DETERMINATION SPATIAL LOCATION OF REGIONAL LANDSLIDE USING GIS

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CIVIL & ENVIRONMENTAL ENGINEERING

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Final report submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil & Environmental Engineering)

September 2016

Universiti Teknologi PETRONAS,

32610, Bandar Seri Iskandar,

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

____

(AP Dr. Indra Sati Hamonangan Harahap)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
September 2016

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.

MUHAMMAD HAFIZ BIN ZULKAFLY

ABSTRACT

In Malaysia, the main trigger factor of a landslide is rainfall. Most of the occurrences landslide cases in Malaysia, happen during rainfall. Therefore, it is important to identify those landslide area to minimize the destruction cause by landslide. By developing landslide hazard map could potentially minimize the destruction. This research was conducted on Murum reservoir of Murum River, which is in the uppermost part of the Rajang River basin for the Landslide Hazard Assessment (LHA). Therefore, Kriging interpolation method was used in Geographical Information System (GIS) with rainfall information obtained from rainfall station gauges. The variables including slope, elevation, aspect, curvature, distance from reservoir and geology. The ArcGIS software were used to extract it into layers. The landslide hazard map producing the output of landslide risk area into two classes of risk which are low risk and high risk.

***Keywords*: GIS; Landslide Hazard Assessment; Kriging; Rainfall; Murum; Landslide hazard map.**

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LIST OF ABBREVIATIONS

DID	Department of Drainage and Irrigation
GIS	Geographic Information System
LHA	Landslide Hazard Assessment
FYP	Final Year Project
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
GDEM	Global Digital Elevation Model

LIST OF FIGURES AND TABLES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

A landslide is a geological phenomenon which include a wide range of ground movement such as rock falls and deep failure of slope, which can occur in offshore, coastal and onshore environments. There is a factor on contributing a landslide to occur which is gravity acts as primary driving force. Although gravity acts as mainly factor, but there are other factors contribute on the occurrence of landslide. Generally, majority of the landslide take place on embankments or cut slopes alongside highways and roads that located in mountainous areas in Malaysia (Pradhan et al, 2009). Thus it is obligate to identify the potential landslides area to minimize the destruction caused by landslides. By developing the landslide hazard map, it can act as early warning system that help the planners or authorizes association to plan a proper mitigation system in areas that are prone to landslide. Thus, the hazard map could potentially minimize the destruction caused by landslides.

In this project, the factor that will be study is the rainfall. Studies carried out by Matori et al (2011), Pradhan et al (2009), Tyng (2014) and Dahal et al (2007) shown that the rainfall has dependency relationship with the occurrence of landslide. This study will compress the data acquired from DID to create the dependency relationship between the amount of precipitation toward its effects on landslide. GIS is the preferred way to be used on conducting the landslide hazard assessment. Thus, by applying the GIS in this hazard analysis, layers of maps are created which consist of landslide hazard zonation throughout the research area.

1.2 PROBLEM STATEMENT

Landslides cause fatalities and known as one of the costliest geo-hazards throughout the global which also contributes to major economic losses. In Malaysia, statistics had reported landslides and fatalities from 1973 to 2007, indicating an increase number of fatalities with an incline number of landslides (Slope Master Plan 2-3). Thus, it is necessitating to identify the potential landslides area to avoid occurring of fatalities. Rainfall usually is the main factor of a landslide in Malaysia. Data provided in Sarawak Management Master Plan, the annual precipitation in Sarawak was about 4000 mm. Therefore, hydroelectric power generation is highly potential and suitable in Sarawak due to the abundance of water. Landslides on the reservoir area could trigger disaster where debris flow slides would result the tsunami overtopping the dam because the Murum dam is confined in between a narrow gorge of river. Therefore, the flood could inundate the villages along Murum River. So, early warning system is done to predict the area that prone to unstable slope before the landslide happen. (Tyng, 2014). According to Amiruzan (2006), identification of factor aspect contributing to the event are necessary to consider for the proper mitigation planning for future development. This qualitative research aims to study the dependency between landslide factors and rainfall characteristics using GIS predominantly in Murum reservoir.

1.3 OBJECTIVES OF STUDY

The following is the objective of the project:

i. To produce a landslide hazard map on Murum dam reservoir based on landslide conditioning factors and rainfall characteristic using GIS.

1.4 SCOPE OF STUDY

The assessment was conducted on constructing a landslide hazard map in Murum Dam reservoir area, where hazard management is considered possible to be applied to this site. As the figure below depicts the whole East Malaysia, this study area concentrated in the state of Sarawak, particularly in Belaga and Marudi districts, where the Murum reservoir is located. The districts border which is Belaga and Marudi are color in green.

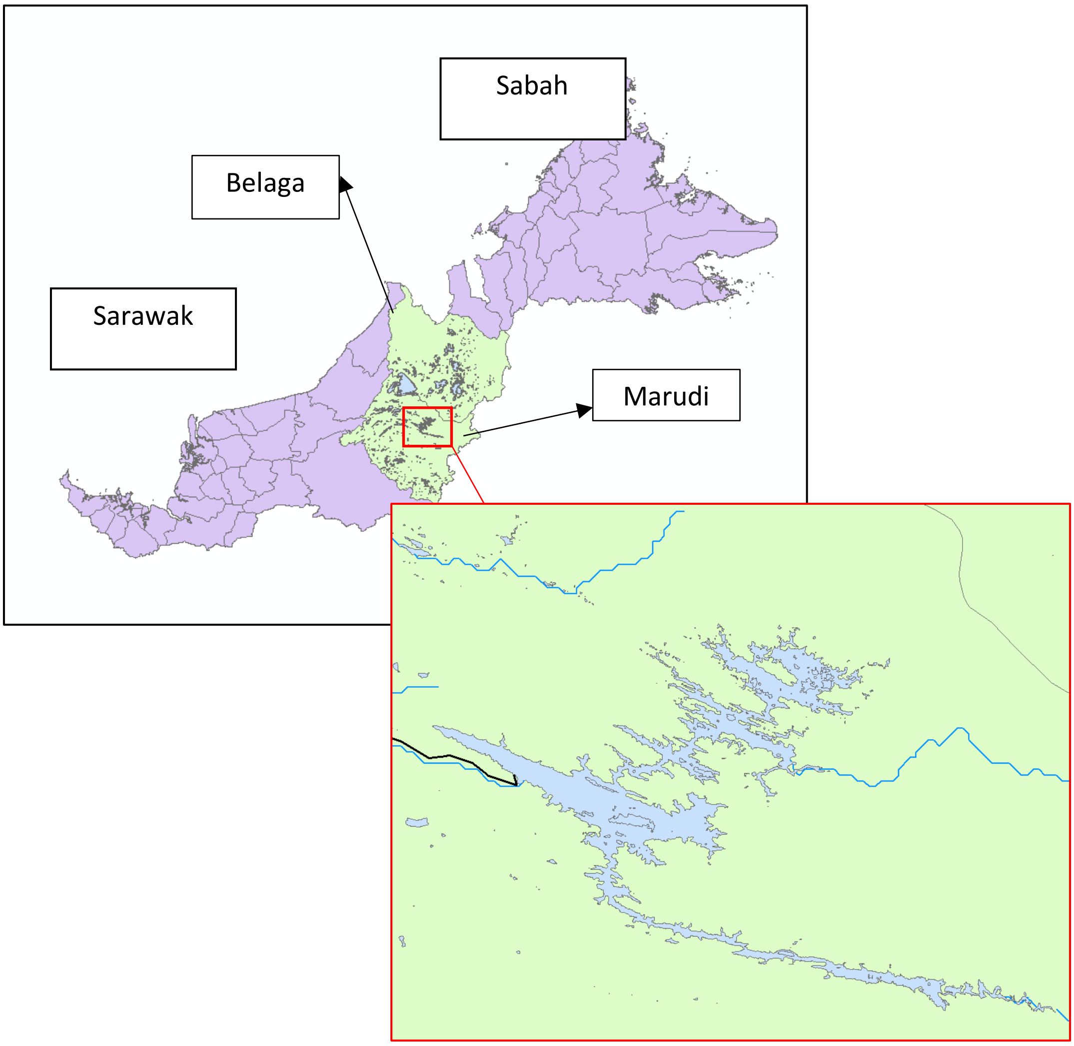


Figure 1 Study Area of Murum Dam Reservoir area.

The scope of study mainly focusing on:

FYP 1

1. The familiarization of GIS program and study on literature while gathering relevant data of the site.
2. Analyzing the site for spatial identification of signification factors contributing to landslide event in reservoir.
3. Evaluating the spatial factors and using weighting system to organize accordingly which contribute to the landslides occurrence.
4. Integrate all information into GIS programme.
5. Develop landslide hazard map of the site by overlap all possible hazard characteristics.

FYP 2

1. Collecting the other data for precision of the Landslide Hazard map.
2. Generate the signification causative factor into the layer.
3. Overlaying all the layers which contribute to the occurrence of landslides using weighted overlay tools.
4. Produce landslide hazard map surrounding the project site.
5. Categorize all the possible landslide using rating system; low risk, medium risk and high risk.
6. Discuss the output which and recommend to improve the precision of the landslide hazard map.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the literature review on the application of GIS in landslide assessment. Also, this chapter presenting the literature review on the triggering and causative factors that affect the occurrence on landslide.

