and from different time periods or sources. All this data was synthesized to frame a holistic view of the problem.

3.7 Analytical Hierarchy Process (AHP) criteria weighing

Using Multi-Criteria Decision Analysis (MCDA), weights were assigned to each factor based on expert`s opinion. According to Eastman (1996) and Navalgund (1997) defined MCDA as a technique that allows each factor to be weighted in accordance with its relative importance/influence (Jessy Paquette, 2012). Expects chosen in this study are well understands about this natural disaster. Hence, Analytical Hierarchy Process (AHP) method by Saaty (1980) was assigned in determining the relative weights of each flood influencing factor considered herein.

In our study, the major goal of AHP is to identify the relative importance of several factors in defining the main cause of flooding in the study area. To achieve that causative factors causing flood in the study area need to be determined and secondly, is applying the Multi-Criteria Decision Analysis technique in ranking the flood-related factors of the study area to identify the flood-susceptible. Pair-wise Comparison Method will be used to rank each factor causing flood in the study area. This helps in detecting the flood-susceptible areas in the study area by identifying the most flood significant criteria based on the decision makers’ preferences.

Based on Saaty`s scales of relative importance table (provided in table 3), all the factors will be rank in pair-wise comparison in form of pair-wise comparison matrix. In this method, two factors will be compared and scored at a time according to their degrees of influence in flood generation based on the expert’s opinions gathered during the AHP survey questionnaires administered. A matrix of pairwise comparison of factors of AHP comparison will be produced.

Since individual judgement will never be agreed perfectly, the degree of consistency achieved in the ratings will be measured by a Consistency Ratio (CR) indicating the probability that the matrix ratings were randomly generated. A CR ratio must be less than or equal to 0.10 to ensure that it is an acceptable reciprocal matrix, and it is not acceptable or need to be revised if the ratio is over 0.10 (Dano Umar Lawal et al., 2012).

Methodology for Analytical Hierarchy Process (AHP) as illustrated below:

i. First step: Pairwise comparisons

In this method, experts need to rank each factor in the yellow fields prepared in the excel files. Each comparison will be based on Saaty`s scales of relative importance table and the comparison will be made based on each row.

	Item Number	1	2	3	4	5	6
Item Number	Item Description	Slope angle	Rainfall	Distance from river	Land use	Soil type	Capacity of existing
1	Slope angle	1.00	4.00	0.33			
2	Rainfall	0.25	1.00				
3	Distance from river	3.00		1.00			
4	Land use				1.00		
5	Soil type					1.00	
6	Capacity of existing drainage						1.00
	Sum I	4.25	5.00	1.33			

Invert value for each value enter in yellow column

Eg; ¼ = 0.25 and 1/0.33= 3

Full number if row (Slope angle) is more important than column (Rainfall)

Fraction number if column (Distance from river) is more important than row (Slope angle)

Eg: 1/3= 0.33

Enter value at yellow field only

ii. Second step: Determining the relative criterion weights

Relative criterion weights will be calculated for each item based on pairwise comparison table. Each rank will be divided with Sum I.

Item Number	Item Description	Slope angle	Rainfall	Distance from river	Land use	Soil type	Capacity of existing	Weight
1	Slope angle	0.24	0.80	0.25				21.4%
2	Rainfall	0.06	0.20					4.3%
3	Distance from river	0.71		0.75				24.3%
4	Land use							
5	Soil type							
6	Capacity of existing drainage							
	Sum	1.00	1.00	1.00				0.50

From Pairwise comparison table

Eg; $\frac{1}{4.25} = 0.24$

Relative criterion weight will be calculated for each row

iii. Third step: Consistency Ratio (CR) Calculation

Value in pairwise comparison need to be multiply with relative criterion weight and form a CR table.

Slope angle	1.00	4.00	0.33	0.00	0.00	0.00
Rainfall	0.25	1.00	0.00	0.00	0.00	0.00
Distance from river	3.00		1.00	0.00	0.00	0.00
Land use				1.00	0.00	0.00
Soil type					1.00	0.00
Capacity of existing drainage						1.00
	*	*	*	*	*	
	21.4%	4.3%	24.3%			
	=	=	=	=	=	=

Item Number	Item Description	Slope angle	Rainfall	Distance from river	Land use	Soil type	Capacity of existing	SUM II		Weight		SUM/Weight
1	Slope angle	0.21	0.17	0.08				0.47		21.4%		2.18
2	Rainfall	0.05	0.04					0.10	/	4.3%	=	2.24
3	Distance from river	0.64		0.24				0.89		24.3%		3.65
4	Land use											
5	Soil type											
6	Capacity of existing drainage											
											SUM III	8.07

Pairwise comparison value multiply with relative criterion weight

Eg;1 x 21.4% = 0.21

Sum III obtained

Figure 10: Pairwise comparison

Consistency Index (CI) will be calculated using formula (R.K. Jaiswal, et al., 2015):

$$CI = \frac{\lambda - n}{n - 1}$$

Where,

n = Number of factors = 6

λ = Average value of the consistency vector determined

$= \frac{Sum\ III}{n}$

Using the CI calculated, Consistency Ratio will be calculated using formula (R.K. Jaiswal, et al., 2015):

$$\boldsymbol{CR = \frac{CI}{RI}}$$

Where,

RI = Random inconsistency index whose value depends on the number (n)

RI will be determined from,

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table 4: Random inconsistency index

Consistency Ratio (CR) value calculated will be compared and make sure it is more than or equal to 0.1, or else modification should be done in the ranking.

3.8 Building the database

This step involves creating the land use, geology, rainfall, drainage network, elevation, slope angle, SPI and TWI map from satellite images that had been processed through the classification by using ArcGIS software. All data collected was processed based on their need and criteria saved in GIS system together with all spatial and attribute data. The maps are being used in the software after registered into the local coordinate system.

To generate a model for the evaluation of hazard susceptibility, a set of conditioning factors should be defined. Flood conditioning factor datasets was constructed using eight factors mentioned above: stream power index (SPI), land use, slope angle, topographic wetness index (TWI), geology, runoff, elevation and drainage network. These factors were gathered from various sources, comprising various degrees of generalization and scales, and consequently resized to 30m cell size. All the conditioning factors were prepared in ArcGIS.

The methodology of building database is summarised below:

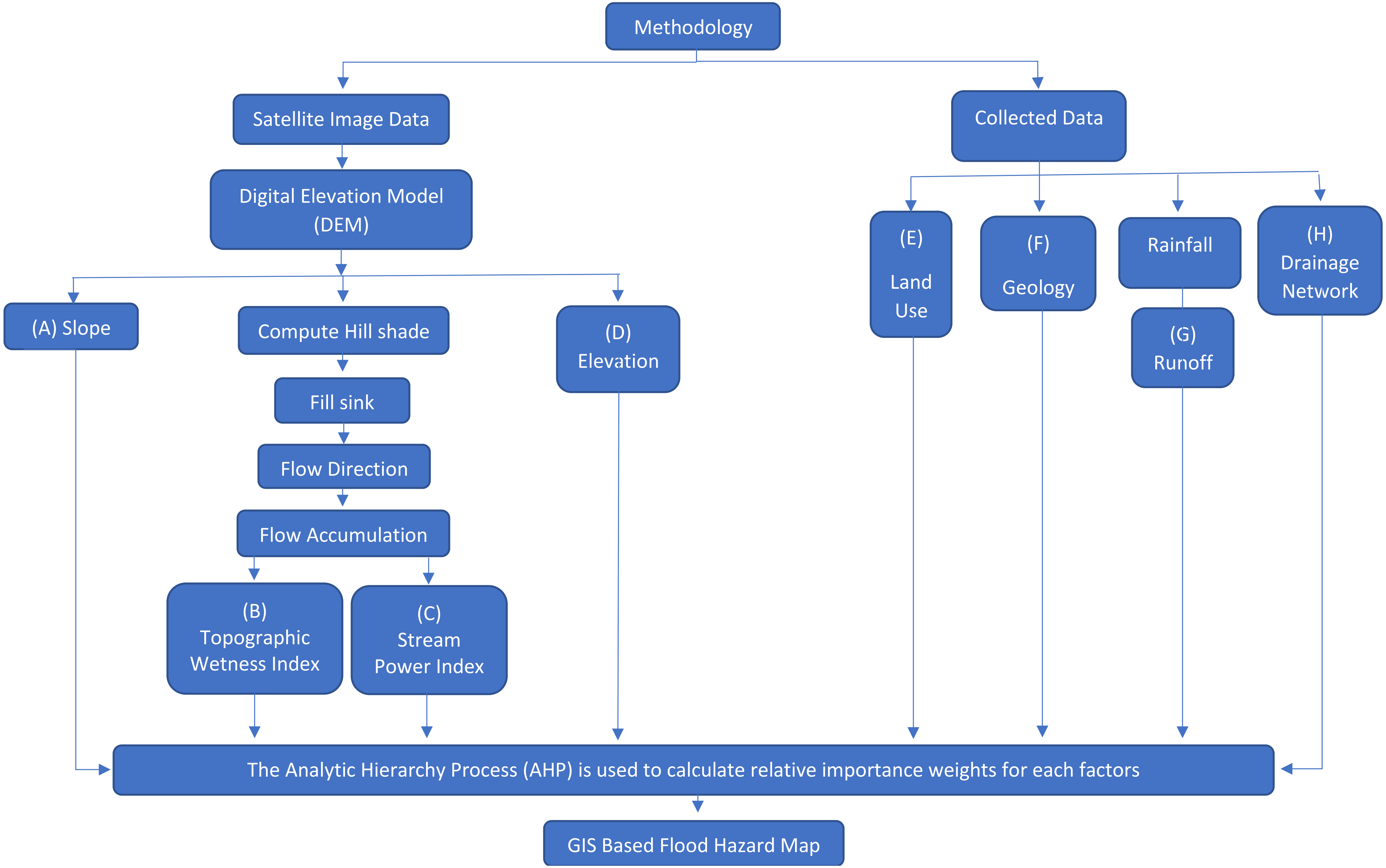
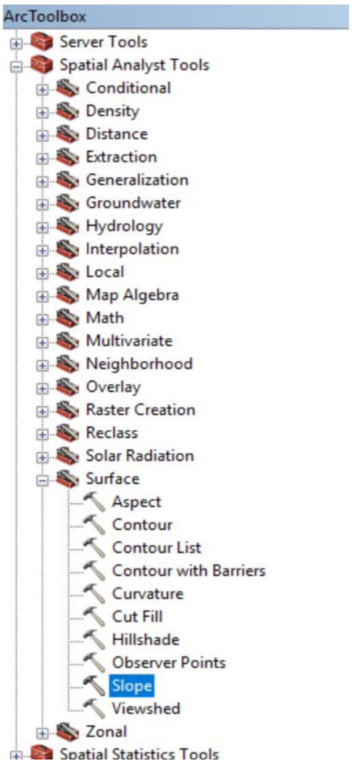


Figure 11: Methodology of data processing

3.8.1 Slope Angle layer

To generate slope map, slope tool in ArcGIS was used. It can be found at Arc Toolbox/ Spatial Analyst Tools/ Surface/ Slope. It was extracted from the Digital Elevation Model (DEM) with output measurement in degree.



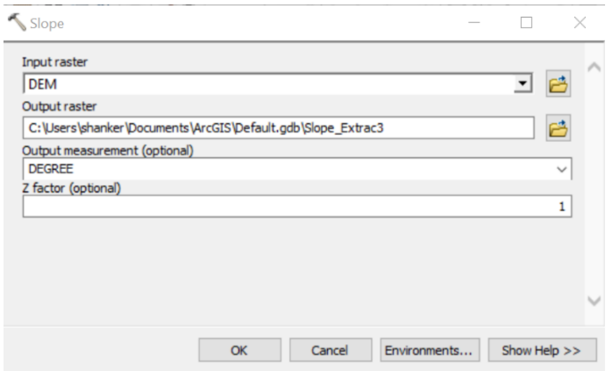


Figure 12: Slope Tool

3.8.2 Stream Power Index (SPI) & Topographic Wetness Index (TWI) layers

Flow across a surface will always be in the steepest downslope direction. Once the direction of flow out of each cell is known, it is possible to determine which and how many cells flow into any given cell. This information can be used to define flow accumulation which will be useful to create TWI and SPI.

Firstly, the Digital Elevation Model (DEM) was used to determine the flow direction. Water from one cell flow to which direction. However, if there are errors in the elevation model, there may be some cell locations that are lower than the surrounding cells. If this is the case, all surface flow travelling into the cell will not travel out. These depressions are called sinks. The hydrologic analysis tools were used to identify the sinks and fill them.

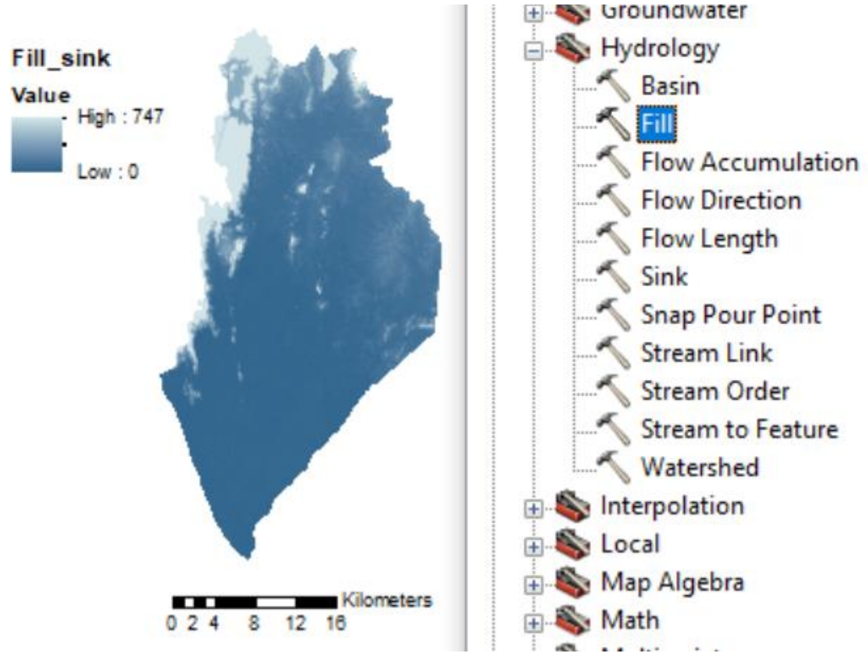


Figure 13: Fill sink

The flow direction of the water changes due to the slope angle and direction. Flow direction tool in ArcGIS creates a raster of flow direction from each cell to its steepest downslope neighbour. Water will flow from the higher elevation to lower elevation.

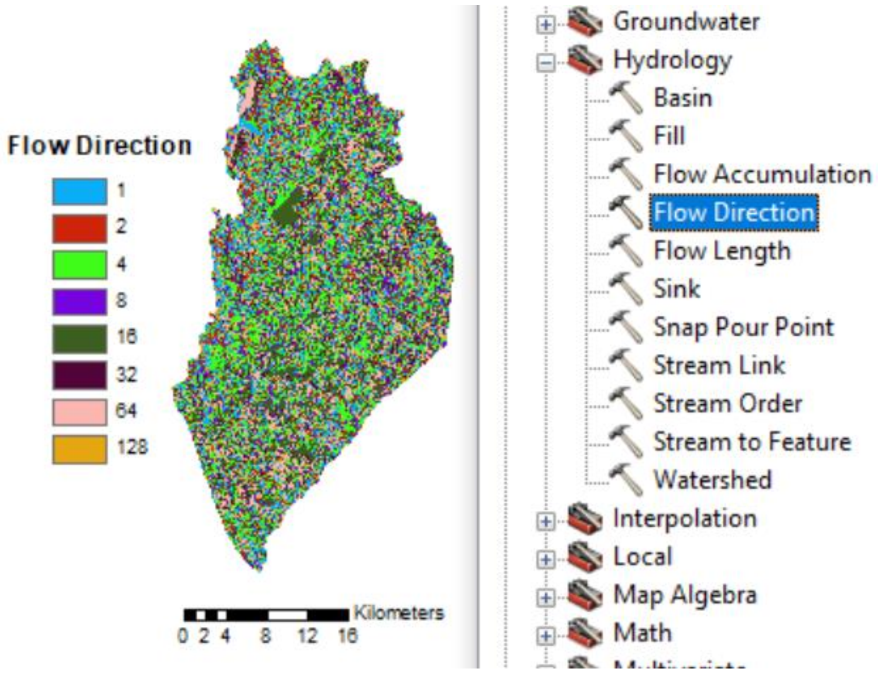


Figure 14: Flow direction

Flow accumulation tool creates a raster of accumulated flow into each cell. A weight factor can optionally be applied. Water from steeper slopes will flow to the downslope and accumulates. The accumulated flow is based on the number of cells flowing into each cell in the output raster. The current processing cell is not considered in this accumulation. Higher value in flow accumulation raster represent drainage depressions, where lower values represent crests and ridges

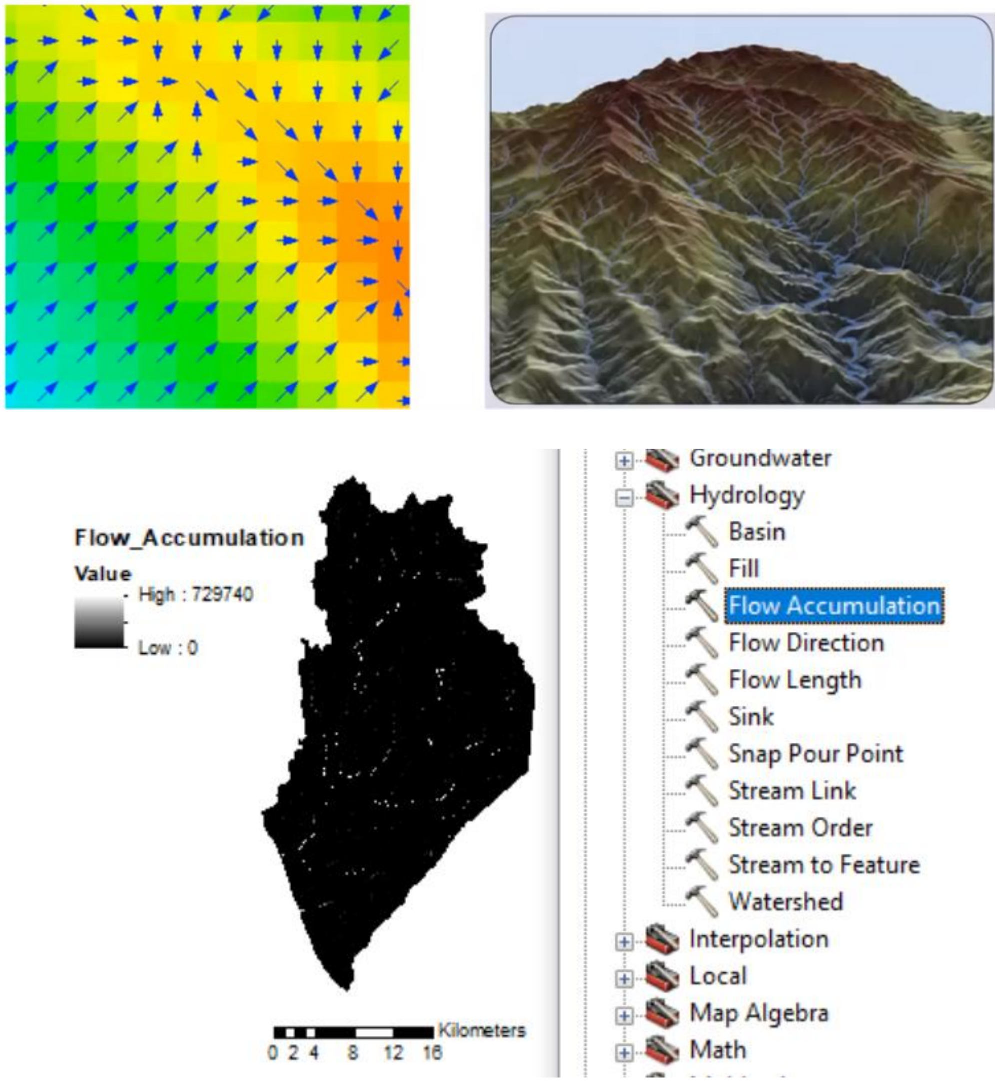


Figure 15: Flow accumulation raster

Stream Power Index (SPI) represents the power of water flow in terms of erosion. Topographic Wetness Index (TWI) shows an amount of the flow accumulation at any place in a drainage basin and the trend of the water to go downslope by the power of gravity. These both parameters have a relationship with slope gradient and flow accumulation of the place and it has been shown in the equations below.

All those SPI and TWI layers can be calculated respectively by inputting those empirical equations below in raster calculator tool in ArcGIS.

TWI $= \ln \left(\frac{\alpha}{\tan\beta + 0.01}\right)$

SPI $= \ln\left((\alpha + 0.001) \text{ x } \left(\frac{\beta}{100} + 0.001\right)\right)$

Where, α = Flow accumulation and β = Slope angle in degree (Slope gradient)

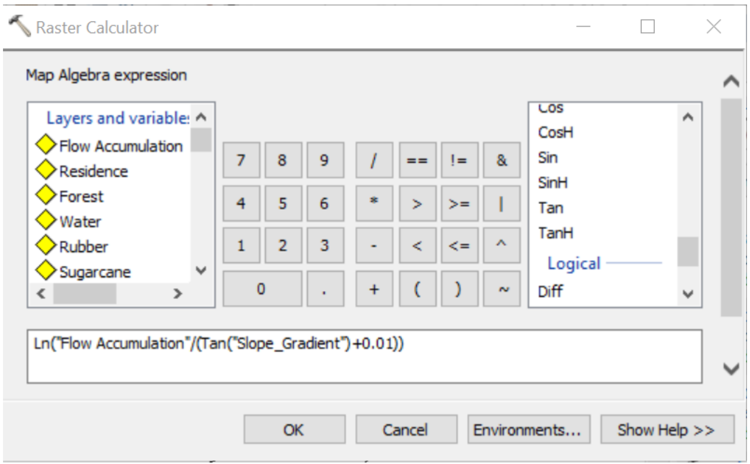


Figure 16: Computing TWI using raster calculator

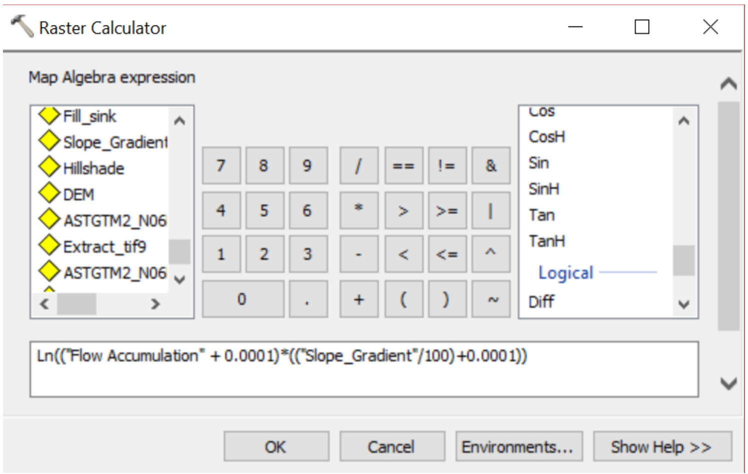


Figure 17: Computing SPI using raster calculator

3.8.3 Runoff

Surface runoff is the water flow that happens when the soil is saturated to full capacity over the land. It is generated by rainstorms and the occurrence and intensity are based on the characteristics of rainfall event. When the rain falls, the first drops will be absorbed by the leaves and other structures on earth surface. As the rain continues, the rainwater will be infiltrates into the soil until it reaches where the rate of rainfall exceeds the infiltration capacity of soil. The excess rainfall water then flows on earth surface forms runoff (Critchley Will, and Klaus Siegert, 2013).

To calculate the runoff layer using empirical equations derived from Quenzer and Maidment (1998), rainfall map of Perlis state must be produce (Mahyat S.T., et al., 2014).

Firstly, to produce rainfall map, 20 years (from January 1996 until December 2016) of daily rainfall data for every rain gauge station in Perlis was obtained from Department of Irrigation and Drainage (DID) Malaysia. Total number of station used in the project are 14. The maximum rainfall for each station was used in the equation to consider the worst-case scenario. The station name, number and rainfall values are shown below:

Num.	Station Number	Station Name	Maximum Rainfall (mm)
1	6301001	Kg. Behor Lateh	3511
2	6401002	Padang Katong di Kangar	2375.7
3	6402006	Guar Nangka	2216.2
4	6402007	Arau	2540.5
5	6402008	Ngolang	2418
6	6403001	Ulu Pauh	2314.5
7	6501005	Abi Kg. Bahru	2428
8	6502010	Bukit Temiang	2088
9	6503001	Ldg. Perlis Selatan	2293.5

Num.	Station Number	Station Name	Maximum Rainfall (mm)
10	6601001	Wang Kelian	2500.2
11	6602002	Kaki Bukit	2139.5
12	6602003	Tasoh di Perlis	2332
13	6602005	Lubok Sireh	2003.5
14	6603001	Padang Besar	2169

Table 5: List of rain gauge station

Since only 14 rain gauge stations which are in point form used out of whole Perlis state, it is necessary to do interpolation to identify the rainfall at other entire regions of Perlis. To interpolate a raster surface from rain gauges, kriging tool was used in ArcGIS.

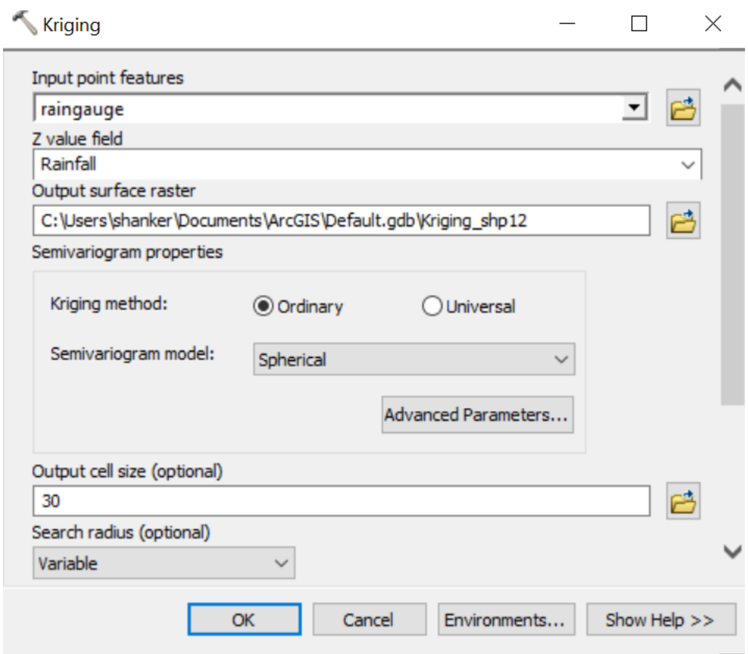


Figure 18: Kriging tool to do interpolation

By doing interpolation based on the rainfall and rain gauge location, a map of rainfall of Perlis state was created.

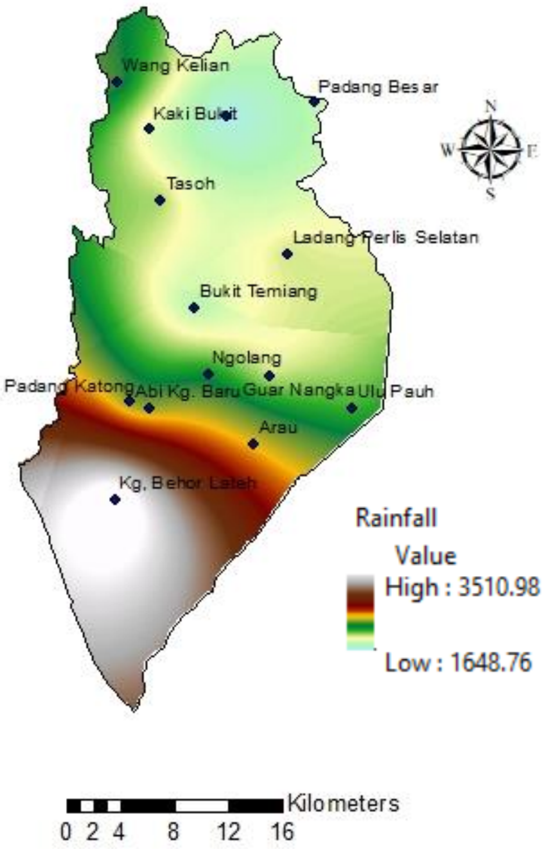


Figure 19: Rain gauge Location

Secondly, land use and land cover (LULC) factors were divided into four classes namely, agriculture, forest, urban, and water body. Subsequently, the runoff values were calculated for each type individually using the following empirical equations derived from Quenzer and Maidment (1998).

$$Q_{Agriculture} = 0.008312 * e^{0.011415*P}$$

$$Q_{Forest} = 0.0053 * e^{0.010993*P}$$

$$Q_{Urban} = 0.24 * P$$

$$Q_{Water} = 0$$

Where, Q = Runoff (mm/year) and P = Rainfall (mm/year)

In our study area, there are varieties of land use, such as rubber, sugarcane, paddy, water body, forest and residential area. Rubber, sugarcane and paddy were considered as agriculture altogether. Based on all those empirical equations, the map of runoff for each land use type was created by substituting rainfall map created in P (Mahyat S.T., et al., 2014).

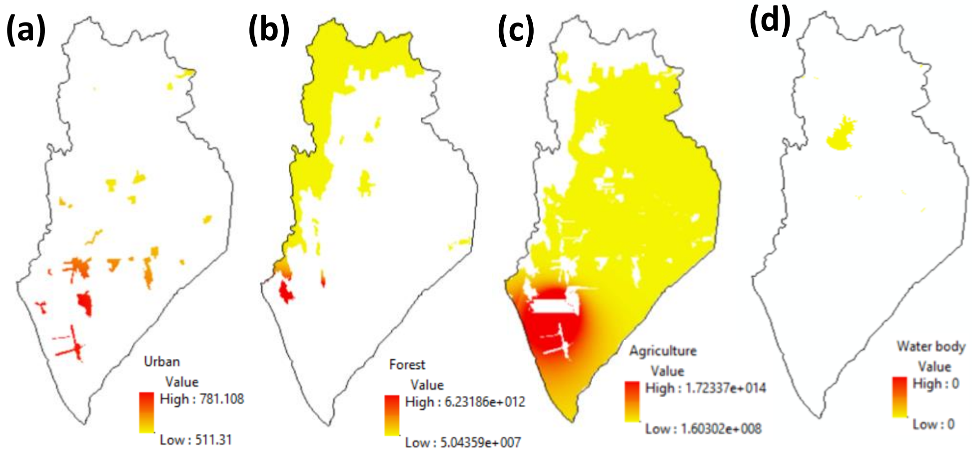


Figure 20: (a) QUrban (b) QForest (c) QAgriculture (d) QWaterbody

Thirdly, all those runoff maps created separately for each land use were merged to create a Runoff map for whole Perlis State. Mosaic tool in ArcGIS was used to merge all those raster layers into a single map.