2.2 APPLICATION OF GIS IN LANDSLIDE ASSESSMENT

GIS is a system designed to capture, store, manipulate, analyze, manage and present all types of spatial or geographical data. Because of its ability in manipulation of large amount of spatial data, data input, data management and analysis, GIS has been practically become an obligatory instruments in risk assessment and landslide hazard (Matori et al, 2011). By having these specialty of GIS, investigation on area which are exposed to high risk of landslide can be implemented and using several sample of study regarding to landslide that applying GIS can be found Western (2000), Amiruzan (2006), Guinau et al (2007), Pradhan and Youssef (2009), Tyng (2014), Chalkias et al (2014) and Shahabi and Hashim (2015).

There are three approaches as stated by Matori et al (2011) for structuring landslide hazard zonation by using GIS and approaches that are appropriate for a specific scale or coverage are shown as follows:

- Heuristic (qualitative) approach for small-scale regional surveys.
- Statistical (quantitative) approach for medium-scale surveys.
- Deterministic (quantitative) approach for detailed scale surveys.

According to Westen (2000) defined on these three approaches, regional planning agencies commonly used heuristic qualitative approach among those three. While planning agencies or consulting companies used for statistical quantitative approaches. Whereas, the third is deterministic approaches that is no involvement engineering geological site investigation normally used by regional local planning organizations or consulting companies which is required detailed planning of infrastructural works.

Heuristic qualitative approach refers as a direct or semi-direct mapping methodology that infers during the landslide inventory (Westen, 2000). Hence, heuristic qualitative approaches specifically fits in this study since it applied direct correlation between causative factor parameters and the landslide occurrence. All possible causative parameters are entered in GIS and able to generate a hazard map that combined will all the causative factors. Tyng (2014) had mentioned that in the most landslide hazard assessment that uses heuristic qualitative approach, landslide distribution or landslide inventory is used as a base map to compare the relationship between landslide and causative factor. Therefore, this research implements the use of maps which is used to overlay with rainfall data and causative factors to obtain the site that prone to landslide.

2.3 TRIGGERING AND THE CAUSATIVE FACTORS

A triggering factor is a single stimulus that initiates a landslide, while causative factor are the contributors to the occurrences of landslides. During heavy rainfall periods of every year, some incidence of landslide and fatalities was reported in different paths of Malaysia. Nearly all of the landslide was initiated by frequent rainfall occurrence event; usually after prolonged rainfall (Saadatkhah et al, 2014).

It was essential to recognize the factors that affect the susceptibility if a slope to failure with the intention of preparing landslide map on the basis of the causative factor. From the Jordan Journal Urban Planning 126(1) page 7, the causative factors are including soil wetness, land use, lineaments rock and soil type, rainfall, drainage work and shape. Based on Lan et al (2014), the dependency relationship between landslide and factor affecting are established by the Certainty Factor model (CF). CF method is use to select the significant causative factors in the site area. Thus, there will be only a few factors that are seen as important and significant varies according to the site of study.

2.3.1 TRIGGERING FACTOR: PRECIPITATION

As mention in Slope Master Plan 2-3, cases that associated with monsoon rainfalls produce a massive landslide that show high number of fatality as recorded on 26 December 1996, Tropical Storm Gregg caused debris flow and claimed 302 lives. So, it important to study the effect of precipitation towards the occurrence of landslides. In this study, the precipitation data are obtained from the rain gauge installed in Marudi and Belaga districts as in figure 7. These rain gauges were installed to monitor and record the daily rainfall readings (mm).

From the Figure 1, the study area was located between Marudi and Belaga districts. Thus, it important to locate and justified the nearest rainfall station towards the study location. Figure 7 show there are only 6 stations that located near to the Murum reservoir which are Long Anap, Long Jee, Long Jek, Long Lidam, Belaga and Sambop. The possible gain of those rainfall data were needed to be able to interpolate those data.

2.3.2 CAUSATIVE FACTORS

As for now, the causative factors that author included in this project are elevation, slope, aspect, curvature, distance to reservoir and geology. Those factors including the triggering factors will be included into layer then overlay it together as shown in Figure 2. Depending on the location of the project the causative factors could also be the triggering factor (Tyng, 2014). Each category of triggering and causative factors will be assigned a weighing value based on landslide frequency when using the weighted sum in ArcGIS software. All the raster layers will be reclassifying according to the following Table 3 and Table 4 below.

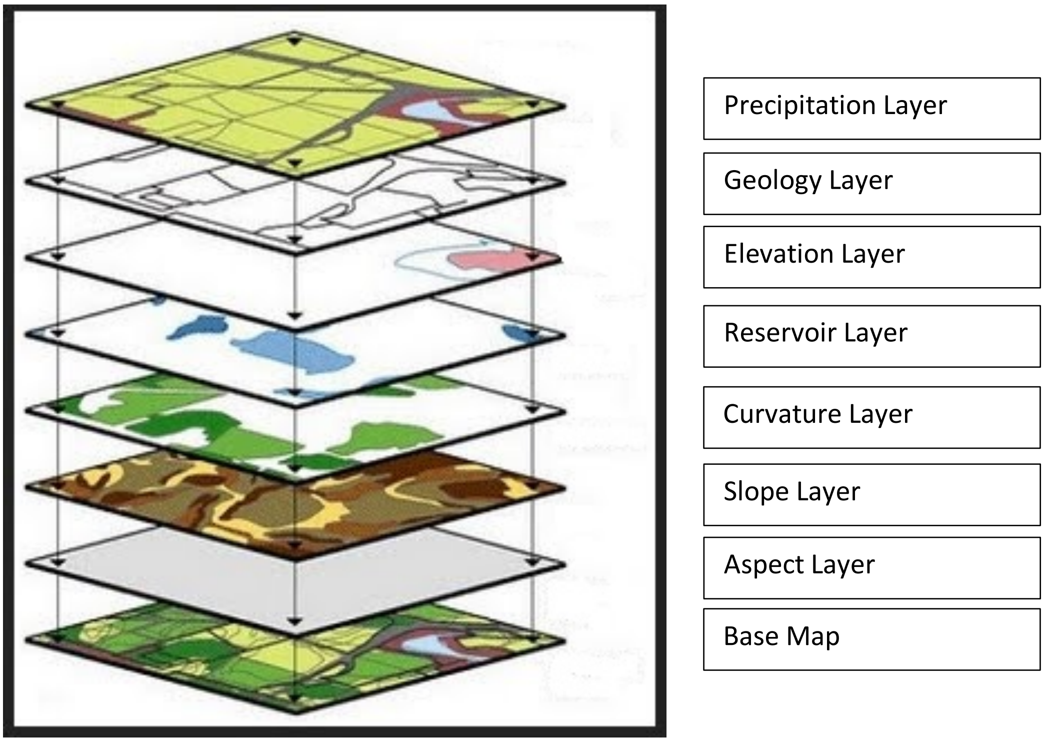


Figure 2 GIS layers.

Factors	Class Code 1	2	3	4	5	6	7
Slope gradient	<15°	15°–25°	25°–35°	35°–45°	>45°	—	—
Slope aspect	North (315°–45°)	East (45°–135°)	South (135°–225°)	West (225°–315°)	—	—	—
Elevation	<1800 m	1800 m–2000 m	2000 m–2200 m	>2200 m	—	—	—
Drainage basin order	First	Second	Third	—	—	—	—
Distance from ridge	<50 m	50 m–100 m	>100 m	—	—	—	—
Distance from valley	<50 m	50 m–100 m	>100 m	—	—	—	—
Geology	Slates with quartzites or limestones	Limestones	Slates with metasandstones and phyllites	Schists with quartzites and marbles	Biotite schists and micaceous quartzites	Granite	Alluvium
Land use/land cover	Crops	Coniferous forest	Broad leaf forest	Mixed forest	Shrub land	—	—

Table 3 Factors and their classes in GIS for analysis (Dhakal et al, 2000).

Landslide factors 1	Classes 2	Number of landslide 3	Weightage 4
Land use	Crop land	182	5
	Forest	93	4
	Built up	39	2
	Cut slope	43	3
	River/lake bank	1	1
Geology	Granite	231	5
	Others/undifferentiated	82	4
	Alluvium	1	2
	Schist	44	3
Elevation	<805 m	4	1
	805–1,070 m	16	2
	1,070–1,335 m	181	5
	1,335–1,600 m	131	4
	>1,600 m	26	3
Slope	<10.2	90	4
	10.2–20.4	82	3
	20.4–30.6	111	5
	30.6–40.8	57	2
	>40.8	18	1
Slope aspect	Flat (−1)	0	1
	North (0–22.5)	17	2
	Northeast (22.5–67.5)	56	5
	East (67.5–112.5)	39	3
	Southeast (112.5–157.5)	44	3
	South (157.5–202.5)	43	3
	Southwest (202.5–247.5)	51	4
	West (247.5–292.5)	37	3
	Northwest (292.5–337.5)	53	5
	North (337.5–360)	18	2
Curvature	<−8.4	19	2
	−8.4–−2.1	76	4
	−2.1–4.2	208	5
	4.2–10.5	46	3
	>10.5	9	1
Distance to road	<500	278	5
	500–1,000	44	4
	1,000–1,500	22	3
	1,500–2,000	11	2
	>2,000	3	1
Distance to lineament	<1,000	143	5
	1,000–2,000	111	4
	2,000–3,000	69	3
	3,000–4,000	28	2
	>4,000	7	1
Distance to river lake	<1,000	123	5
	1,000–2,000	55	4
	2,000–3,000	48	3
	3,000–4,000	60	2
	>4,000	72	1

Table 4 Rating weight of landslide factors (Matori et al, 2011).