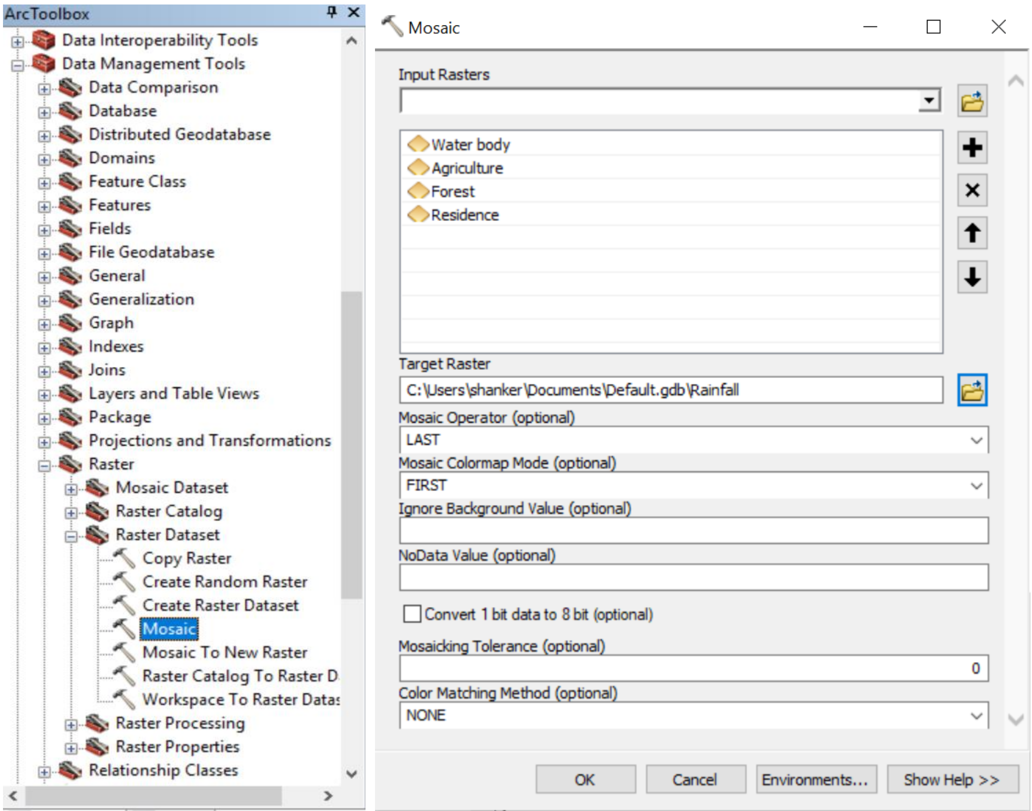


Figure 21: Mosaic Tool

3.8.4 Elevation

Elevation of the study area can be extracted directly from the Digital Elevation Model (DEM) (Shown in figure 29).

3.8.5 Land use & Geology

There is various type of land use and geology in the study area. Types of land use were explained in the runoff, where the type of geology in the study area are, alluvium, limestone, granite, sand and gravel, and shale and siltstone. Weightage for each type of land use and geology factors was assigned based on Analytical Hierarchy Process (AHP) separately.

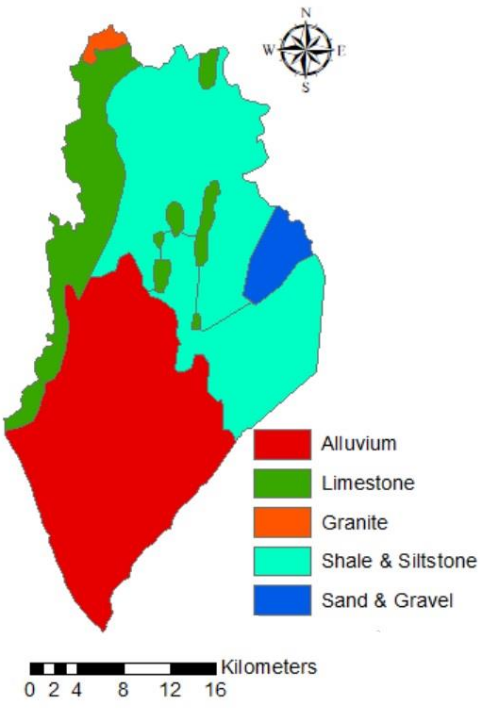


Figure 22: Geology

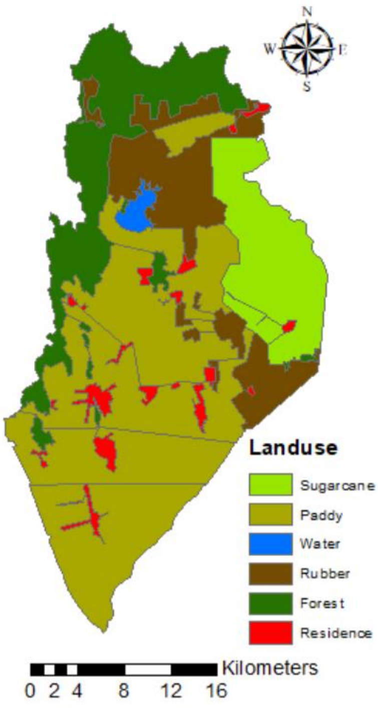


Figure 23: Land use

3.8.6 Drainage network

The distance from drainage network raster can be compute by using Euclidean Distance tool in ArcGIS. Euclidean distance tool gives the distance from each cell in the raster to the closest drainage.

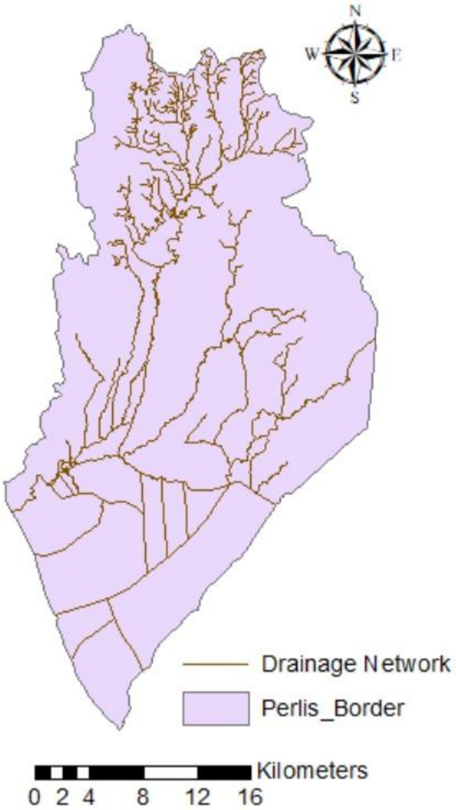


Figure 24: Drainage Network

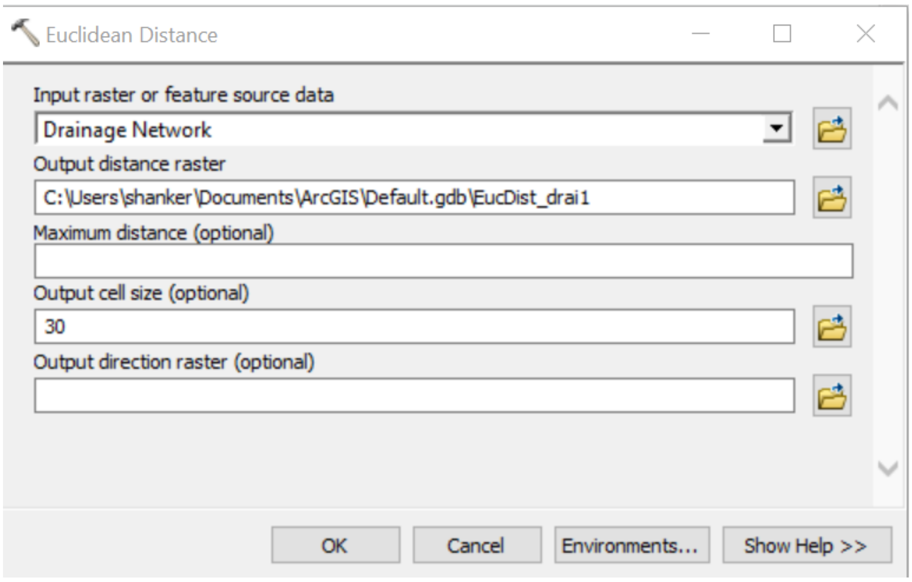


Figure 25: Euclidean Distance Tool

3.9 Rating/scoring of the classified thematic layers

This stage involved the integration of the AHP model into GIS system. Once thematic layer for each factor was produced (as explained in section 3.8), ranks were assigned to each parameter according to the order of influence of the class on flood hazard potential. The normalized rate of each factor was calculated based on rate obtained from the AHP questionnaire survey conducted in term of percentage.

3.10 Preparation of flood susceptibility map

It involved combining all the thematic layers using the Weighted Linear Combination (WLC) method based on the computed weights generated from the AHP method into GIS. The weighted linear combination, or simple additive weighting, depends upon the theory of a weighted average in which continuous criterions are standardized to a collective numeric range and then combined by means of a weighted average (S.Drobne and A.Lisec, 2009). These thematic layers were summed to obtain the final flood prediction map in accordance with the AHP model developed. The Weighted Linear Combination (WLC) formula is shown below:

$$\text{FSZ} = \sum wx$$

Where,

FSZ = Flood Susceptibility Zone

w = Factor weights which must be sum of 1

x = Criterion score i

Raster calculator tool from ArcGIS will be used to compute the equation by substituting all the thematic layers as raster file in the equation. The result of the final analysis will indicate the potential areas of flood.

CHAPTER 4

RESULTS & DISCUSSION

4.1 Data processing

As a result, maps for every flood causing factor layers was prepared in ArcGIS and symbolize every area with criteria intensity with dimensions of colour. All data processed was set in Malaysian coordinate WGS_1984_UTM_Zone_48N to avoid error in overlapping. The raster data also set to 30, 30 cell size (X, Y). The concentration of each factor can be expressed according to the colour used on the map. Colours are often expressed as red, green, blue triplets (RGB) or sometimes as hue, saturation and intensity (HIS). For this example, HIS colours being used to express the concentration of each factors availability at every area.

4.1.1 Slope Angle

Slope can be measured by the angle among the terrain and horizontal datum. This factor has high value in hydrology. The estimation of slope angle for Perlis was extracted from DEM. From Figure 26, almost 80% of the slope in this study area are in range of 0-10^{o}. The mean slope angle is 6.09^{o} and the highest slope angle is 70.82^{o}.

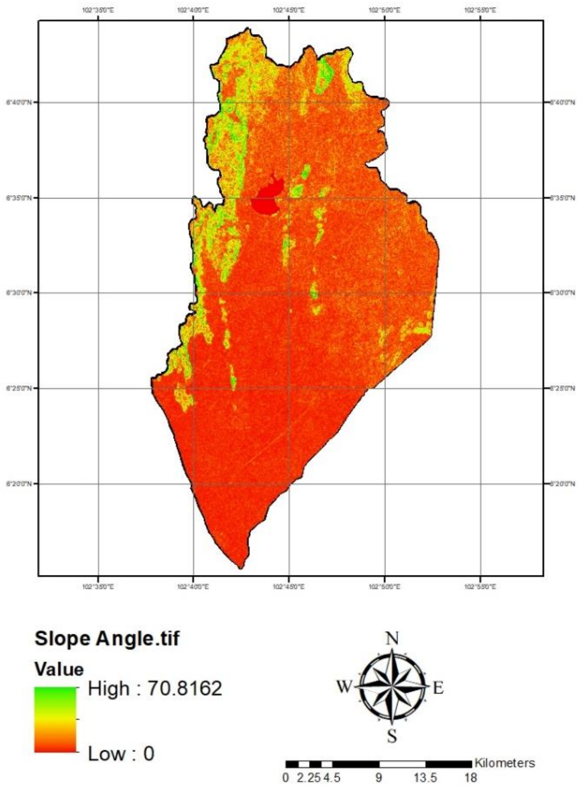


Figure 26: Slope angle

4.1.2 Stream Power Index (SPI)

By using slope map and the flow accumulation raster, Stream Power Index (SPI) map was produced. From Figure 27, the estimated maximum Stream Power Index (SPI) is 10.1824 and the minimum value is -13.8155. According to the map produced, most of the SPI values vary in the range of 3.832.

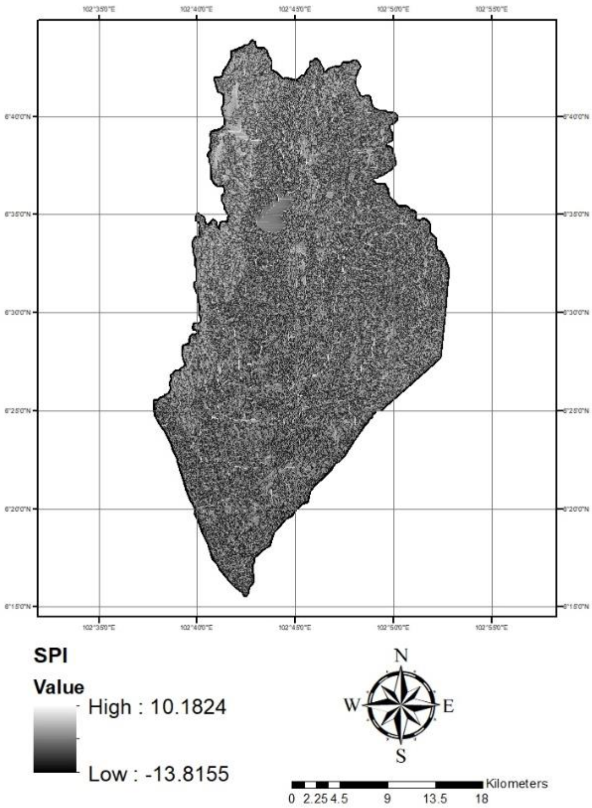


Figure 27: Stream Power Index (SPI)

4.1.3 Topographic Wetness Index (TWI)

By using slope map and flow accumulation raster, Topographic Wetness Index (TWI) map was produced. From Figure 28, the estimated maximum Topographic Wetness Index (TWI) is 18.0235 and the minimum value is -1.05926. According to the map produced, most of the TWI values vary in the range of 10.223.

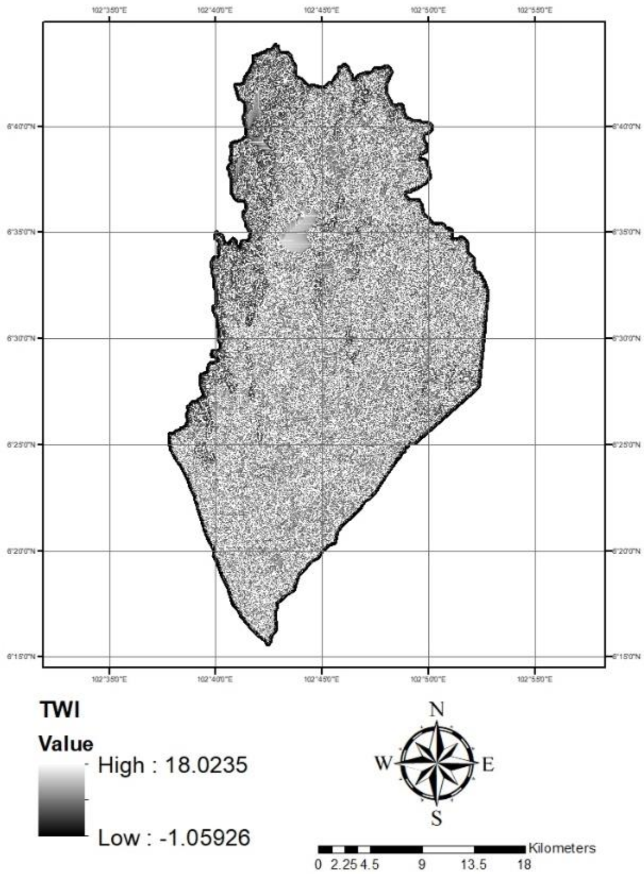


Figure 28: Topographic Wetness Index (TWI)

4.1.4 Elevation

Elevation data is extracted directly from Digital Elevation Model (DEM). From Figure 29, the maximum and minimum elevation in the Perlis are 747m and 0m. The mean elevation is 73.656m.