2.3.3 SPATIAL INTERPOLATION

High intensity of rainfall and duration in Malaysia, it is important to study the precipitation characteristics in order to predict the landslide hazard. Different intensity of precipitation of rainfall can affect differently on slope. Also based on Mendez et al (2016), spatial interpolation of rainfall data is of great relevance for modelling purposes, as it has a direct impact on runoff generation and catchment response. In Sarawak where the project were study, is majorly in mountainous areas, where patterns of rainfall spatial distribution are influenced by factors such as topography of the area.

There are various methods to obtain the distribution intensity of precipitation. In this study, spatial interpolation were used to produce the distribution intensity of rainfall precipitation. There are two categories of interpolation which are categories into two main which are deterministic and geostatistical interpolation (Tyng, 2014).

Deterministic interpolation technique produce surface based on mathematical formulas and calculated points include Inverse Distance Weight (IDW). IDW methods are grounded by the extent of resemblance of cells where the observed values closer to the prediction location have more influence on predicted location compared to observed values that are further apart. According to Tyng (2014), there are major disadvantage to this method which is the bull's eye effect which means there are higher values near observed location.

Geostatistical interpolation technique such as Kriging are based on statistics and are used for more advanced prediction surface modelling that also includes some measure of the certainty or accuracy of prediction. Kriging believe direction or distance between sample points signals a spatial relationship that can be used to explain variation in the surface.

In this study, Kriging interpolation method is use due to its prediction and is the best suits when spatial correlated distance bias in the data is exposed.

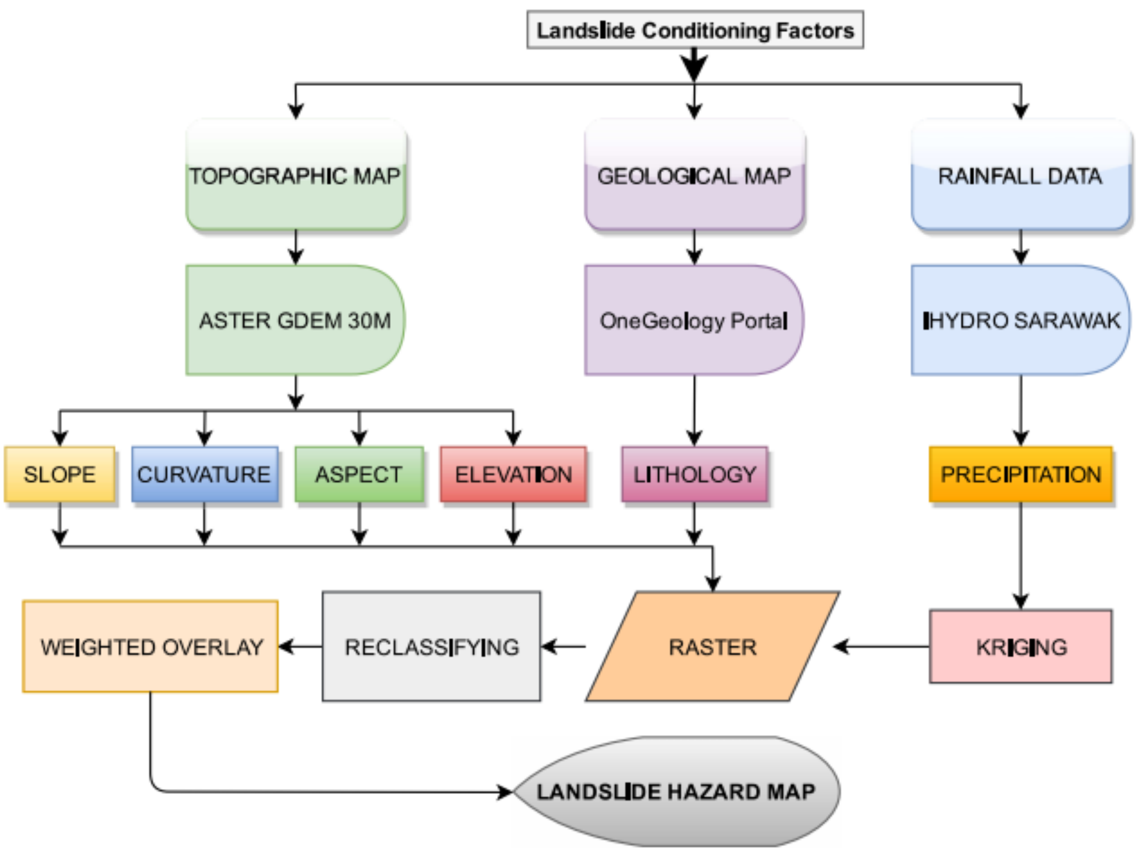
CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

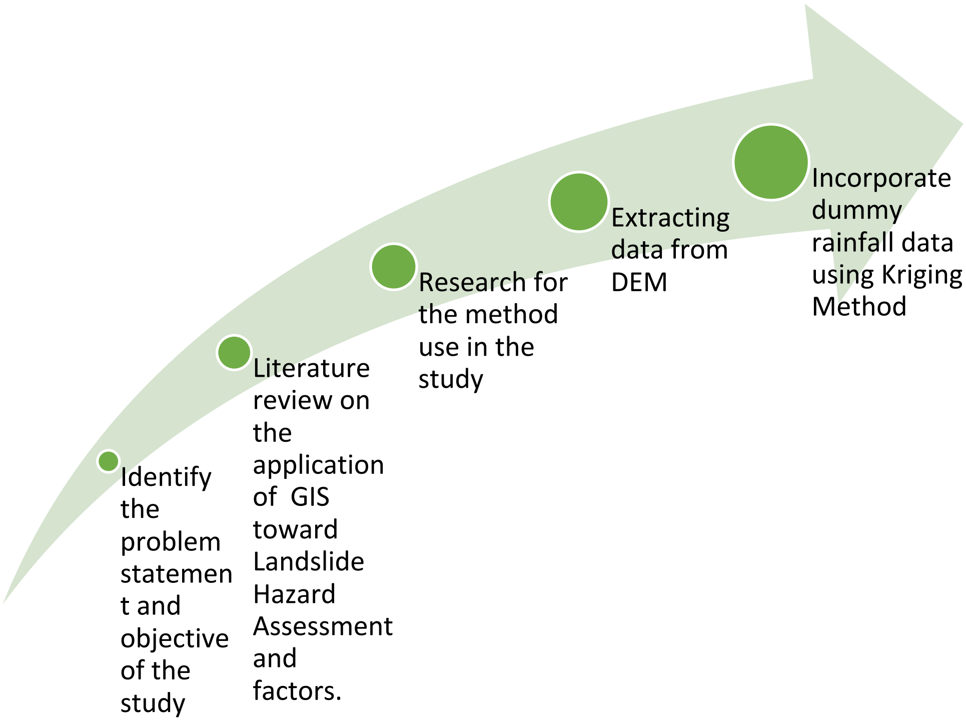
In this chapter, the main objective is to describe the methodology that be implement in this study. This chapter elaborates on the research methodology, project activities that are involved, key milestone, Gantt chart and software required.