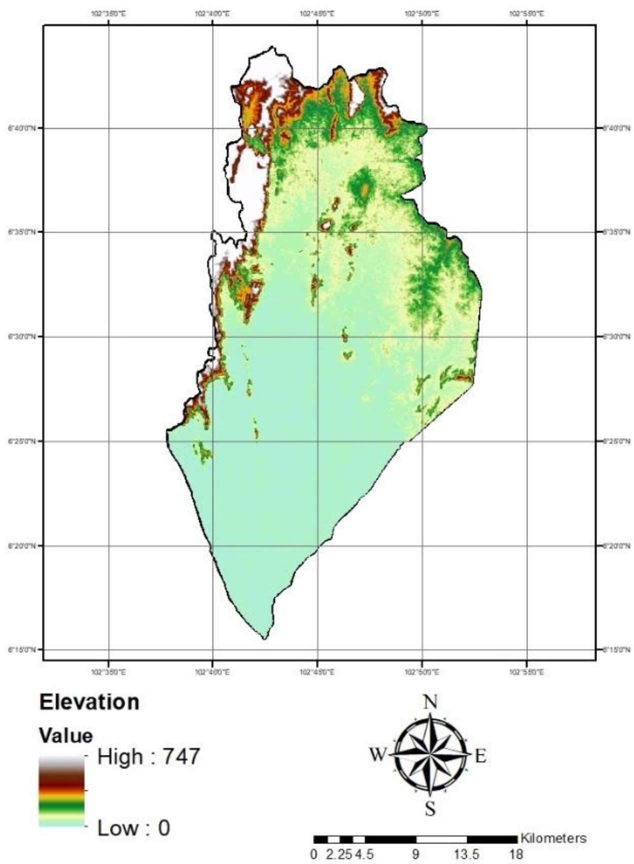


Figure 29: Elevation

4.1.5 Drainage Network

Drainage network was extracted from the DEM as well using Euclidean distance tool. It considered the whole Perlis region in calculating the distance from drainage network. From figure 30, area that is most further from the drainage network is at 5749.13m away. The longest drainage is Sungai Arau, which is 26077.621m.

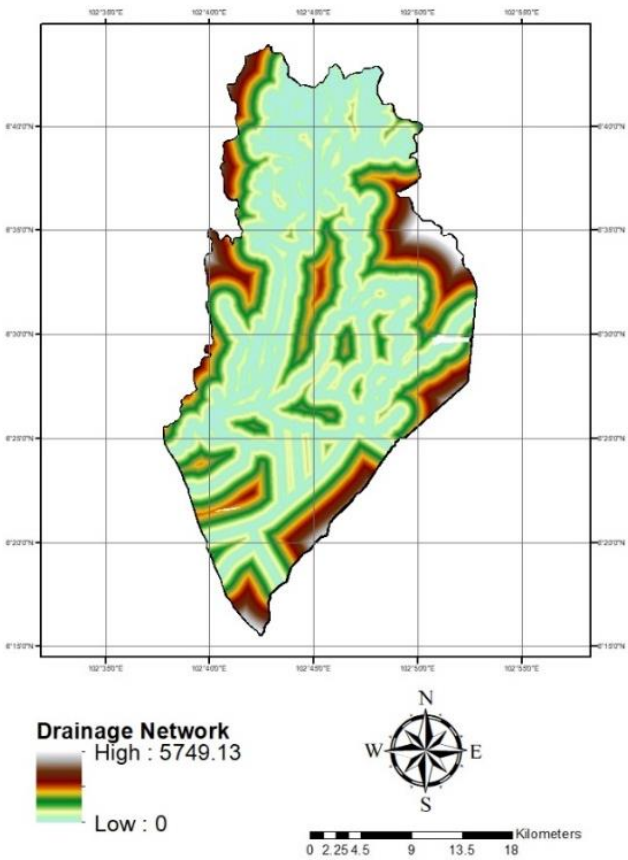


Figure 30: Drainage Network

4.1.6 Runoff

Runoff map was produced by creating raster layers for each land use using the formula based on the rainfall at the particular area and merged all together using mosaic tool in ArcGIS. From figure 31, the highest runoff value is 65535 and the lowest is 2488. Those forest areas have the least runoff compared to other area.

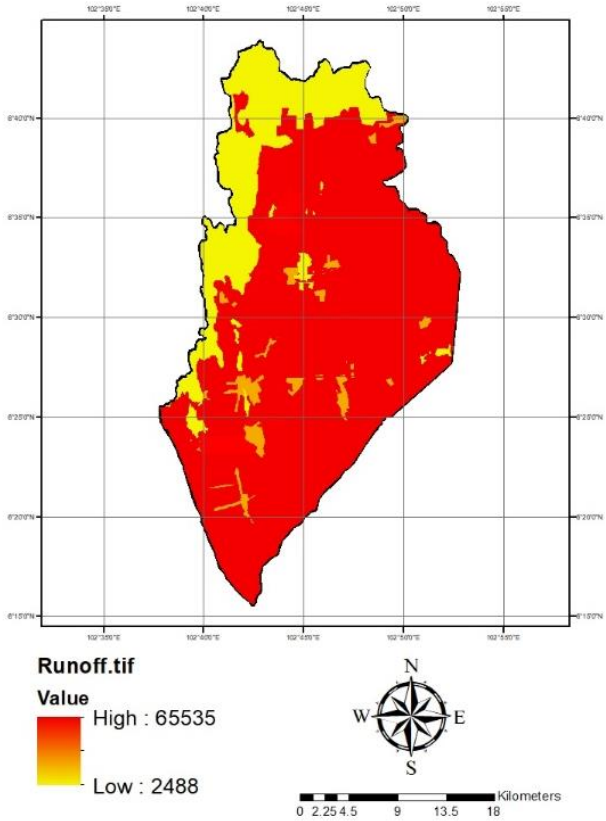


Figure 31: Runoff

4.1.7 Geology

Geology map was produced based on a separate Analytical Hierarchy Process (AHP) by weighing each geology types. From the survey, it shown that granite has the highest average rank causing flood which is 30%, where the least average rank is on sand & gravel which is 11%. Table 6 and figure 32 below shows the average rank obtained for each soil type in the study area.

Soil types	Expert 1	Expert 2	Expert 3	Sum	Average
Alluvium	12%	46%	6%	65%	22%
Limestone	22%	28%	26%	77%	26%
Granite	44%	5%	42%	90%	30%
Shale & Siltstone	12%	13%	10%	36%	12%
Sand & Gravel	9%	8%	16%	33%	11%
Sum	100%	100%	100%	300%	100%

Table 6: Rank from each expert (Geology)

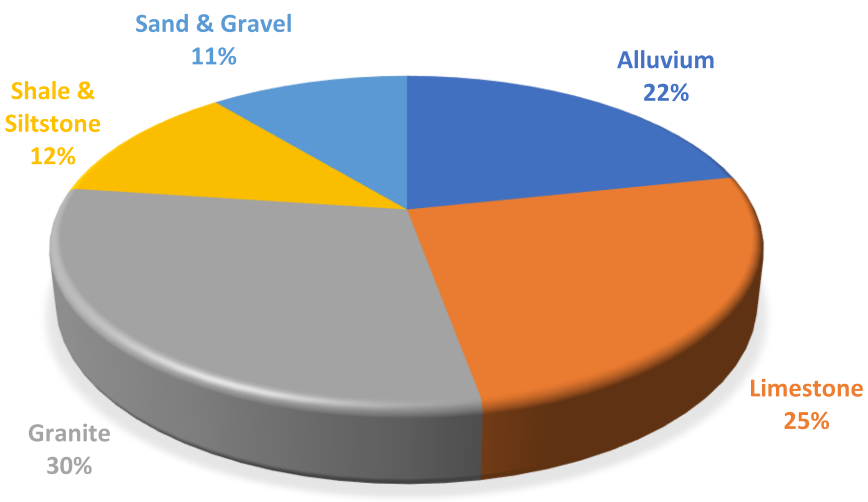


Figure 32: Chart of Weights (Geology)

This survey proves that granite area has high potential to get flooded because it has lower permeability than any other soil type in Perlis state, thus the capacity of water will allow to infiltrate in granite will be lower.

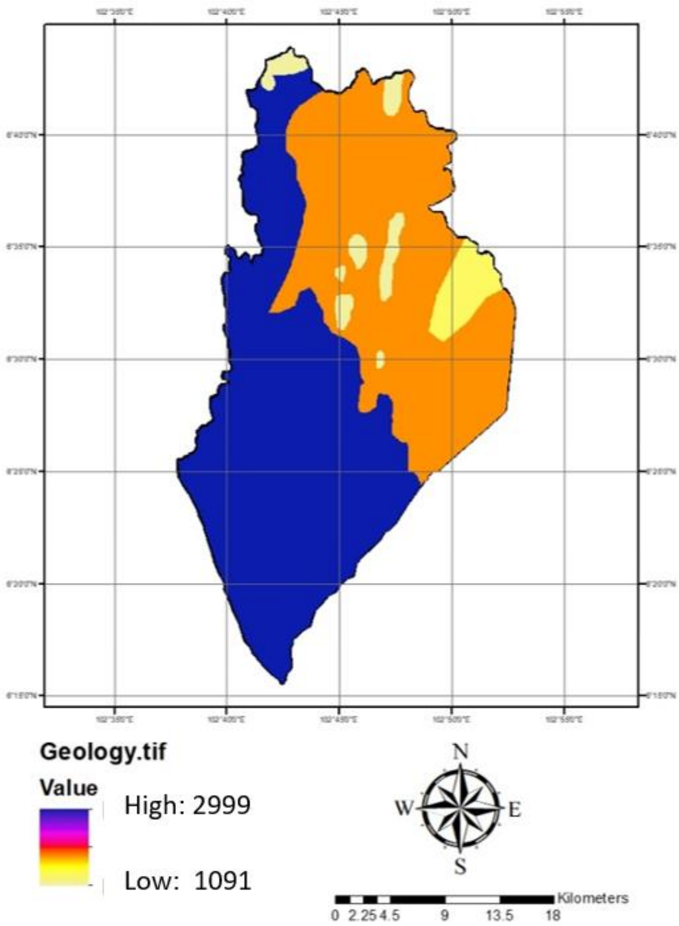


Figure 33: Geography map

4.1.8 Land use

Same as geology, land use map also was produced based on another separate Analytical Hierarchy Process (AHP) by weighing each land use types. Based on the AHP survey questionnaire conducted from experts, residence have the highest average weightage which is 32% where the lowest average weightage in flood causing is sugarcane which is 9%. Since most of the Perlis region is covered with paddy (weightage of 14%), the overall mean weigh of the whole Perlis was lowered to 13.14%.

Land use types	Expert 1	Expert 2	Expert 3	Sum	Average
Sugarcane	11%	19%	4%	35%	12%
Paddy	11%	24%	7%	43%	14%
Water Bodies	13%	8%	16%	36%	12%
Rubber	12%	4%	10%	26%	9%
Forest	24%	16%	25%	65%	22%
Residence	28%	29%	38%	95%	32%
Sum	100%	100%	100%	300%	100%

Table 7: Rank from each expert (Land use)

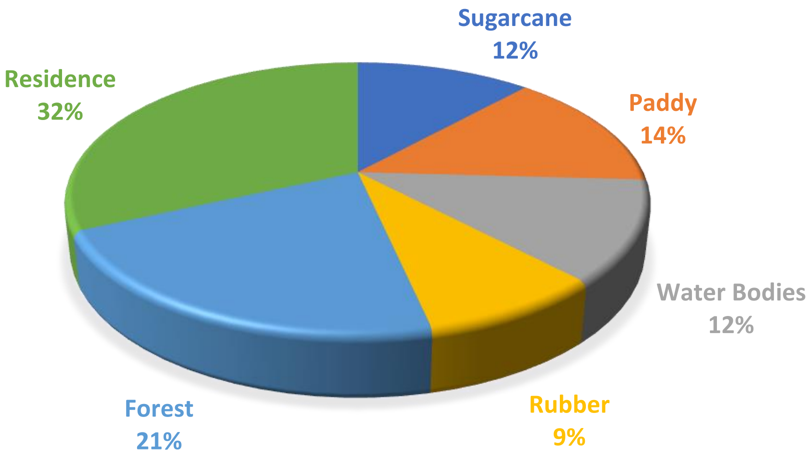


Figure 34: Chart of Weights (Land use)

This survey proves that residence area has high potential to get flooded because the residential area has land cover which covered with cement and asphaltic pavements which prevents the water to infiltrate into the soil and produces runoff and water catchment area.

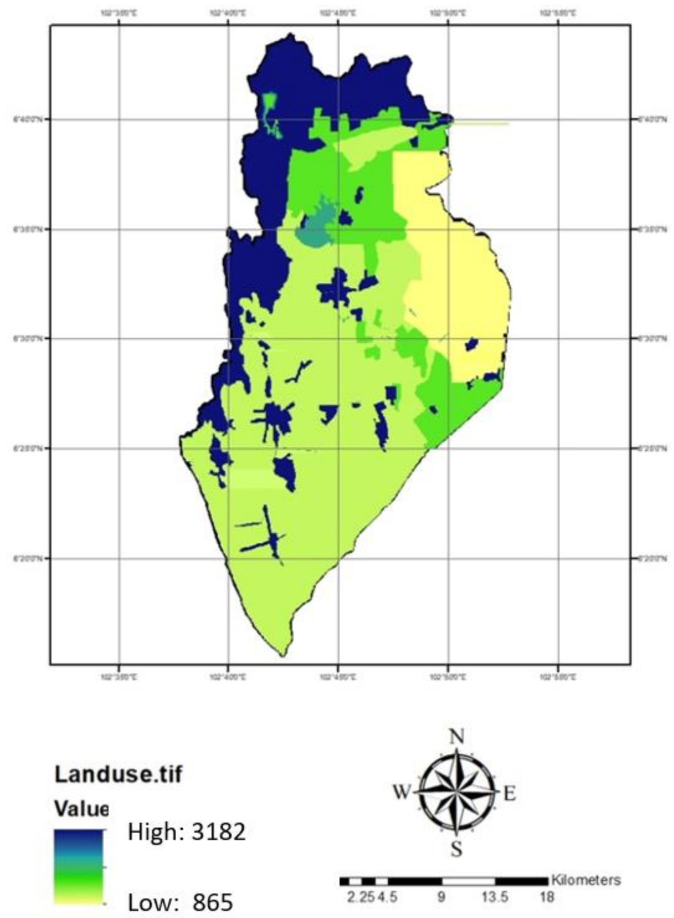


Figure 32: Land use map

4.2 Computation of the Pair-wise Comparison Matrix and Consistency - Analytic Hierarchy Process (AHP) model.

Pairwise comparison matrix is created by assigning weights by experts. The weights are further evaluated in finding alternatives and estimating associated absolute numbers from 1 to 9 in Saaty`s scale of the AHP. The pairwise comparison matrixes are calculated herein using Microsoft Excel software called Multi-Criteria Decision Analysis (MCDA) tool in determining priority weights.