3.2 RESEARCH METHODOLOGY

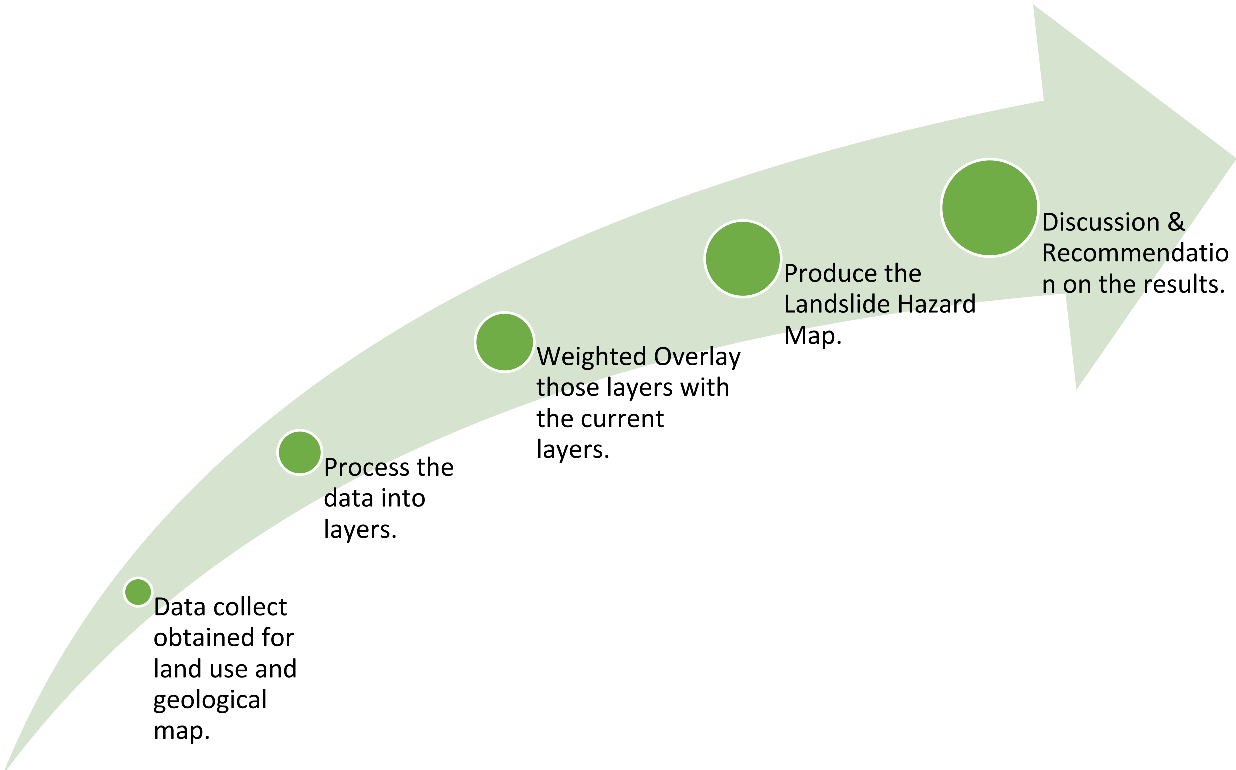


3.3 RESEARCH ACTIVITIES

3.3.1 MILESTONE FOR FYP 1



3.3.2 MILESTONE FOR FYP 2



3.4 GANTT CHART

		FYP 1													
No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Identify the Problem Statement and Objective														
3	Research on the Application of GIS and the factors causing landslide														
4	Research on Method Processing the Landslide Mapping														
5	Submission of Extended Proposal														
6	Collection of Data; Rainfall and Topography														
7	Proposal Defense														
8	Submission of Interim Draft Report														
9	Submission of Interim Report														

	Milestone
	Guideline Requirement

		FYP 2													
No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Collect other Data														
	Extract the Data into layer														
2	Submission of Progress Report														
3	Weighted All the layers														
4	Pre-SEDEX														
5	Submission of Draft Final Report														
6	Submission of Dissertation (soft bound)														
7	Submission of Technical Paper														
8	Viva														
9	Submission of Project Dissertation (Hard Bound)														

	Milestone
	Guideline Requirement

3.5 TOOLS REQUIRED

Software and hardware
• **Laptop** • **ArcGIS 10.2.2** • **Windows 10** • **Microsoft Office** • **Google Earth**

3.6 LANDSLIDE HAZARD MAP

The purpose of this project is to produce a landslide hazard map based on the applying triggering and the causative factors. The author need to determine the method or factors that which will be weighted and raster layers could be produced. The raster layers then be overlaying together according to their influence that are susceptible to slope failure. All the raster layers will be categorized with weighted sum tools that available in ArcGIS software and the final output which the landslide hazard map be developed.

3.6.1 COLLECT THE DATA

The rainfall data will be obtained from the Department of Irrigation and Drainage (DID). For the progress of this project, the author will use the collected rainfall data to create a layer. These data will then be put into excel spreadsheet with known rainfall station coordinates included with longitude and latitude that can be imported into ArcGIS software.

In the Table 5 below shows the list of data that are going to be used in this study which also includes the sources of the data.

Type of Data	Detail Data	Source
Topographic Map	Slope Aspect Curvature Contour	ASTER GDEM 30m Available on: http://asterweb.jpl.nasa.gov/gdem.asp
Topographic Map	River Road	Diva-GIS Available on: http://www.diva-gis.org/Data
Rainfall Data	Point Feature	IHYDRO SARAWAK Available on: http://www.ihydro.did.sarawak.gov.my/iHydro/en/index.jsp
Geological Map	Lithology	Geological Map of Sarawak Available on: http://www.jmg.gov.my/add_on/mt/swk/tiles/ OneGeology Portal Available on: http://portal.onegeology.org/OnegeologyGlobal/

Table 5 Type of Data and Sources.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the progress results from rainfall interpolation by Kriging were discussed. The rainfall data that were used were collected for two weeks from 1 November 2016 until 14 November 2016. The layers that are created from topography raster files are also included in the results section.

4.2 RESULTS AND DISCUSSION

Rainfall stations with their own coordinated are first to be computed in excel spreadsheet before be able to be imported in ArcGIS. For this study, the author just using the highest average rainfall from the collected rainfall for two weeks from 1 November 2016 until 14 November 2016 to compute into ArcGIS. The latitude and longitude of each of the station are already in degree, minutes and seconds and its must be converted into decimal by a simple calculation which is A + (B/60) + (C/3600), where A is the degree, B is the minute and C is the second. The data of each station location are shown in Table 6 below.

No	Location	Station ID	latitude northing	longitude easting	Precipitation Data (mm)
1	Long Anap	3048026	3.063433	114.818732	29
2	Long Jek	2843001	2.809225	114.315744	32
3	Long Jee	2949001	2.987635	114.959662	78.5
4	Long Lidam	2346001	2.337	114.678813	69
5	Sambop	2939045	2.73675	113.790044	42.5
6	Belaga	2737103	2.703884	113.784427	48.5

Table 6 Location of rainfall station and precipitation data.

4.3 DATA PREPARATION

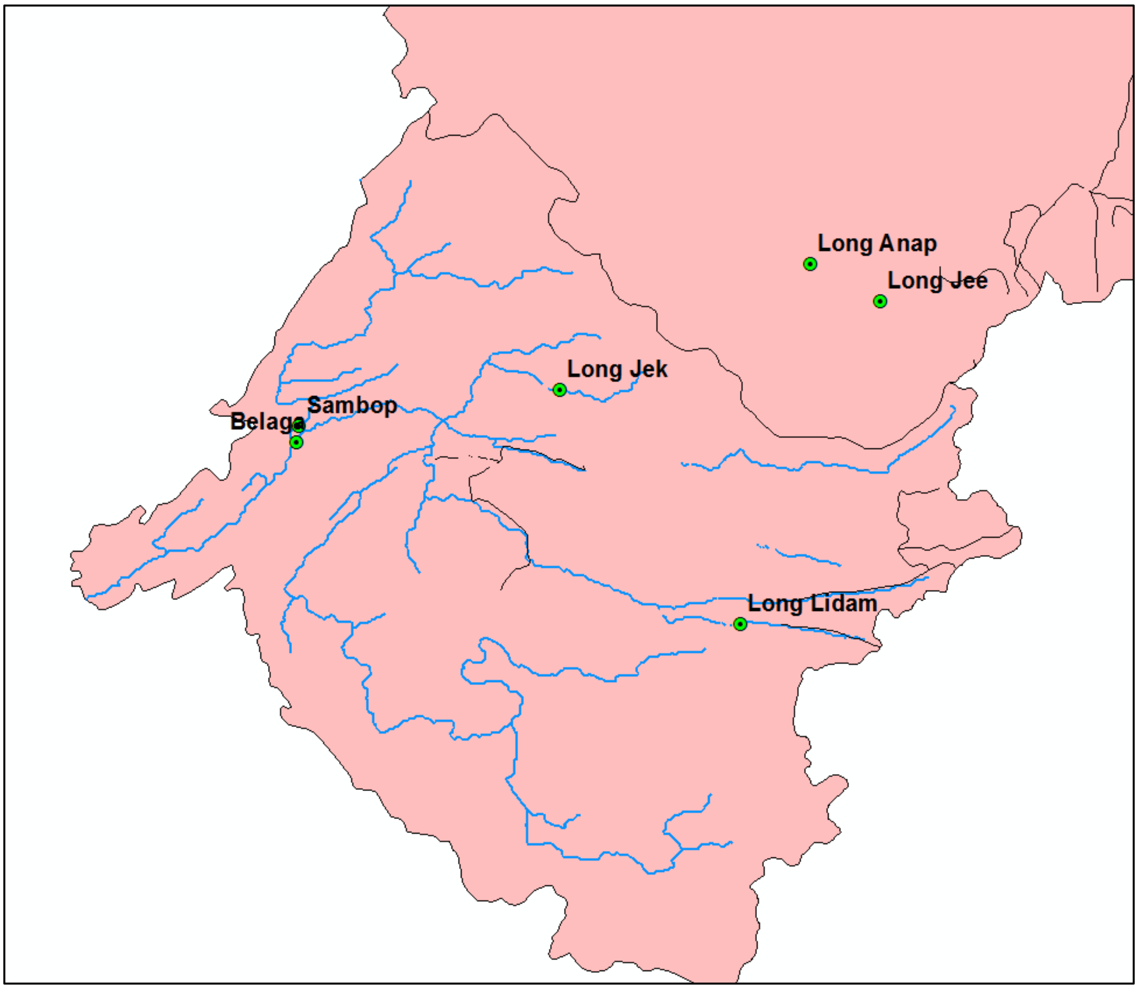


Figure 7 Location of rainfall station in districts boundary data.

Figure 7 above shows that the location of rainfall stations data near Murum reservoir. The location data is obtained from web-based Online Hydrological Information System (IHYDRO) website provided by DID Sarawak together with the boundary area of Marudi and Belaga districts provided by DIVA-GIS.

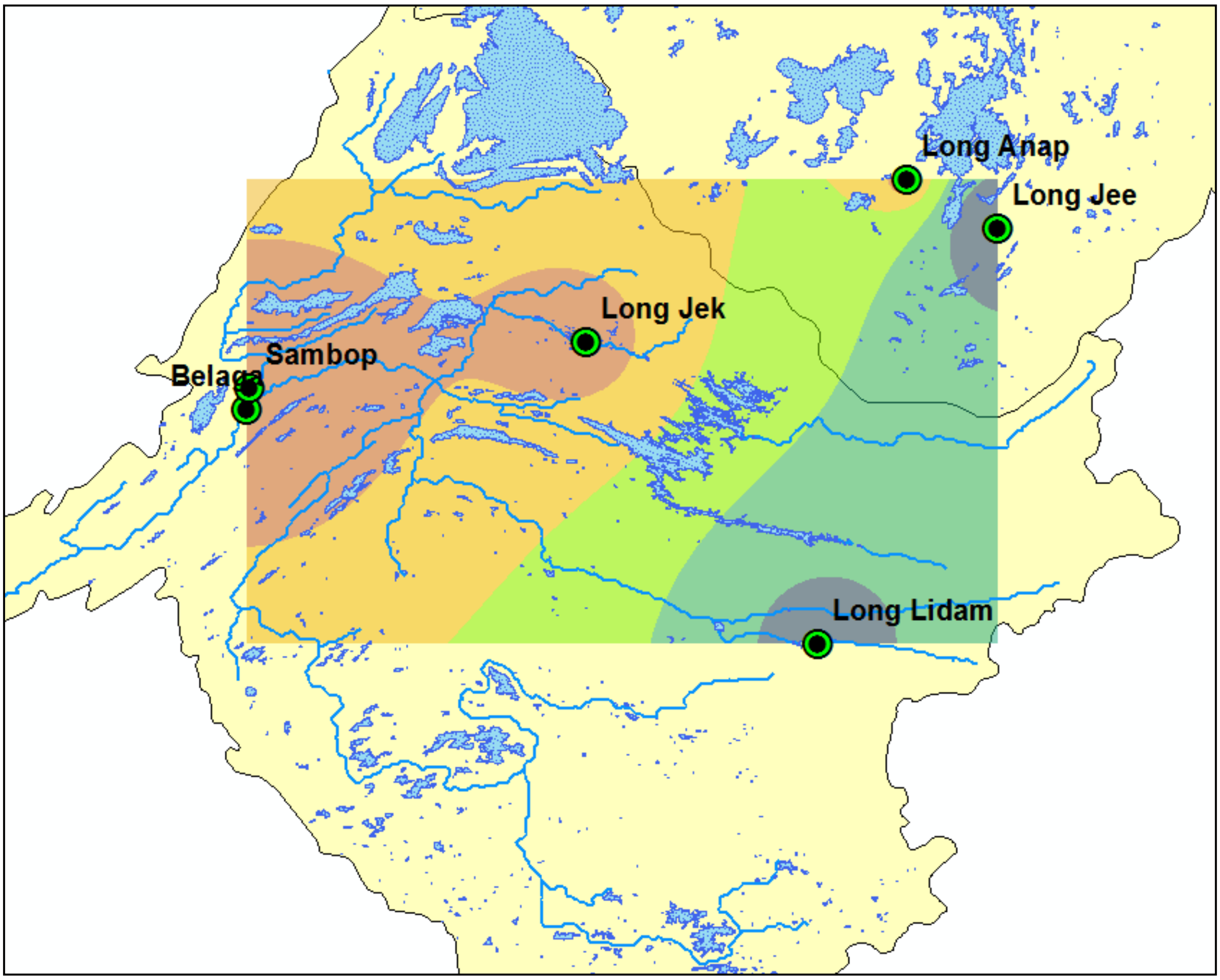


Figure 8 Kriging process of rainfall stations.

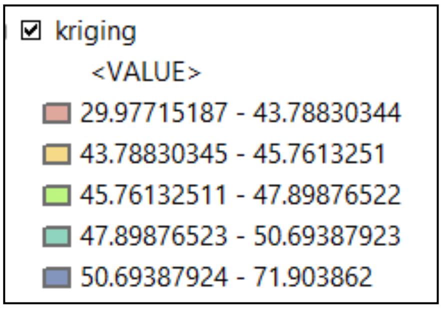


Figure 9 Code color and value.

Figure 9 above shows the different zone color after Kriging process in ArcGIS software. Each color represent the values in range of the precipitation (mm).

Others layers are also extracted from the topography data sets provided by ASTER GDEM. Slope, aspect, curvature, distance to reservoir, geology and elevation layers can be processed in ArcGIS software by using Spatial Analyst Toolbox in Surface category. The tools are available in ArcToolBox.

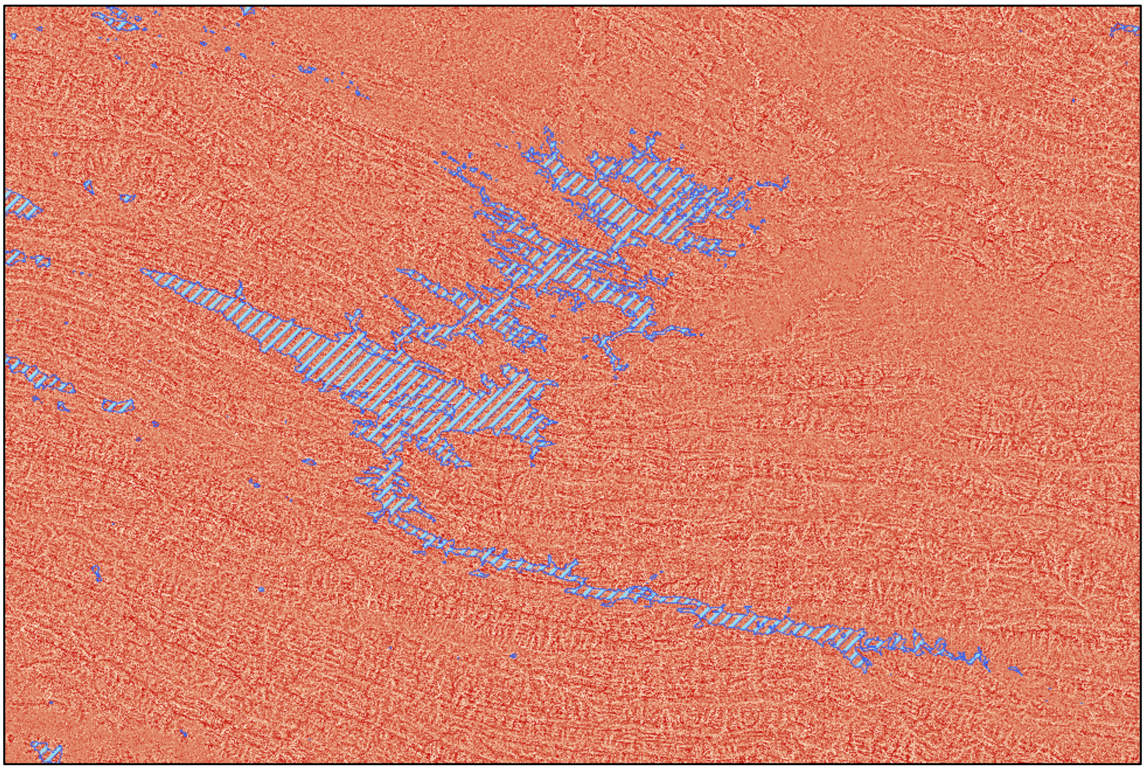
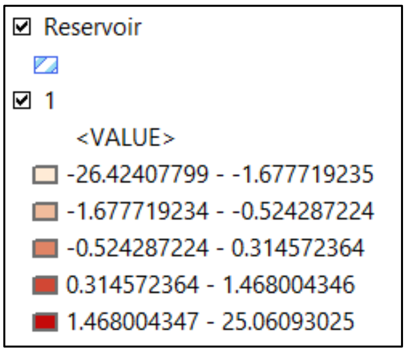


Figure 10 Curvature layer.