Pairwise comparisons

	Item Number	1	2	3	4	5	6	7	8
Item Number	Item Description	Stream Power Index (SPI)	Land Use	Slope Angle	Topographic Wetness Index (TWI)	Geology	Runoff	Elevation	Drainage Network
1	Stream Power Index (SPI)	1.00	0.14	0.33	0.25	0.50	0.13	0.20	0.17
2	Land Use	7.00	1.00	5.00	4.00	6.00	0.50	3.00	2.00
3	Slope Angle	3.00	0.20	1.00	0.50	2.00	0.17	0.33	0.25
4	Topographic Wetness Index (TWI)	4.00	0.25	2.00	1.00	3.00	0.20	0.50	0.33
5	Geology	2.00	0.17	0.50	0.33	1.00	0.14	0.25	0.20
6	Runoff	8.00	2.00	6.00	5.00	7.00	1.00	4.00	3.00
7	Elevation	5.00	0.33	3.00	2.00	4.00	0.25	1.00	2.00
8	Drainage Network	6.00	0.50	4.00	3.00	5.00	0.33	0.50	1.00
	Sum I	36.00	4.59	21.83	16.08	28.50	2.72	9.78	8.95

STANDARDIZED MATRIX

Item Number	Item Description	Stream Power Index (SPI)	Land Use	Slope Angle	Topographic Wetness Index (TWI)	Geology	Runoff	Elevation	Drainage Network	Weight
1	Stream Power Index (SPI)	0.03	0.03	0.02	0.02	0.02	0.05	0.02	0.02	2.4%
2	Land Use	0.19	0.22	0.23	0.25	0.21	0.18	0.31	0.22	22.7%
3	Slope Angle	0.08	0.04	0.05	0.03	0.07	0.06	0.03	0.03	5.0%
4	Topographic Wetness Index (TWI)	0.11	0.05	0.09	0.06	0.11	0.07	0.05	0.04	7.3%
5	Geology	0.06	0.04	0.02	0.02	0.04	0.05	0.03	0.02	3.4%
6	Runoff	0.22	0.44	0.27	0.31	0.25	0.37	0.41	0.34	32.5%
7	Elevation	0.14	0.07	0.14	0.12	0.14	0.09	0.10	0.22	12.9%
8	Drainage Network	0.17	0.11	0.18	0.19	0.18	0.12	0.05	0.11	13.8%
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

SUM II	/	Weight	=	SUM/Weight
0.20		2.4%		8.23
1.97		22.7%		8.67
0.40		5.0%		8.12
0.60		7.3%		8.22
0.28		3.4%		8.13
2.80		32.5%		8.62
1.11		12.9%		8.64
1.16		13.8%		8.37
			SUM III	66.99

Sum III was obtained = 66.99
Index (CI) was calculated using formula:

$$\boldsymbol{CI = \frac{\lambda - n}{n - 1}}$$

Where,
n = Number of factors = 8

λ = Average value of the consistency vector determined

$= \frac{Sum\ III}{n} \qquad = \frac{66.99}{8} = 8.375$

CI $= \frac{8.375-8}{8-1} \qquad = \frac{0.375}{7} = 0.0536$

Using the CI calculated, Consistency Ratio was calculated using formula:

$$\boldsymbol{CR = \frac{CI}{RI}}$$

Where,

RI = Random inconsistency index whose value depends on the number (n)

RI will be determined from table 4, since n value is 8,

RI = 1.41

CR $= \frac{0.0536}{1.41} = 0.038$

The Consistency Ratio (CI) should be lower than 0.1. Since value that we get is 0.038 which is lower than 0.1, it is acceptable. This is one of the sample questionnaire conducted from one of the experts, this questionnaire was conducted to totally 3 experts to obtain more accurate ranks by preventing individual error. Other questionnaire survey results are attached in APPENDIX II.

Based on the results obtained from the questionnaire conducted from 3 experts, average rank for each factor was assigned. The weight of each expert is shown below:

Factors	**Expert 1**	**Expert 2**	**Expert 3**	**Sum**	**Average**
Stream Power Index (SPI)	2%	3%	5%	10%	3%
Land Use	23%	15%	16%	54%	18%
Slope Angle	5%	17%	17%	38%	13%
Topographic Wetness Index (TWI)	7%	4%	8%	20%	7%
Geology	3%	12%	2%	18%	6%
Runoff	33%	23%	24%	79%	26%
Elevation	13%	11%	25%	49%	16%
Drainage Network	14%	14%	4%	31%	10%
Sum	100%	100%	100%	300%	100%

Table 8: Rank from each expert (Overall)

All the significance of the factors has been identified using AHP process as explained above. The weights of each factors are:

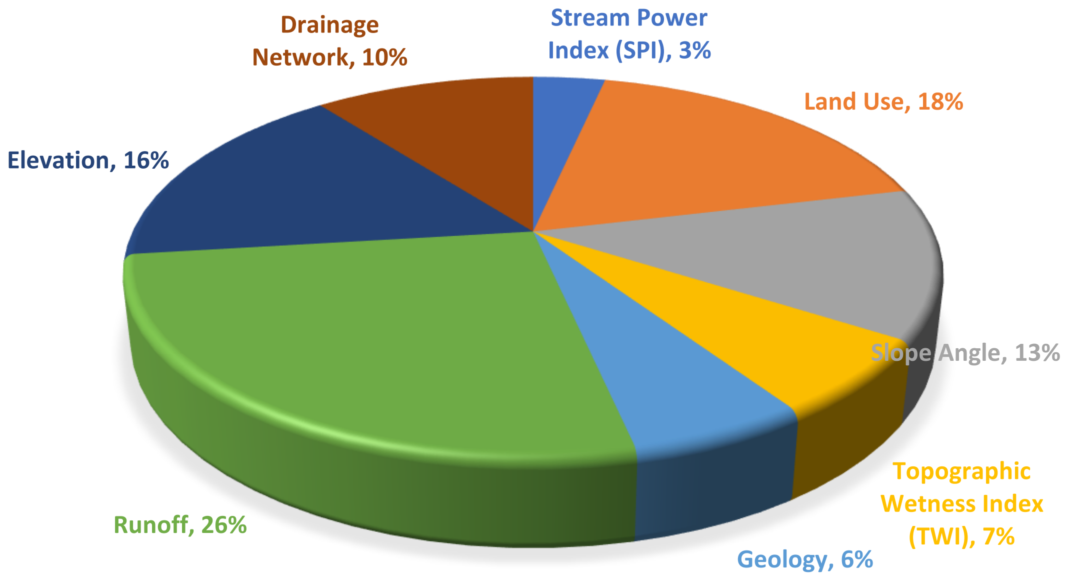


Figure 34: Chart of Weights (Overall)

By ranking all those factor-based-maps based on the AHP, we can identify flood hazard areas which will be used to produce a flood susceptibility map for the whole area considering all the factors according to the rank and the concentration of factors at the study area. Raster calculator was used to creating the flood susceptibility map based on all the weighs for every factor. (Runoff > Land use > Elevation > Slope angle > Drainage Network > Topographic Wetness Index (TWI) > Geology > Stream Power Index (SPI))

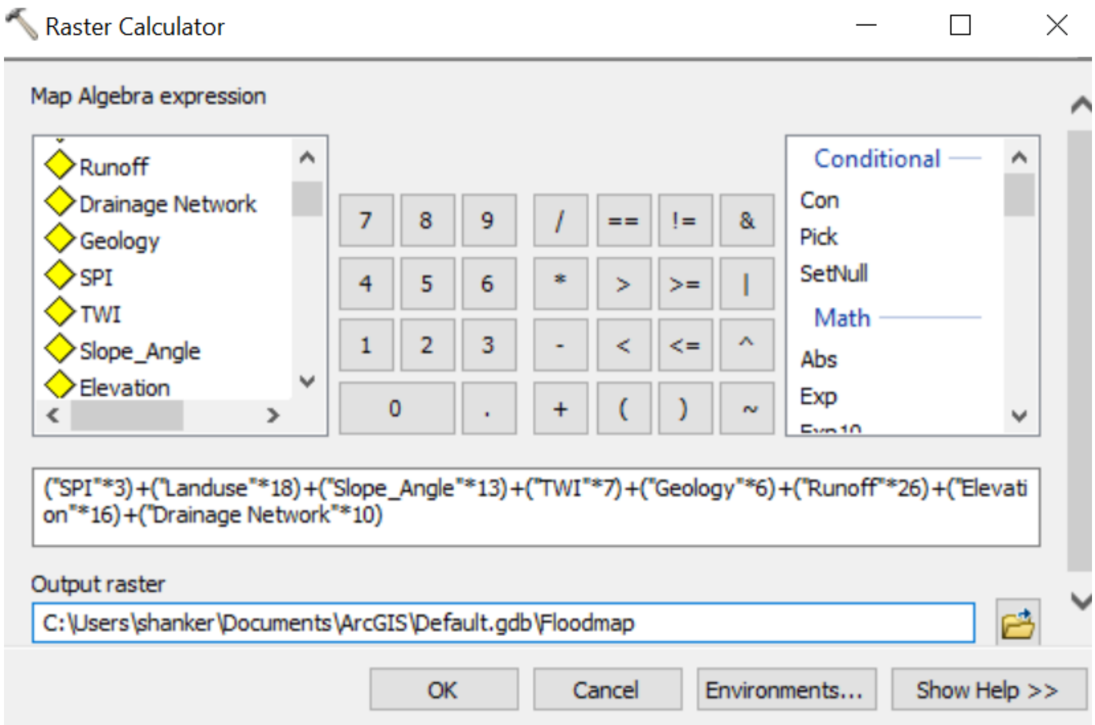


Figure 35: Raster Calculator

4.3 Multi-criteria flood susceptibility map

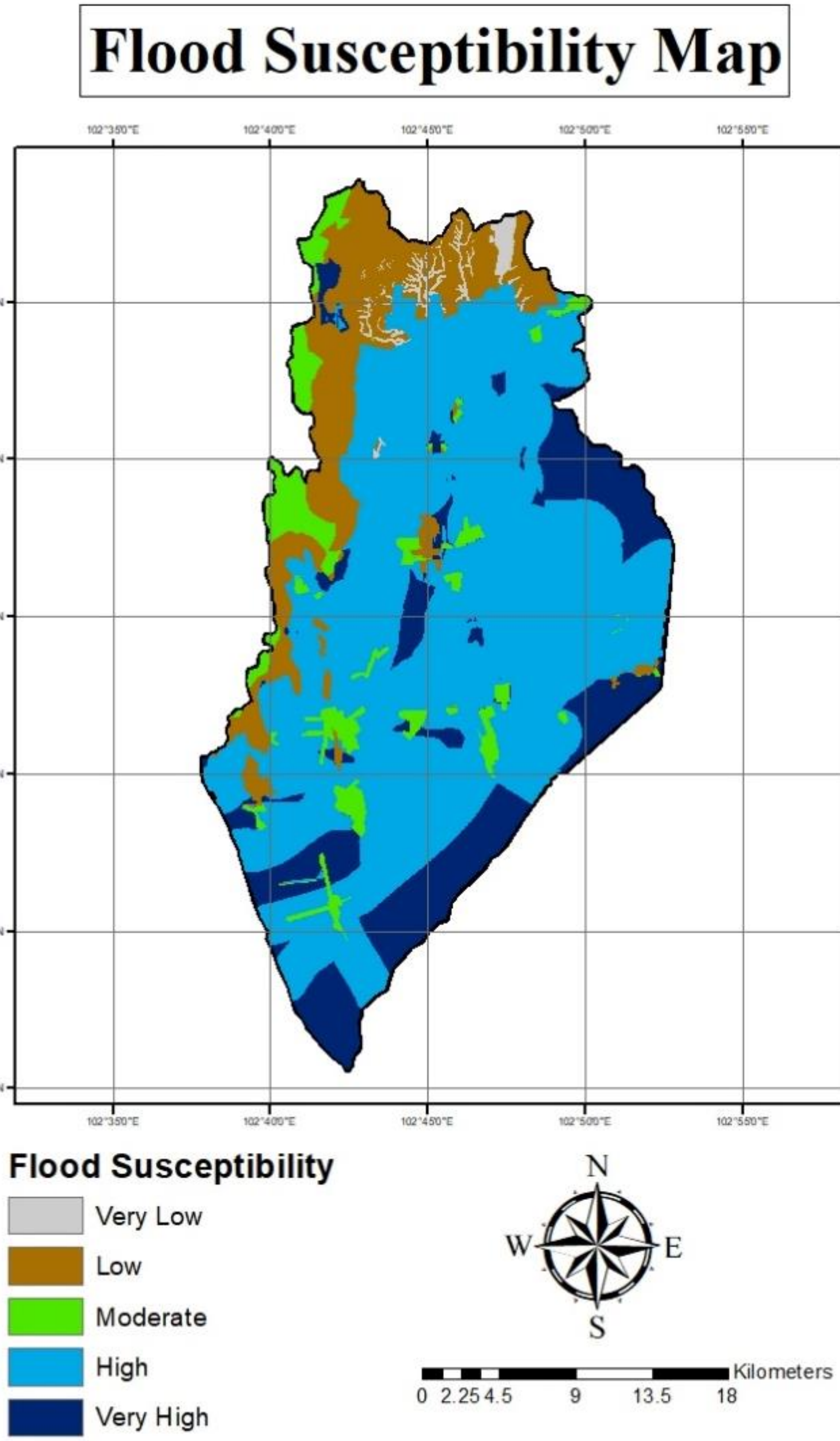


Figure 36: Final flood susceptibility map

The final flood susceptibility map has been produced based on all the factors and their ranks. Based on the chart (Figure 34), runoff was considered the most and Stream

Power Index (SPI) was considered the least in producing this flood hazard prone area. On the basis of adopted criteria and determination of the weight, the WLC is used to execute the aggregation map of the criteria in final flood susceptibility map. The flood hazard index produced on the map was then reclassified by the Standard Deviation method from Reclass Spatial Analysis Tool in ArcGIS. From this, each cell was classified into five categories and receives new value from 1 to 5 representing Flood Hazard Index (FHI).

As the map above illustrated, the susceptibility of flooding at each area can be easily determined in the map with the help of variation of colours. As mentioned, classification of five categories enabled the map varies area to five different zones such as very high, high, moderate, low and very low chance of having flood in the area.

Most of the area in Perlis state are falls under high-risk zone because those areas have low elevation, low slope angle and high runoff which will influence the area to easily get flooded. The area which is under very high-risk zone is because, they have low elevation, low slope angle, high runoff and further from the drainage network.

4.4 Validation of flood susceptibility map

Validation of flood susceptibility map was performed based on historical flood events that have been recorded in Perlis, Malaysia. Data on flood occurred in the period from 2010 to 2017 have been gathered from all relevant sources.

Floods are becoming common in Perlis and it is becoming worst in some areas. A series of major floods have been occurred in Perlis state caused by high rainfall, and spill from the bed of the channel and river.

Based on the studies regarding the previous flooding happened in Perlis, there are few locations have been sorted out in based on most flooding occurred area (G.C. Tan, 2017). Among the worst-hit areas were:

Num.	**Name**	**Latitude ° N**	**Longitude ° E**
1	Kampung Tebing Tinggi	6.433	100.167
2	Sungai Batu Pahat	6.4329	100.223
3	Padang Melangit	6.5	100.217
4	Repoh	6.4406	100.1984
5	Kampung Bakau	6.4308	100.198
6	Jejawi	6.43	100.229
7	Titi Tinggi	6.642	100.236
8	Kampung Padang Malau, Padang Besar	6.5557	100.2338
9	Beseri	6.5484	100.2264
10	Santan in Padang Besar	6.46103	100.2325
11	Bintong	6.446	100.2
12	Kayang	6.417	100.167
13	Tambun Tulang	6.367	100.217
14	Kampung Guar Sanji	6.417	100.283
15	Simpang Empat	6.3326	100.1586
16	Kuala sanglang	6.267	100.2
17	Arau	6.4297	100.2698

Table 9: Historically-Flooded area

This project has been conducted to identify the flood-prone area. So, it is essential to compare the flood susceptibility map created with the real-life situation to make sure the map produced is equitable and suitable to be used in the real life. For the purpose of this analysis, all the historically-flooded area was created as point feature in ArcGIS and overlaid on flood susceptibility map. The cell grid that corresponds to historically-flooded areas, based on the spatial coincidence, is extracted in one of five different levels of flood hazard. The result of this analysis is presented below:

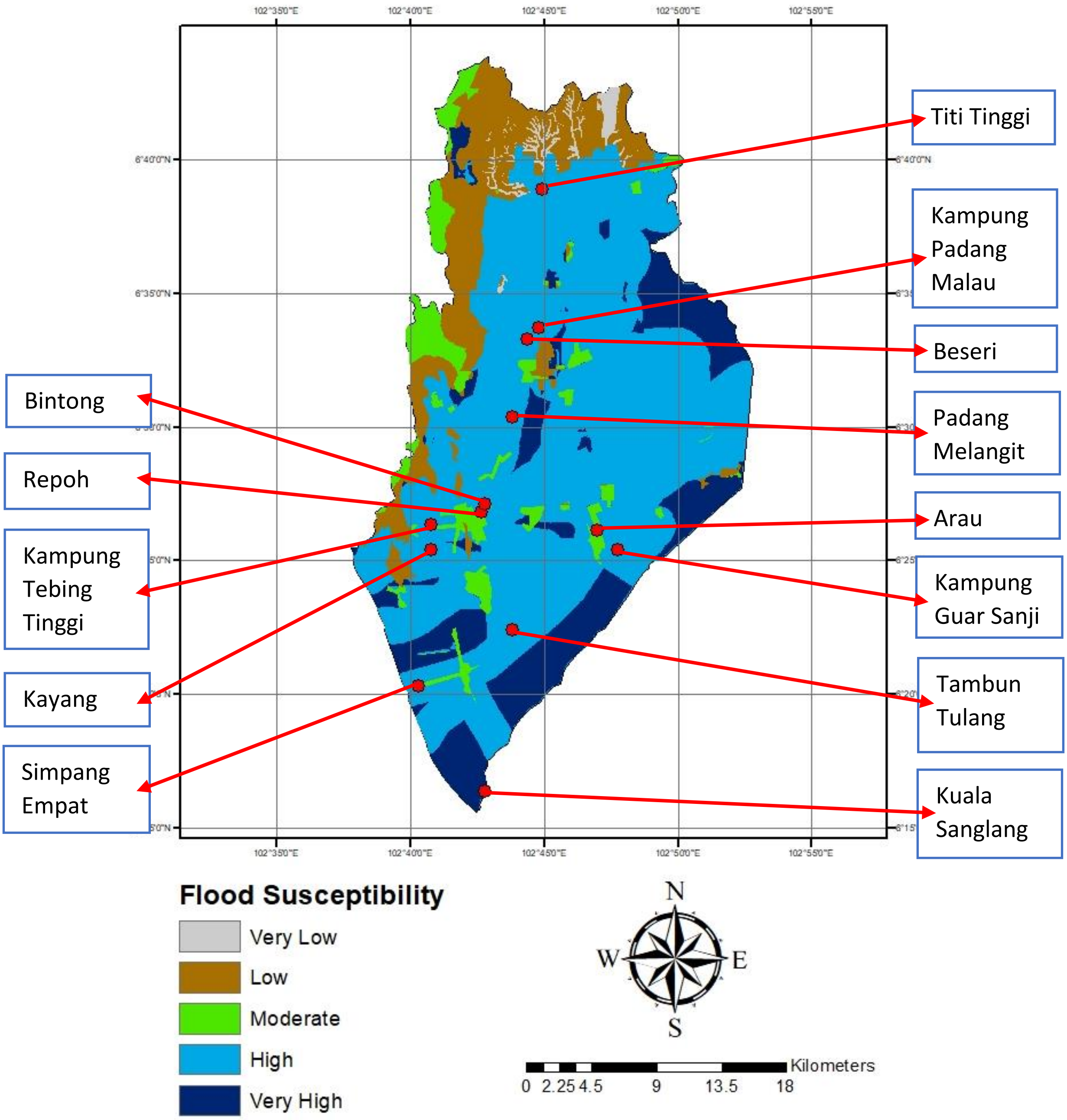


Figure 37: Historically-flood occurred places in Perlis

Historically-Flooded Points	Flood Hazard Index/Zone				
	Very High	High	Moderate	Low	Very Low
14	1 (7.14%)	12 (85.72%)	1 (7.14%)	0 (0%)	0 (0%)

Table 10: Level of coincide

In view of the investigation led, 85.72% of the area that was affected by flood coincides with the zone of ‘High flood susceptibility zone’, while one area (7.14%) named Kuala Sanglang is coincided with the zone of ‘very high flood susceptibility zone’ in the map. Flood also has been occurred at Arau, which coincides with the zone of ‘moderate flood susceptibility zone' (7.14%), this might be happened due of unusually heavy rainfall, failure in the drainage system or any other cause.

Based on the validation analysis on the table 10 above, a relatively high level of coincide can be seen. From this, the reliability of the proposed methodology in producing flood susceptibility was proven, thus ensuring the certainty of the results of this analysis. Therefore, it can be concluded that the flood susceptibility map produced is valid.

4.5 Gantt chart

No.	Detail \ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Collecting data and conducting questionnaire															
2	Submission of progress report															
3	Multi-criteria flood susceptibility mapping															
4	Pre-SEDEX															
5	Submission of draft final report															
6	Submission of Dissertation (soft bound)															
8	Submission of technical paper															
9	Viva															
10	Submission of project Dissertation (Hard bound)															

	Milestone
	Administrative requirement

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

A new method of identifying flood susceptibility area was determined in this study. The study has been conducted to determine the flood-prone area with respect to Spatial Decision Support System (SDSS). Flooding is a major disaster occurring in Malaysia and it needs to predict earlier before any damages occur. All those areas can be identified using Analytical Hierarchy Process (AHP) questionnaire method which using a knowledge-driven expert-based method to identify the significance of flood-causing factors in the study area.

Eight parameters including Stream Power Index (SPI), land use, slope angle, Topographic Wetness Index (TWI), geology, runoff, elevation, and drainage network were presented to 3 experts to paired comparison and assigning weight as the main factors for flood hazard mapping in the framework of GIS. ArcGIS software by ESRI was used to build the database by overlay each factor-layers according to their weights to produce flood susceptibility map. The output of the process produced inundated maps of 20- and 50-year floods. The result of this research showed flood hazard zoning map of SDSS which is reliable. Hence, AHP and GIS techniques are promising for making rather a reliable prediction for flood extent and can be suggested for assessment of the flood hazard potential, specifically in no-data regions.

To ensure the validity of the map produced, historical-flood events that have been recorded in Perlis was compared with the map, and it concluded that most of the historically-flooded points are coincides in the map as High flood-susceptible area. This also shows that the map produced is valid and suitable to be used in real life.

This multi-criteria flood susceptibility map produced can provide a cheap and comprehensive assessment of the study area in identifying the flood-prone area and helps prioritise migration and response efforts. This map also will be used as a valuable source for planning the future development of the city to identify flood susceptibility area.

As the conclusion, the student has successfully achieved the objectives of the study where could able to determine the significance of flood-causing factors using AHP and also can able to produce a multi-criteria flood susceptibility map which classifies Perlis state into five categories as very high flood prone area until very low flood prone area.

5.2 Recommendation

SDSS gives a very wide application in analysing task other than classifying study area into flood-prone area and non-flood prone area. The result of this study is depending on the accuracy of the data collected. Malaysia is common with heavy rainfall for every year while there is now a climate change issue. Therefore, in order to obtain more accurate data, latest information regarding the study area must be collected. It is also necessary to do a site visit to get a visualise and confirmation of the study area and the factors. Furthermore, it is possible to adapt more methodologies such as, frequency ratio, interval rough numbers method, fuzzy technique, and many more methods to provide a more detailed mapping of flood hazard zone in the study area, which can improve the result. All these factors may have an additional role which will upgrade the present methodology and to increase the accuracy of the flood susceptibility map produced.

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APPENDICES

APPENDIX I: Survey Questionnaire Sample

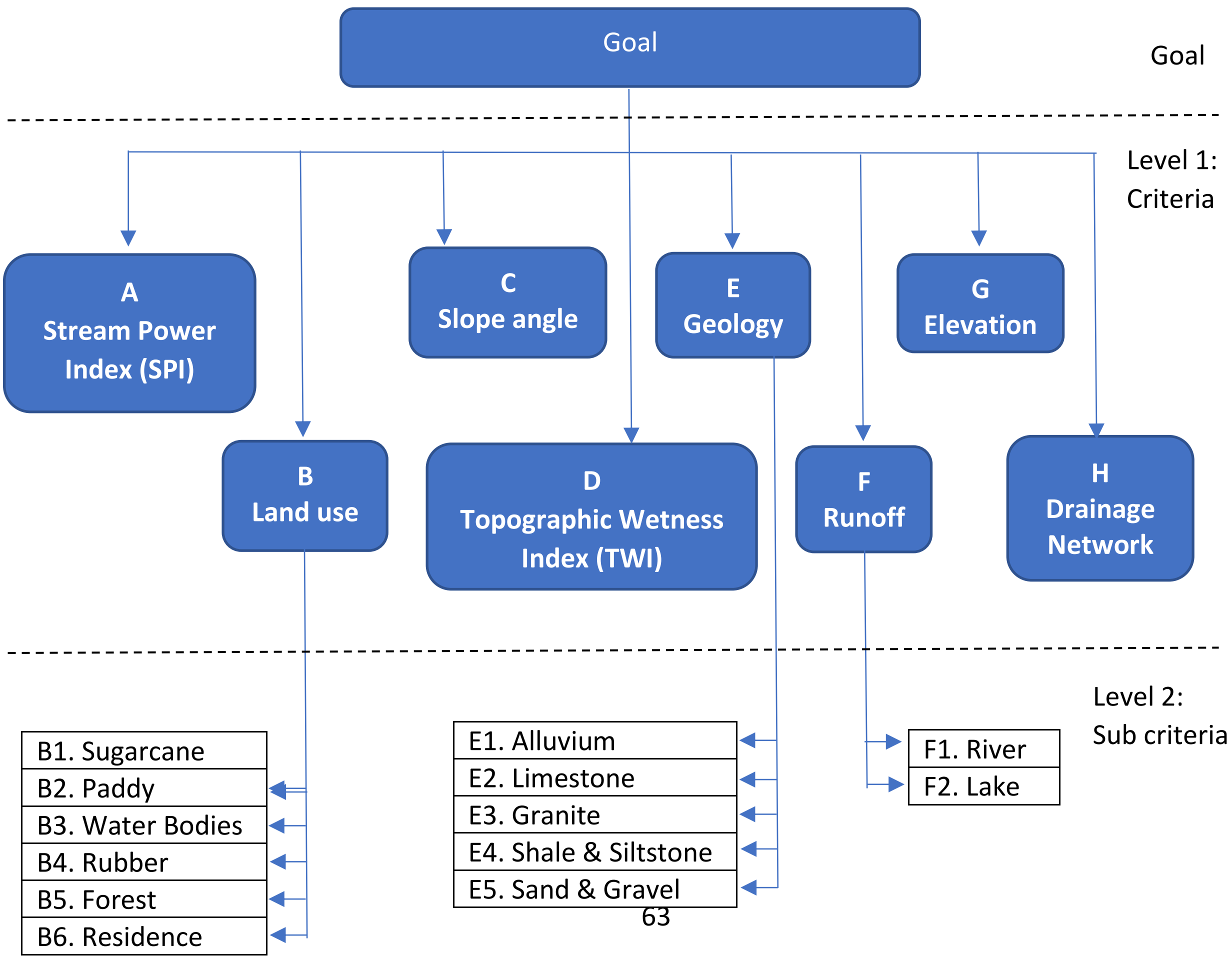
SDSS for multi-criteria flood susceptibility mapping in Malaysia

Name : Shanker Chandrasegaran
ID : 18843
Couse : Civil Engineering
Supervisor: Dr Abdul - Lateef Babatunde Balogun

INTRODUCTION

This questionnaire is to assign weights to rank the factors causing flood. The readings will be used to identify the flood susceptibility area at study area, which is Perlis, Malaysia. Spatial Decision Support System (SDSS) will be used to predict the area that most likely affected by flood. This will be actualized through integration of Geographical Information System (GIS) and a Decision Support System (DSS) techniques. Multi-Criteria Decision Analysis (MCDA) being used as a core in conducting DSS technique. This system would help to identify the flood prone areas using related geo-susceptibility criteria.

RANKING OF ROUTE SELECTION CRITERIA – ANALYTIC HEIRARCHY PROCESS (AHP) MODEL



INSTRUCTIONS

In this questionnaire, various factors are arranged in a comparison matrix as shown in figure 1 below. You need to compare each item in row with items in column. Each item needs to be compared in accordance to its relative importance/influence in causing flooding. After careful comparison, you will fill in the appropriate value from Saaty`s scales of relative importance table shown in Table 1 below, inside the cross cell of matrix.

For example, comparing item A and item B, if item A is most extremely more important than B, you rank "9" for value A (row) at appropriate cell (row 2; column 3). In the reverse statement position (row 3; column 2), you need to fill in the reciprocal value, 1/9. Similarly, for comparing item B and C, if item B is less important than C, but item C have strong importance than B, you rank "5" for value C (row) at appropriate cell (row 4; column 3). In the reverse statement position (row 3; column 4), you need to fill in the reciprocal value, 1/5. All other cells should be filled accordingly by comparing one factor (row) against another (column) i.e. A and C, A and D, C and A, C and D, D and A, D and B, D and C.

Take note that comparing item A and item A will be the same, so rank "1" will be given when both same item is being compared i.e. row 2; column 2, row 3; column 3, row 4; column 4, and row 5; column 5.

	A	**B**	**C**	**D**
A	1	9		
B	1/9	1	1/5	
C		5	1	
D				1

Figure 1: Example of comparison matrix

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective(s)
3	Weak importance	Experience and judgement strongly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	Where compromise is needed
Reciprocals of the nonzero	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

Table 1: Scales of relative importance according to Saaty (1980)

SECTION A: LEVEL 1: CRITERIA

Part I: First level criteria

In the following matrix, A, B, C, D, E, F, G and H are the eight first level criteria/factors to be considered for identifying flood susceptibility area. Please compare the factors (two factors at one time) and fill the appropriate rating score in the cross cell. A, B, C, D, E, F, G and H represents Stream Power Index (SPI), land use, slope angle, Topographic Wetness Index (TWI), geology, runoff, elevation and drainage network respectively.

A. Stream Power Index (SPI)

   Stream Power Index is measurement of erosive power of flowing water. It can be used to describe potential flow erosion at the given point of the topographic surface. As the gradient of the slope increase, the velocity and amount of water contributed by upslope will increase, hence stream power index increases.

B. Land use

   Various surface type will cause different level of runoff at catchment area. Since changes in the state of land cover were likely to modify flow paths and storage capacities of the area.

C. Slope angle

   Slope angle can determine rate and duration of water flow by influencing surface runoff velocity and vertical percolation.

D. Topographic Wetness Index (TWI)

   Topographic Wetness Index is a steady state wetness index. TWI indicates the amount of water accumulation at a point in watershed and trend of water to flow downslope by gravity

E. Geology

   Geological maps can show why flooding will not necessarily occur in every part of a valley floor. Capacity of water absorb by the soil is related to underlying geology. Some of the soil can will allow water to infiltrate, called as permeable soil, On the other hand, there are also nonporous or impermeable soil such as clay and shale which prevent the water to infiltrate.

   Porosity or permeability of a soil varies depends on the shape and grain size of the soil. If they are mixed, the porosity will be lowered, because the smaller particles fill the voids between the larger ones. The wider the range in grain sizes, the lower the resulting porosity.

F. Runoff

Streams are fed by runoff from rainfall and snowmelt moving as overland or subsurface flow. Floods occur when large volumes of runoff flow quickly into streams and rivers.

G. Elevation

Changes in elevation will change the direction of runoff. Water runs downhill. When water drains from the soil on local topographic highs, it drains into the low areas on the landscape.

H. Drainage network.

Drainage will help to transport water to prevent flooding in any area. Higher the drainage capacity, higher the amount of water will be transported to prevent flood occurring at the study area.

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
A	1							
B		1						
C			1					
D				1				
E					1			
F						1		
G							1	
H								1

SECTION B: LEVEL 2: SUB CRITERIA

Part II: Second level criteria

B. Land use

Please rank the following sub criteria and fill the score in the appropriate cross cell.

B.1.	Sugarcane	: Roots of sugarcane is tended to absorb water in the study area
B.2.	Paddy	: Rainfalls and water can be stored in paddy field for farming purpose. Also, there will be silty sands will be used for paddy farming.
B.3.	Water Bodies	: Stores rainfall and other water sources in a place. Water tend to overflow when there is excess of water.
B.4.	Rubber	: Root of rubber tress is tended to absorb water in the study area.
B.5.	Forest	: Forest will have lot of wild plants which have long roots which can absorb more water in the area.
B.6.	Residence	: Reduces permeability of the land cover because of using cement surface for residential and commercial developments. It creates more runoff to transport water to more permeable land.

	B.1	**B.2**	**B.3**	**B.4**	**B.5**	**B.6**
B.1	1					
B.2		1				
B.3			1			
B.4				1		
B.5					1	
B.6						1

E. Geology

Please rank the following geological sub criteria and fill the score in the appropriate cross cell.

E.1.	Alluvium	: Alluvium is loose, unconsolidated soil or sediments, which has been eroded, reshaped by water in some form, and redeposited in a non-marine setting. Have has a porosity of 0.2 to 0.35.
E.2.	Limestone	: They are typically organic soils. Have less permeability.
E.3.	Granite	: Non-porous or impermeable
E.4.	Shale & Siltstone	: Permeable soil. Grain size 35%-50%
E.5.	Sand & Gravel	: Permeable soil. Grain size 20%-35%

	E.1	**E.2**	**E.3**	**E.4**	**E.5**
E.1	1				
E.2		1			
E.3			1		
E.4				1	
E.5					1

F. Runoff

Please rank the following sub criteria and fill the score in the appropriate cross cell.