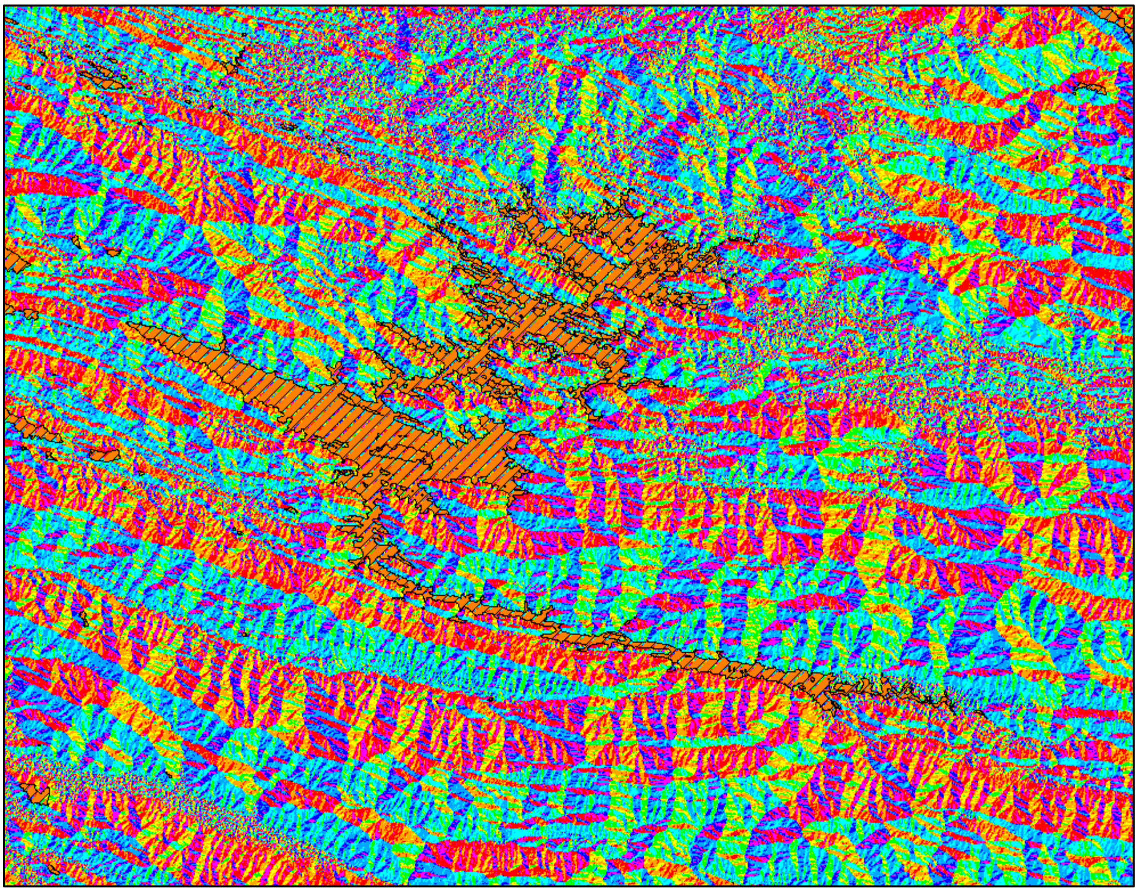
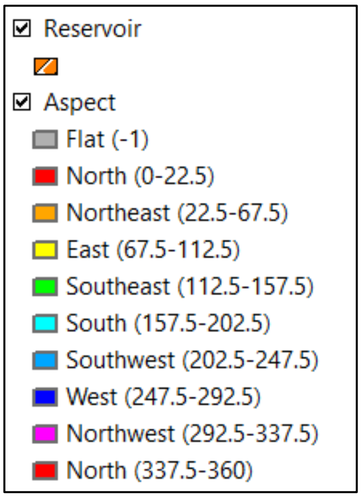


Figure 11 Aspect layer.



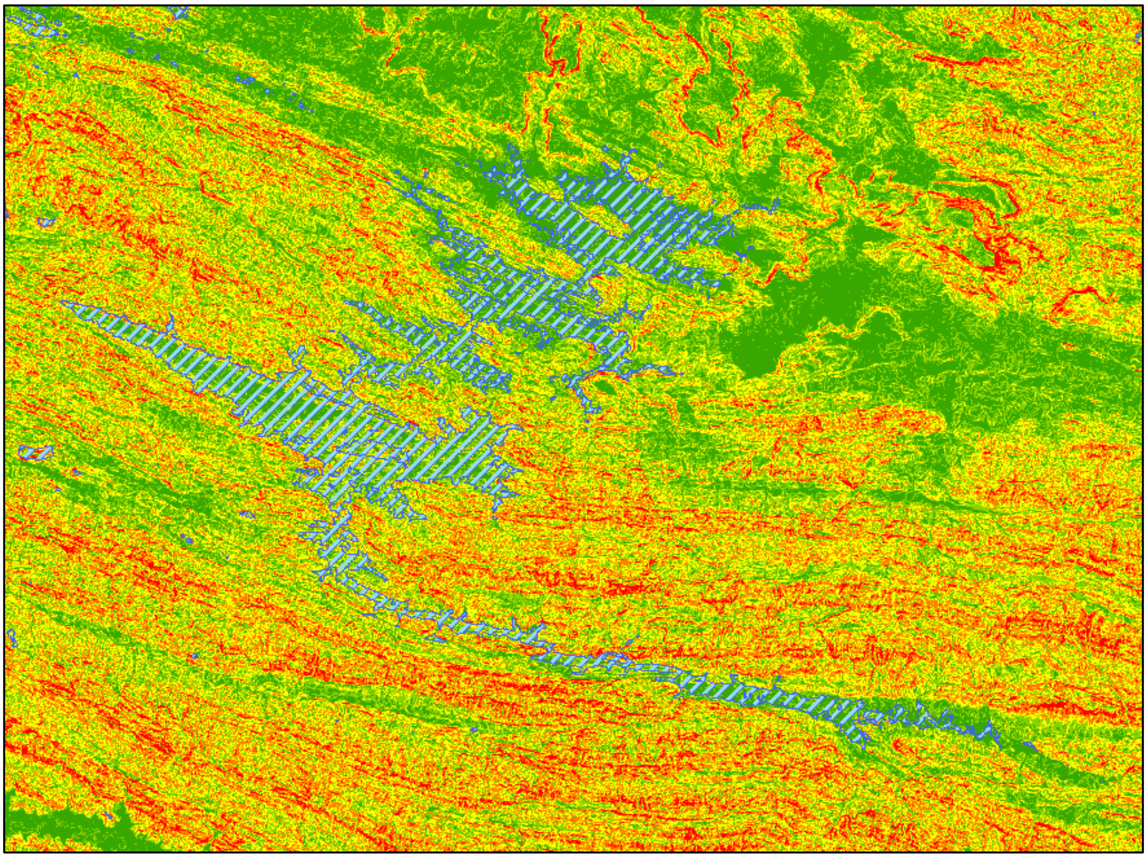
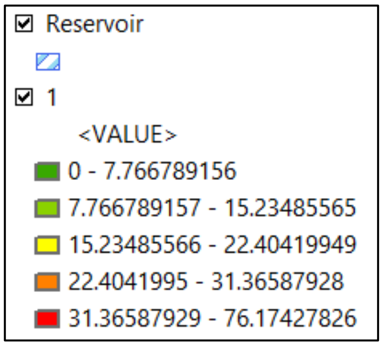


Figure 12 Slope layer.



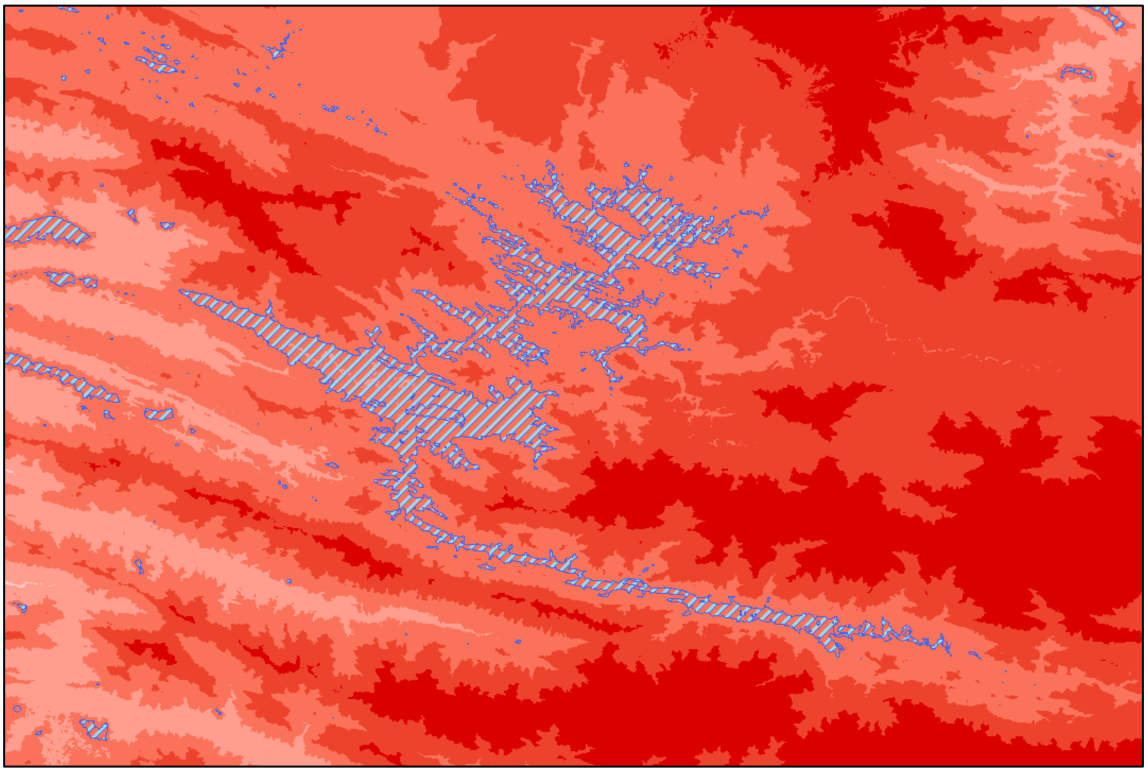
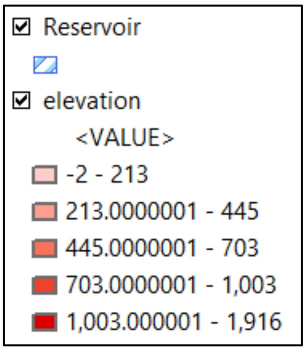