F.1. River : Helps to transport water from one location to another. Amount of water transported is based on the capacity of the drainage

F.2. Lake : Stores rainfall and other water sources in a place. Water tend to overflow when there is excess of water.

	F.1	**F.2**
F.1	1	
F.2		1

SECTION C: RESPONDENT PROFILE

Name :……………………………………………………………………….

Organization/

Institution/ Company :………………………………………………………………………….

Phone :………………………………………………………………………….

Profession :……………………………………………………………………….

Years of professional Experience : <2 / 3-5 / 6-10 / 11-15 / >15 years

Position :……………………………………………………………………….

Degree : Bachelor / Master / Doctorate / Other…………….

Date :…………………………………………………………………….

SECTION D: GENERAL QUESTIONS

1. To what extend do you think GIS will help in multi-criteria flood susceptibility mapping?

   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………

2. Why do you think people are not aware of surrounding geographical and meteorological which might cause flooding?

   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………

3. Other comments and suggestions

   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………

APPENDIX II

Pairwise comparison based on questionnaire survey from experts

EXPERT 1

i. AHP for Geology

Pairwise comparisons

	Item Number	1	2	3	4	5
Item Number	Item Description	Alluvium	Limestone	Granite	Shale & Siltstone	Sand & Gravel
1	Alluvium	1.00	2.00	8.00	4.00	6.00
2	Limestone	0.50	1.00	5.00	3.00	4.00
3	Granite	0.13	0.20	1.00	0.25	0.50
4	Shale & Siltstone	0.25	0.33	4.00	1.00	2.00
5	Sand & Gravel	0.17	0.25	2.00	0.50	1.00
	Sum I	2.04	3.78	20.00	8.75	13.50

STANDARDIZED MATRIX

Item Number	Item Description	Alluvium	Limestone	Granite	Shale & Siltstone	Sand & Gravel	Weight
1	Alluvium	0.49	0.53	0.40	0.46	0.44	46.4%
2	Limestone	0.24	0.26	0.25	0.34	0.30	28.0%
3	Granite	0.06	0.05	0.05	0.03	0.04	4.6%
4	Shale & Siltstone	0.12	0.09	0.20	0.11	0.15	13.5%
5	Sand & Gravel	0.08	0.07	0.10	0.06	0.07	7.6%
	Sum	1.00	1.00	1.00	1.00	1.00	1.00

Alluvium	1.00	2.00	8.00	4.00	6.00
Limestone	0.50	1.00	5.00	3.00	4.00
Granite	0.13	0.20	1.00	0.25	0.50
Shale & Siltstone	0.25	0.33	4.00	1.00	2.00
Sand & Gravel	0.17	0.25	2.00	0.50	1.00
	*	*	*	*	*
	46.4%	28.0%	4.6%	13.5%	7.6%
	=	=	=	=	=

Item Number	Item Description	Alluvium	Limestone	Granite	Shale & Siltstone	Sand & Gravel	SUM II		Weight		SUM/Weight
1	Alluvium	0.46	0.56	0.37	0.54	0.45	2.38		46.4%		5.14
2	Limestone	0.23	0.28	0.23	0.40	0.30	1.45	/	28.0%	=	5.18
3	Granite	0.06	0.06	0.05	0.03	0.04	0.23		4.6%		5.04
4	Shale & Siltstone	0.12	0.09	0.18	0.13	0.15	0.68		13.5%		5.05
5	Sand & Gravel	0.08	0.07	0.09	0.07	0.08	0.38		7.6%		5.04
										SUM III	25.44

Count (n)	=5.00
Lambda (λ)	=5.089
CI	=0.022
constant (RI)	=1.12
CR	**=0.02**

CR Value =	**0.020**	**OK**

ii. AHP for Land use

Pairwise comparisons

	Item Number	1	2	3	4	5	6
Item Number	Item Description	Sugarcane	Paddy	Water Bodies	Rubber	Forest	Residence
1	Sugarcane	1.00	0.50	4.00	6.00	8.00	0.33
2	Paddy	2.00	1.00	3.00	7.00	9.00	0.50
3	Water Bodies	0.25	0.33	1.00	2.00	4.00	0.17
4	Rubber	0.17	0.14	0.50	1.00	2.00	0.14
5	Forest	0.13	0.11	0.25	0.50	1.00	9.00
6	Residence	3.00	2.00	6.00	7.00	0.11	1.00
	Sum I	6.54	4.09	14.75	23.50	24.11	11.14

STANDARDIZED MATRIX

Item Number	Item Description	Sugarcane	Paddy	Water Bodies	Rubber	Forest	Residence	Weight
1	Sugarcane	0.15	0.12	0.27	0.26	0.33	0.03	19.4%
2	Paddy	0.31	0.24	0.20	0.30	0.37	0.04	24.5%
3	Water Bodies	0.04	0.08	0.07	0.09	0.17	0.01	7.6%
4	Rubber	0.03	0.03	0.03	0.04	0.08	0.01	3.9%
5	Forest	0.02	0.03	0.02	0.02	0.04	0.81	15.6%
6	Residence	0.46	0.49	0.41	0.30	0.00	0.09	29.1%
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Sugarcane	1.00	0.50	4.00	6.00	8.00	0.33
Paddy	2.00	1.00	3.00	7.00	9.00	0.50
Water Bodies	0.25	0.33	1.00	2.00	4.00	0.17
Rubber	0.17	0.14	0.50	1.00	2.00	0.14
Forest	0.13	0.11	0.25	0.50	1.00	9.00
Residence	3.00	2.00	6.00	7.00	0.11	1.00
	*	*	*	*	*	*
	19.4%	24.5%	7.6%	3.9%	15.6%	29.1%
	=	=	=	=	=	=

Item Number	Item Description	Sugarcane	Paddy	Water Bodies	Rubber	Forest	Residence	SUM II		Weight		SUM/Weight
1	Sugarcane	0.19	0.12	0.30	0.23	1.24	0.10	2.19		19.4%		11.31
2	Paddy	0.39	0.24	0.23	0.27	1.40	0.15	2.68	/	24.5%	=	10.93
3	Water Bodies	0.05	0.08	0.08	0.08	0.62	0.05	0.95		7.6%		12.62
4	Rubber	0.03	0.03	0.04	0.04	0.31	0.04	0.50		3.9%		12.81
5	Forest	0.02	0.03	0.02	0.02	0.16	2.62	2.87		15.6%		18.42
6	Residence	0.58	0.49	0.45	0.27	0.02	0.29	2.11		29.1%		7.23
											SUM III	73.32

Count (n)	6.00
Lambda (λ)	12.220
CI	1.244
constant (RI)	1.24
CR	**1.00**

CR Value =	**1.003**	**Not OK**

iii. AHP overall

Pairwise comparisons

Item Number	Item Description	Stream Power Index (SPI)	Land Use	Slope Angle	Topographic Wetness Index (TWI)	Geology	Runoff	Elevation	Drainage Network
Item Number		1	2	3	4	5	6	7	8
1	Stream Power Index (SPI)	1.00	0.20	0.14	0.25	2.00	0.33	0.33	2.00
2	Land Use	5.00	1.00	0.33	2.00	6.00	2.00	0.17	4.00
3	Slope Angle	7.00	3.00	1.00	3.00	8.00	0.33	0.14	5.00
4	Topographic Wetness Index (TWI)	4.00	0.50	0.33	1.00	5.00	0.13	0.20	3.00
5	Geology	0.50	0.17	0.13	0.20	1.00	0.25	0.13	0.50
6	Runoff	3.00	0.50	3.00	8.00	4.00	1.00	4.00	3.00
7	Elevation	3.00	6.00	7.00	5.00	8.00	0.25	1.00	2.00
8	Drainage Network	0.50	0.25	0.20	0.33	2.00	0.33	0.50	1.00
	Sum I	24.00	11.62	12.13	19.78	36.00	4.63	6.47	20.50

STANDARDIZED MATRIX

Item Number	Item Description	Stream Power Index (SPI)	Land Use	Slope Angle	Topographic Wetness Index (TWI)	Geology	Runoff	Elevation	Drainage Network	Weight
1	Stream Power Index (SPI)	0.04	0.02	0.01	0.01	0.06	0.07	0.05	0.10	4.5%
2	Land Use	0.21	0.09	0.03	0.10	0.17	0.43	0.03	0.20	15.5%
3	Slope Angle	0.29	0.26	0.08	0.15	0.22	0.07	0.02	0.24	16.8%
4	Topographic Wetness Index (TWI)	0.17	0.04	0.03	0.05	0.14	0.03	0.03	0.15	7.9%

5	Geology	0.02	0.01	0.01	0.01	0.03	0.05	0.02	0.02	2.3%
6	Runoff	0.13	0.04	0.25	0.40	0.11	0.22	0.62	0.15	23.9%
7	Elevation	0.13	0.52	0.58	0.25	0.22	0.05	0.15	0.10	25.0%
8	Drainage Network	0.02	0.02	0.02	0.02	0.06	0.07	0.08	0.05	4.1%
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream Power Index (SPI)	1.00	0.20	0.14	0.25	2.00	0.33	0.33	2.00
Land Use	5.00	1.00	0.33	2.00	6.00	2.00	0.17	4.00
Slope Angle	7.00	3.00	1.00	3.00	8.00	0.33	0.14	5.00
Topographic Wetness Index (TWI)	4.00	0.50	0.33	1.00	5.00	0.13	0.20	3.00
Geology	0.50	0.17	0.13	0.20	1.00	0.25	0.13	0.50
Runoff	3.00	0.50	3.00	8.00	4.00	1.00	4.00	3.00
Elevation	3.00	6.00	7.00	5.00	8.00	0.25	1.00	2.00
Drainage Network	0.50	0.25	0.20	0.33	2.00	0.33	0.50	1.00
	*	*	*	*	*	*	*	*
	4.5%	15.5%	16.8%	7.9%	2.3%	23.9%	25.0%	4.1%
	=	=	=	=	=	=	=	=

Item Number	Item Description	Stream Power	Land Use	Slope Angle	Topographic	Geology	Runoff	Elevation	Drainage Network	SUM II		Weight		SUM/Weight
1	Stream Power Index (SPI)	0.05	0.03	0.02	0.02	0.05	0.08	0.08	0.08	0.41		4.5%		9.12
2	Land Use	0.23	0.16	0.06	0.16	0.14	0.48	0.04	0.16	1.41		15.5%		9.10
3	Slope Angle	0.32	0.47	0.17	0.24	0.18	0.08	0.04	0.21	1.69	/	16.8%	=	10.05
4	Topographic Wetness Index (TWI)	0.18	0.08	0.06	0.08	0.11	0.03	0.05	0.12	0.71		7.9%		8.99
5	Geology	0.02	0.03	0.02	0.02	0.02	0.06	0.03	0.02	0.22		2.3%		9.69
6	Runoff	0.14	0.08	0.50	0.63	0.09	0.24	1.00	0.12	2.80		23.9%		11.72
7	Elevation	0.14	0.93	1.18	0.39	0.18	0.06	0.25	0.08	3.21		25.0%		12.85
8	Drainage Network	0.02	0.04	0.03	0.03	0.05	0.08	0.12	0.04	0.41		4.1%		10.01
													SUM III	81.53

Count (n)	8.00
Lambda (λ)	10.191
CI	0.313
constant (RI)	1.41

CR **0.22**

CR Value =	**0.222**	**Not OK**

EXPERT 2

i. AHP for Geology

Pairwise comparisons

	Item Number	1	2	3	4	5
Item Number	Item Description	Alluvium	Limestone	Granite	Shale & Siltstone	Sand & Gravel
1	Alluvium	1.00	0.20	0.13	3.00	3.00
2	Limestone	5.00	1.00	0.50	0.50	5.00
3	Granite	8.00	2.00	1.00	4.00	7.00
4	Shale & Siltstone	0.33	2.00	0.25	1.00	0.33
5	Sand & Gravel	0.33	0.20	0.14	3.00	1.00
	Sum I	14.67	5.40	2.02	11.50	16.33

STANDARDIZED MATRIX

Item Number	Item Description	Alluvium	Limestone	Granite	Shale & Siltstone	Sand & Gravel	Weight
1	Alluvium	0.07	0.04	0.06	0.26	0.18	12.2%
2	Limestone	0.34	0.19	0.25	0.04	0.31	22.5%
3	Granite	0.55	0.37	0.50	0.35	0.43	43.8%

4	Shale & Siltstone	0.02	0.37	0.12	0.09	0.02	12.5%
5	Sand & Gravel	0.02	0.04	0.07	0.26	0.06	9.1%
	Sum	1.00	1.00	1.00	1.00	1.00	1.00

Alluvium	1.00	0.20	0.13	3.00	3.00
Limestone	5.00	1.00	0.50	0.50	5.00
Granite	8.00	2.00	1.00	4.00	7.00
Shale & Siltstone	0.33	2.00	0.25	1.00	0.33
Sand & Gravel	0.33	0.20	0.14	3.00	1.00
	*	*	*	*	*
	12.2%	22.5%	43.8%	12.5%	9.1%
	=	=	=	=	=

Item Number	Item Description	Alluvium	Limestone	Granite	Shale & Siltstone	Sand & Gravel	SUM II		Weight		SUM/Weight
1	Alluvium	0.12	0.04	0.05	0.37	0.27	0.87		12.2%		7.10
2	Limestone	0.61	0.22	0.22	0.06	0.45	1.57	/	22.5%	=	6.99
3	Granite	0.98	0.45	0.44	0.50	0.63	3.00		43.8%		6.85
4	Shale & Siltstone	0.04	0.45	0.11	0.12	0.03	0.75		12.5%		6.04
5	Sand & Gravel	0.04	0.04	0.06	0.37	0.09	0.61		9.1%		6.78
										SUM III	33.76

Count (n) =5.00
Lambda (λ) =6.751
CI =0.438
constant (RI) =1.12
CR **=0.39**

CR Value =	0.391	Not OK

ii. AHP for Land use

Pairwise comparisons

Item Number	Item Description	Sugarcane	Paddy	Water Bodies	Rubber	Forest	Residence
	Item Number	1	2	3	4	5	6
1	Sugarcane	1.00	0.50	0.33	0.50	0.20	3.00
2	Paddy	2.00	1.00	0.33	0.50	0.33	2.00
3	Water Bodies	3.00	3.00	1.00	0.50	0.33	0.20
4	Rubber	2.00	2.00	2.00	1.00	0.33	0.20
5	Forest	5.00	3.00	3.00	3.00	1.00	0.33
6	Residence	0.33	0.50	5.00	5.00	3.00	1.00
	Sum I	13.33	10.00	11.67	10.50	5.20	6.73

STANDARDIZED MATRIX

Item Number	Item Description	Sugarcane	Paddy	Water Bodies	Rubber	Forest	Residence	Weight
1	Sugarcane	0.08	0.05	0.03	0.05	0.04	0.45	11.4%
2	Paddy	0.15	0.10	0.03	0.05	0.06	0.30	11.5%
3	Water Bodies	0.23	0.30	0.09	0.05	0.06	0.03	12.5%
4	Rubber	0.15	0.20	0.17	0.10	0.06	0.03	11.8%

5	Forest	0.38	0.30	0.26	0.29	0.19	0.05	24.3%
6	Residence	0.03	0.05	0.43	0.48	0.58	0.15	28.4%
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Sugarcane	1.00	0.50	0.33	0.50	0.20	3.00
Paddy	2.00	1.00	0.33	0.50	0.33	2.00
Water Bodies	3.00	3.00	1.00	0.50	0.33	0.20
Rubber	2.00	2.00	2.00	1.00	0.33	0.20
Forest	5.00	3.00	3.00	3.00	1.00	0.33
Residence	0.33	0.50	5.00	5.00	3.00	1.00
	*	*	*	*	*	*
	11.4%	11.5%	12.5%	11.8%	24.3%	28.4%
	=	=	=	=	=	=

Item Number	Item Description	Sugarcane	Paddy	Water Bodies	Rubber	Forest	Residence	SUM II		Weight		SUM/Weight
1	Sugarcane	0.11	0.06	0.04	0.06	0.05	0.85	1.17		11.4%		10.28
2	Paddy	0.23	0.11	0.04	0.06	0.08	0.57	1.09	/	11.5%	=	9.55
3	Water Bodies	0.34	0.34	0.13	0.06	0.08	0.06	1.01		12.5%		8.05
4	Rubber	0.23	0.23	0.25	0.12	0.08	0.06	0.96		11.8%		8.15
5	Forest	0.57	0.34	0.38	0.36	0.24	0.09	1.98		24.3%		8.16
6	Residence	0.04	0.06	0.63	0.59	0.73	0.28	2.33		28.4%		8.19
											SUM III	52.36

Count (n) =6.00
Lambda (λ) =8.727
CI =0.545
constant (RI) =1.24

CR **=0.44**

CR Value =	**0.440**	**Not OK**

iii. AHP Overall

Pairwise comparisons

	Item Number	1	2	3	4	5	6	7	8
Item Number	Item Description	Stream Power Index (SPI)	Land Use	Slope Angle	Topographic Wetness Index (TWI)	Geology	Runoff	Elevation	Drainage Network
1	Stream Power Index (SPI)	1.00	0.14	0.33	1.00	0.33	0.14	0.20	0.33
2	Land Use	7.00	1.00	0.33	5.00	2.00	0.33	3.00	0.50
3	Slope Angle	3.00	3.00	1.00	3.00	2.00	0.50	1.00	2.00
4	Topographic Wetness Index (TWI)	1.00	0.20	0.33	1.00	0.50	0.20	0.50	0.50
5	Geology	3.00	0.50	0.50	2.00	1.00	0.33	3.00	2.00
6	Runoff	7.00	3.00	2.00	5.00	3.00	1.00	2.00	0.50
7	Elevation	5.00	0.33	1.00	2.00	0.33	0.50	1.00	2.00
8	Drainage Network	3.00	2.00	0.50	2.00	0.50	2.00	0.50	1.00
	Sum I	30.00	10.18	6.00	21.00	9.67	5.01	11.20	8.83

STANDARDIZED MATRIX

Item Number	Item Description	Stream Power Index (SPI)	Land Use	Slope Angle	Topographic Wetness Index (TWI)	Geology	Runoff	Elevation	Drainage Network	Weight

1	Stream Power Index (SPI)	0.03	0.01	0.06	0.05	0.03	0.03	0.02	0.04	3.4%
2	Land Use	0.23	0.10	0.06	0.24	0.21	0.07	0.27	0.06	15.3%
3	Slope Angle	0.10	0.29	0.17	0.14	0.21	0.10	0.09	0.23	16.6%
4	Topographic Wetness Index (TWI)	0.03	0.02	0.06	0.05	0.05	0.04	0.04	0.06	4.4%
5	Geology	0.10	0.05	0.08	0.10	0.10	0.07	0.27	0.23	12.4%
6	Runoff	0.23	0.29	0.33	0.24	0.31	0.20	0.18	0.06	23.1%
7	Elevation	0.17	0.03	0.17	0.10	0.03	0.10	0.09	0.23	11.4%
8	Drainage Network	0.10	0.20	0.08	0.10	0.05	0.40	0.04	0.11	13.5%
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream Power Index (SPI)	1.00	0.14	0.33	1.00	0.33	0.14	0.20	0.33
Land Use	7.00	1.00	0.33	5.00	2.00	0.33	3.00	0.50
Slope Angle	3.00	3.00	1.00	3.00	2.00	0.50	1.00	2.00
Topographic Wetness Index (TWI)	1.00	0.20	0.33	1.00	0.50	0.20	0.50	0.50
Geology	3.00	0.50	0.50	2.00	1.00	0.33	3.00	2.00
Runoff	7.00	3.00	2.00	5.00	3.00	1.00	2.00	0.50
Elevation	5.00	0.33	1.00	2.00	0.33	0.50	1.00	2.00
Drainage Network	3.00	2.00	0.50	2.00	0.50	2.00	0.50	1.00
	*	*	*	*	*	*	*	*
	3.4%	15.3%	16.6%	4.4%	12.4%	23.1%	11.4%	13.5%
	=	=	=	=	=	=	=	=

Item Number	Item Description	Stream Power Index	Land Use	Slope Angle	Topographic Wetness	Geology	Runoff	Elevation	Drainage Network	SUM II		Weight		SUM/Weight
1	Stream Power Index (SPI)	0.03	0.02	0.06	0.04	0.04	0.03	0.02	0.05	0.30		3.4%		8.82
2	Land Use	0.24	0.15	0.06	0.22	0.25	0.08	0.34	0.07	1.40		15.3%		9.13
3	Slope Angle	0.10	0.46	0.17	0.13	0.25	0.12	0.11	0.27	1.60	/	16.6%	=	9.68
4	Topographic Wetness Index (TWI)	0.03	0.03	0.06	0.04	0.06	0.05	0.06	0.07	0.40		4.4%		9.07
5	Geology	0.10	0.08	0.08	0.09	0.12	0.08	0.34	0.27	1.16		12.4%		9.36
6	Runoff	0.24	0.46	0.33	0.22	0.37	0.23	0.23	0.07	2.14		23.1%		9.29
7	Elevation	0.17	0.05	0.17	0.09	0.04	0.12	0.11	0.27	1.01		11.4%		8.90
8	Drainage Network	0.10	0.31	0.08	0.09	0.06	0.46	0.06	0.14	1.29		13.5%		9.54
													SUM III	73.79

Count (n)	=8.00
Lambda (λ)	=9.224
CI	=0.175
constant (RI)	=1.41
CR	**=0.12**

CR Value =	**0.124**	**Not OK**

EXPERT 3

i. AHP for Geology

Pairwise comparisons

	Item Number	1	2	3	4	5
Item Number	Item Description	Alluvium	Limestone	Granite	Shale & Siltstone	Sand & Gravel
1	Alluvium	1.00	0.25	0.20	0.50	0.33
2	Limestone	4.00	1.00	0.50	3.00	2.00
3	Granite	5.00	2.00	1.00	4.00	3.00
4	Shale & Siltstone	2.00	0.33	0.25	1.00	0.50
5	Sand & Gravel	3.00	0.50	0.33	2.00	1.00
	Sum I	15.00	4.08	2.28	10.50	6.83

STANDARDIZED MATRIX

Item Number	Item Description	Alluvium	Limestone	Granite	Shale & Siltstone	Sand & Gravel	Weight

1	Alluvium	0.07	0.06	0.09	0.05	0.05	6.2%
2	Limestone	0.27	0.24	0.22	0.29	0.29	26.2%
3	Granite	0.33	0.49	0.44	0.38	0.44	41.6%
4	Shale & Siltstone	0.13	0.08	0.11	0.10	0.07	9.9%
5	Sand & Gravel	0.20	0.12	0.15	0.19	0.15	16.1%
	Sum	1.00	1.00	1.00	1.00	1.00	1.00

Alluvium	1.00	0.25	0.20	0.50	0.33
Limestone	4.00	1.00	0.50	3.00	2.00
Granite	5.00	2.00	1.00	4.00	3.00
Shale & Siltstone	2.00	0.33	0.25	1.00	0.50
Sand & Gravel	3.00	0.50	0.33	2.00	1.00
	*	*	*	*	*
	6.2%	26.2%	41.6%	9.9%	16.1%
	=	=	=	=	=

Item Number	Item Description	Alluvium	Limestone	Granite	Shale & Siltstone	Sand & Gravel	SUM II		Weight		SUM/Weight
1	Alluvium	0.06	0.07	0.08	0.05	0.05	0.31		6.2%		5.03
2	Limestone	0.25	0.26	0.21	0.30	0.32	1.34	/	26.2%	=	5.11
3	Granite	0.31	0.52	0.42	0.39	0.48	2.13		41.6%		5.12
4	Shale & Siltstone	0.12	0.09	0.10	0.10	0.08	0.50		9.9%		5.02
5	Sand & Gravel	0.19	0.13	0.14	0.20	0.16	0.81		16.1%		5.06
										SUM III	25.34

Count (n) =5.00

Lambda (λ)	=5.068
CI	=0.017
constant (RI)	=1.12
CR	**=0.02**

CR Value =	**0.015**	**OK**

ii. AHP for Land use

Pairwise comparisons

	Item Number	1	2	3	4	5	6
Item Number	Item Description	Sugarcane	Paddy	Water Bodies	Rubber	Forest	Residence
1	Sugarcane	1.00	0.50	0.25	0.33	0.20	0.17
2	Paddy	2.00	1.00	0.33	0.50	0.25	0.20
3	Water Bodies	4.00	3.00	1.00	2.00	0.50	0.33
4	Rubber	3.00	2.00	0.50	1.00	0.33	0.25
5	Forest	5.00	4.00	2.00	3.00	1.00	0.50
6	Residence	6.00	5.00	3.00	4.00	2.00	1.00
	Sum I	21.00	15.50	7.08	10.83	4.28	2.45

STANDARDIZED MATRIX

	Item Description	Sugarcane	Paddy		Rubber	Forest	Residence	Weight

Item Number				Water Bodies				
1	Sugarcane	0.05	0.03	0.04	0.03	0.05	0.07	4.3%
2	Paddy	0.10	0.06	0.05	0.05	0.06	0.08	6.5%
3	Water Bodies	0.19	0.19	0.14	0.18	0.12	0.14	16.0%
4	Rubber	0.14	0.13	0.07	0.09	0.08	0.10	10.2%
5	Forest	0.24	0.26	0.28	0.28	0.23	0.20	24.9%
6	Residence	0.29	0.32	0.42	0.37	0.47	0.41	37.9%
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Sugarcane	1.00	0.50	0.25	0.33	0.20	0.17
Paddy	2.00	1.00	0.33	0.50	0.25	0.20
Water Bodies	4.00	3.00	1.00	2.00	0.50	0.33
Rubber	3.00	2.00	0.50	1.00	0.33	0.25
Forest	5.00	4.00	2.00	3.00	1.00	0.50
Residence	6.00	5.00	3.00	4.00	2.00	1.00
	*	*	*	*	*	*
	4.3%	6.5%	16.0%	10.2%	24.9%	37.9%
	=	=	=	=	=	=

Item Number	Item Description	Sugarcane	Paddy	Water Bodies	Rubber	Forest	Residence	SUM II		Weight		SUM/Weight
1	Sugarcane	0.04	0.03	0.04	0.03	0.05	0.06	0.26		4.3%		6.06
2	Paddy	0.09	0.07	0.05	0.05	0.06	0.08	0.40	/	6.5%	=	6.03
3	Water Bodies	0.17	0.20	0.16	0.20	0.12	0.13	0.99		16.0%		6.15
4	Rubber	0.13	0.13	0.08	0.10	0.08	0.09	0.62		10.2%		6.07
5	Forest	0.22	0.26	0.32	0.31	0.25	0.19	1.55		24.9%		6.21
6	Residence	0.26	0.33	0.48	0.41	0.50	0.38	2.36		37.9%		6.21
											SUM III	36.74

Count (n)	=6.00
Lambda (λ)	=6.123
CI	=0.025
constant (RI)	=1.24
CR	**=0.02**

CR Value =	**0.020**	**OK**

iii. AHP Overall

Pairwise comparisons

Item Number	Item Description	1 Stream Power Index (SPI)	2 Land Use	3 Slope Angle	4 Topographic Wetness Index (TWI)	5 Geology	6 Runoff	7 Elevation	8 Drainage Network
1	Stream Power Index (SPI)	1.00	0.14	0.33	0.25	0.50	0.13	0.20	0.17
2	Land Use	7.00	1.00	5.00	4.00	6.00	0.50	3.00	2.00
3	Slope Angle	3.00	0.20	1.00	0.50	2.00	0.17	0.33	0.25
4	Topographic Wetness Index (TWI)	4.00	0.25	2.00	1.00	3.00	0.20	0.50	0.33
5	Geology	2.00	0.17	0.50	0.33	1.00	0.14	0.25	0.20
6	Runoff	8.00	2.00	6.00	5.00	7.00	1.00	4.00	3.00
7	Elevation	5.00	0.33	3.00	2.00	4.00	0.25	1.00	2.00
8	Drainage Network	6.00	0.50	4.00	3.00	5.00	0.33	0.50	1.00
	Sum I	36.00	4.59	21.83	16.08	28.50	2.72	9.78	8.95

STANDARDIZED MATRIX

Item Number	Item Description	Stream Power Index (SPI)	Land Use	Slope Angle	Topographic Wetness Index (TWI)	Geology	Runoff	Elevation	Drainage Network	Weight
1	Stream Power Index (SPI)	0.03	0.03	0.02	0.02	0.02	0.05	0.02	0.02	2.4%
2	Land Use	0.19	0.22	0.23	0.25	0.21	0.18	0.31	0.22	22.7%
3	Slope Angle	0.08	0.04	0.05	0.03	0.07	0.06	0.03	0.03	5.0%
4	Topographic Wetness Index (TWI)	0.11	0.05	0.09	0.06	0.11	0.07	0.05	0.04	7.3%
5	Geology	0.06	0.04	0.02	0.02	0.04	0.05	0.03	0.02	3.4%
6	Runoff	0.22	0.44	0.27	0.31	0.25	0.37	0.41	0.34	32.5%
7	Elevation	0.14	0.07	0.14	0.12	0.14	0.09	0.10	0.22	12.9%
8	Drainage Network	0.17	0.11	0.18	0.19	0.18	0.12	0.05	0.11	13.8%
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Stream Power Index (SPI)	1.00	0.14	0.33	0.25	0.50	0.13	0.20	0.17
Land Use	7.00	1.00	5.00	4.00	6.00	0.50	3.00	2.00
Slope Angle	3.00	0.20	1.00	0.50	2.00	0.17	0.33	0.25
Topographic Wetness Index (TWI)	4.00	0.25	2.00	1.00	3.00	0.20	0.50	0.33
Geology	2.00	0.17	0.50	0.33	1.00	0.14	0.25	0.20
Runoff	8.00	2.00	6.00	5.00	7.00	1.00	4.00	3.00
Elevation	5.00	0.33	3.00	2.00	4.00	0.25	1.00	2.00
Drainage Network	6.00	0.50	4.00	3.00	5.00	0.33	0.50	1.00
	*	*	*	*	*	*	*	*
	2.4%	22.7%	5.0%	7.3%	3.4%	13.8%	1382.7%	0.0%
	=	=	=	=	=	=	=	=

Item Number	Item Description	Stream Power	Land Use	Slope Angle	Topographic	Geology	Runoff	Elevation	Drainage Network	SUM II		Weight		SUM/Weight
1	Stream Power Index (SPI)	0.02	0.03	0.02	0.02	0.02	0.04	0.03	0.02	0.20		2.4%		8.23
2	Land Use	0.17	0.23	0.25	0.29	0.20	0.16	0.39	0.28	1.97		22.7%		8.67
3	Slope Angle	0.07	0.05	0.05	0.04	0.07	0.05	0.04	0.03	0.40	/	5.0%	=	8.12
4	Topographic Wetness Index (TWI)	0.10	0.06	0.10	0.07	0.10	0.07	0.06	0.05	0.60		7.3%		8.22
5	Geology	0.05	0.04	0.02	0.02	0.03	0.05	0.03	0.03	0.28		3.4%		8.13
6	Runoff	0.19	0.45	0.30	0.37	0.24	0.33	0.52	0.41	2.80		32.5%		8.62
7	Elevation	0.12	0.08	0.15	0.15	0.14	0.08	0.13	0.28	1.11		12.9%		8.64
8	Drainage Network	0.14	0.11	0.20	0.22	0.17	0.11	0.06	0.14	1.16		13.8%		8.37
													SUM III	66.99

Count (n)	=8.00
Lambda (λ)	=8.373
CI	=0.053
constant (RI)	=1.41
CR	**=0.04**

CR Value =	**0.038**	**OK**