Figure 13 Elevation layer



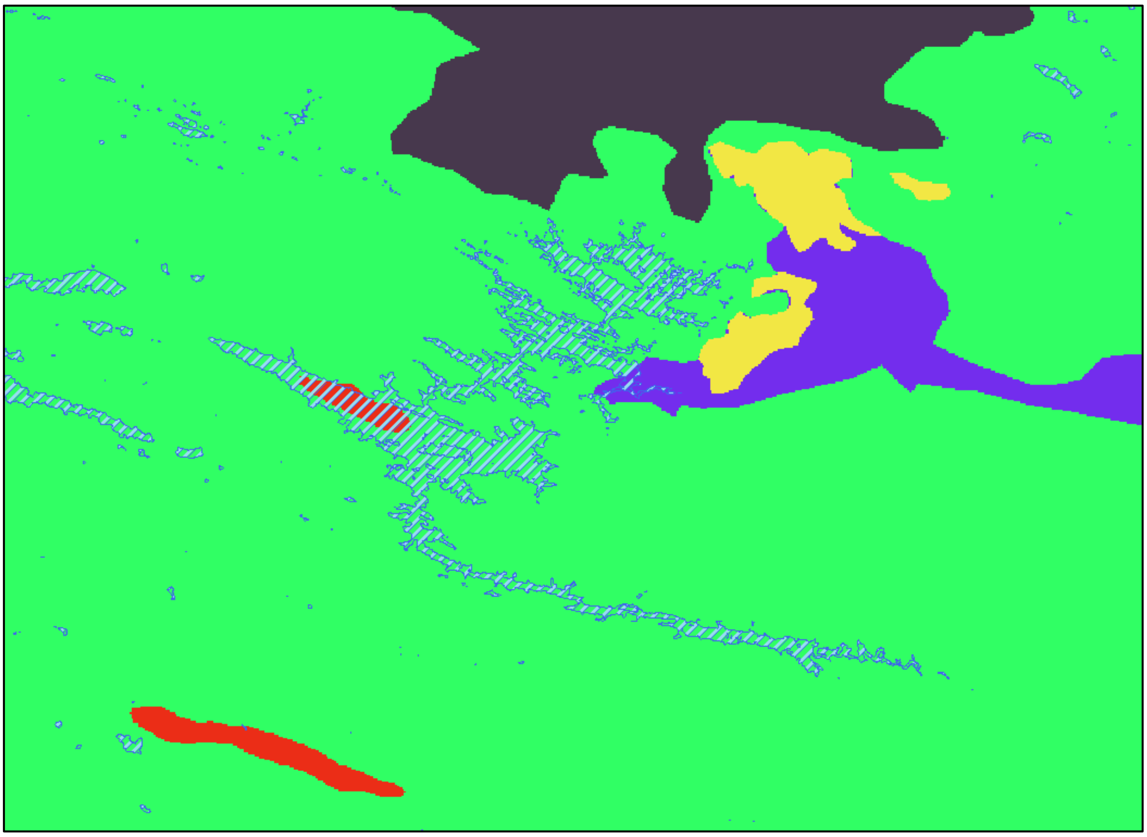
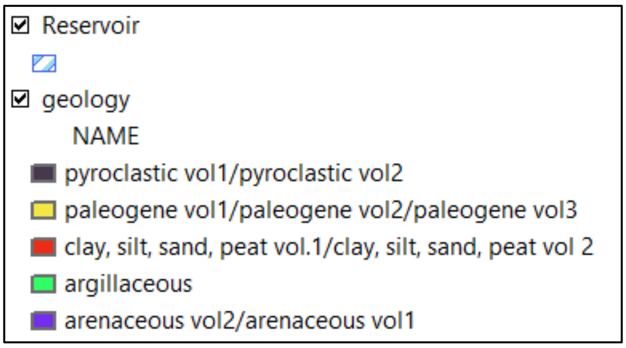


Figure 14 Geology layer.



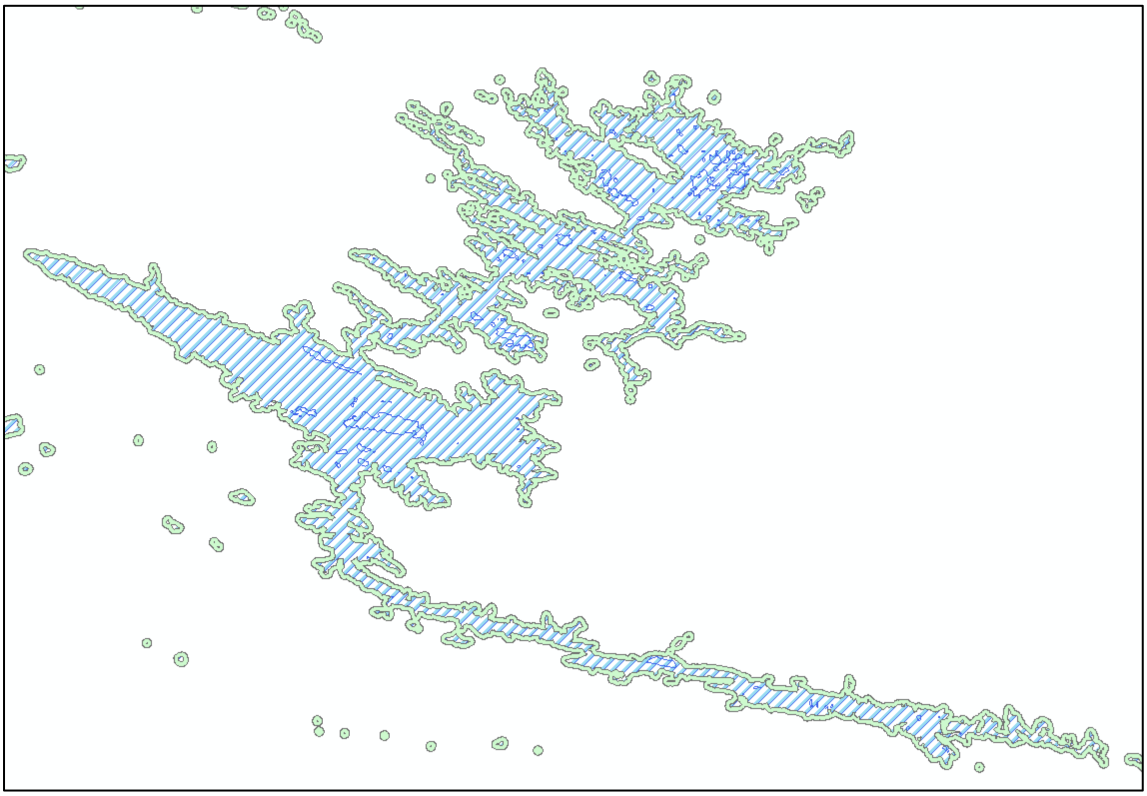
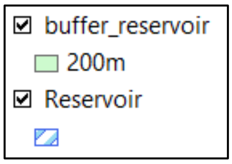


Figure 15 Distance to reservoir.



4.4 RECLASSIFYING THE RASTER

Landslide factor	Classes	Weightage
Aspect (°)	Flat (-1)	1
	North (0-22.5)	2
	Northeast (22.5-67.5)	5
	East (67.5-112.5)	3
	Southeast (112.5-157.5)	3
	South (157.5-202.5)	3
	Southwest (202.5-247.5)	4
	West (247.5-292.5)	3
	Northwest (292.5-337.5)	5
	North (337.5-360)	1
Elevation (m)	< 213	1
	213.0000001-445	2
	445.0000001-703	5
	703.0000001-1003	4
	>1003	3
Slope (°)	< 7.766789156	4
	7.766789157-15.23485565	3
	15.23485566-22.40419949	5
	22.4041995-31.36587928	2
	>31.36587928	1
Curvature	< -1.677719235	2
	-1.677719234- -0.524287224	4
	-0.524287224-0.314572364	5
	0.314572364-1.468004346	3
	> 1.468004346	1
Distance to Reservoir	200m	5
Geology	Clay, Silt, Sand, Peat	2
	Argillaceous/Calcareous rocks	1
	Arenaceous/Coal, Calcareous bed	3
	Pyroclastic/Sandstone	4
	Paleogene/Calcareous bed	5

Kriging (mm)	29.97715187-43.78830344	1
	43.78830345-45.7613251	2
	45.76132511-47.89876522	3
	47.89876523-50.69387923	4
	50.69387924-71.903862	5

Table 16 Reclassifying the classes in the landslide factor.

All the landslide factor must be in raster layer. Then all the raster layers need to be reclass using reclassify toolbox in ArcGIS. It is because to input those layer, its classes on each factors need to be reclassifying for the weighted sum tool to be able to read those raster. Therefore, in this project all those reclassifying were following accordingly in Table 3 and 4. Table 16 shown the summarization of reclassifying classes in each layer in this project. Figure 17 below is 5-point rating scale that were used for the classes for each factors that contributed to the landslide.

Importance	Definition
1	Equal importance
2	Intermediate importance
3	Moderate importance
4	Strong importance
5	Extreme importance

Figure 17 5-point rating scale.

4.5 WEIGHTED OVERLAY ANALYSIS

After preparing all these data needed, these all layers are used to overlay it together by using weighted overlay tool in spatial analyst tool. All the factors involved are set to be of equal influence and the evaluation scale of 1 to 5. It is important to ensure that all the data must be converted into raster layers. The weighted overlay tool only accepts raster layer as input. The sum of the influence must be equal to 100. If not, warning notification will show to the user and order the user to change the influence in order to undergo the next process. The influence of each factor can be set according to the user as long as the sum of influence is 100 percent.

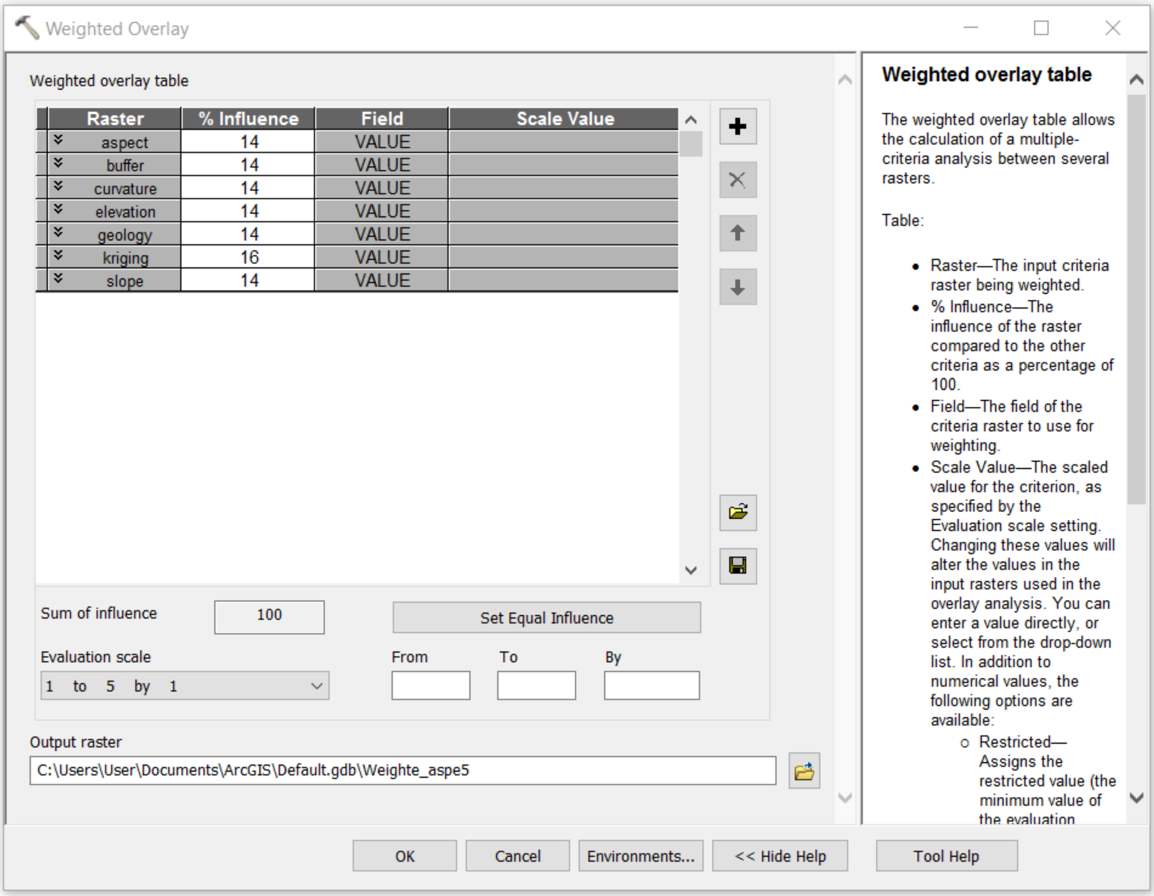


Figure 18 Weighted Overlay Tools.

4.6 FINAL OUTPUT

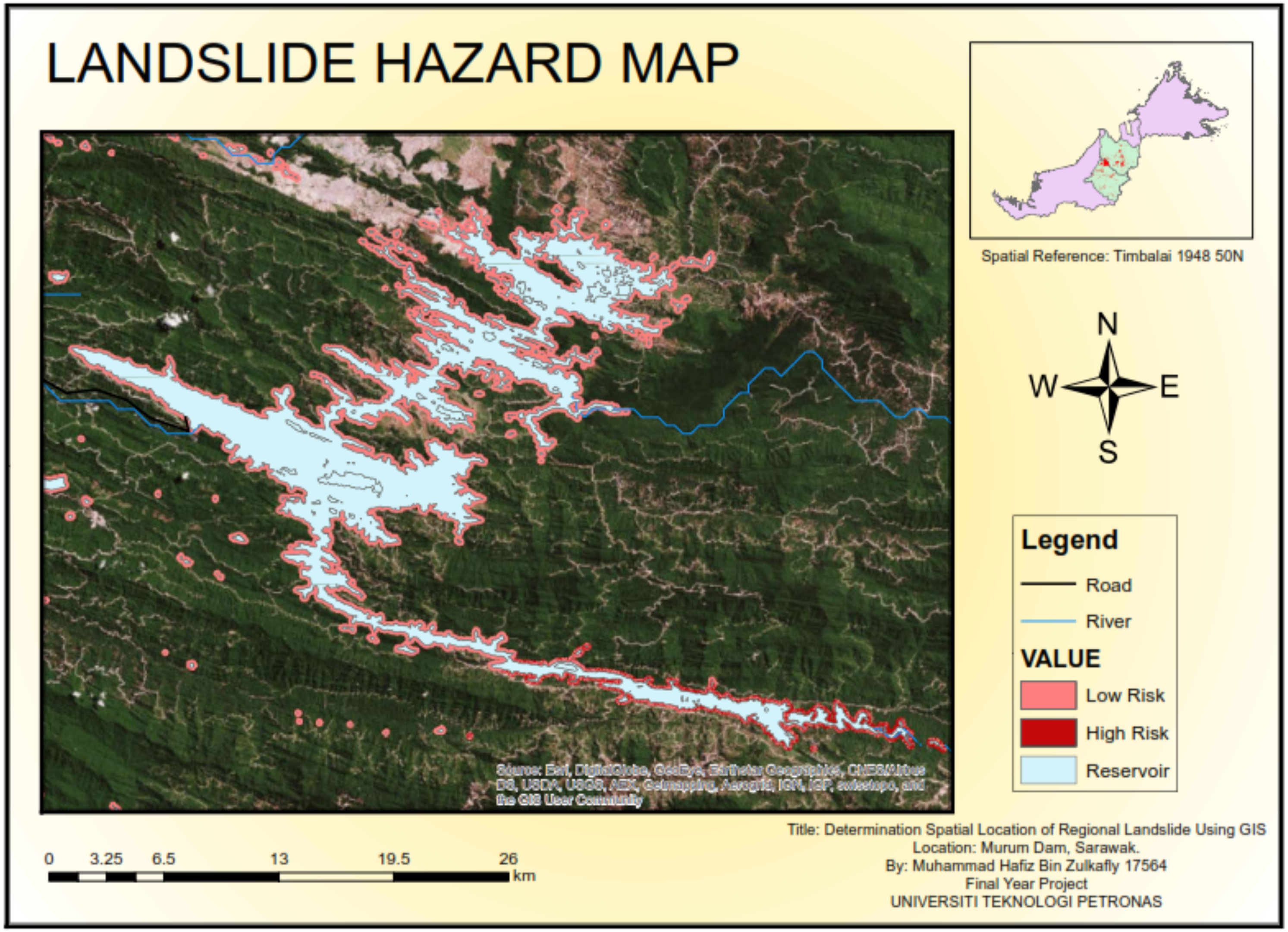


Figure 19 Final Output.

Figure 19 above show the final output of the weighted overlay tool. The system only take account on the areas that are covered by all factors layers and categories the areas according to the summation of the weight. There are two mainly categories of susceptibility to landslides, which are pink (low risk) and red (high risk). The red indicate high risk to landslide where there are the areas that are highly susceptibility of the occurrence of landslides. The table 20 below show that the factors contribute to the low and high risk analysis for the final output above.

Landslide Factor	Low Risk	High Risk
Aspect (°)	North (0-22.5)	East (67.5-112.5) Southeast (112.5-157.5) South (157.5-202.5) West (247.5-292.5)
Elevation (m)	213.0000001-445	>1003
Slope (°)	22.4041995-31.36587928	7.766789157-15.23485565
Curvature	< -1.677719235	0.314572364-1.468004346
Distance to Reservoir	200 m	200 m
Geology	Clay, Silt, Sand, Peat	Arenaceous/Coal, Calcareous bed
Kriging (mm)	43.78830345-45.7613251	45.76132511-47.89876522

Table 20 Factors contribute to the low and high risk analysis.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter presenting about the conclusion of this study from the results obtained in the analysis of landslide using GIS.

5.2 CONCLUSION

Landslide hazard assessment involves many different problems at various stages of analysis. GIS can facilitate a trial-and-error approach for assessment method. Therefore, GIS has become excellent tool and prove its usefulness in spatial analysis for landslide hazard zonation. The GIS environment is a very advantageous one in which to perform modelling. According to Vozenilek (2000), GIS allows one to prepare input data carefully, perform modelling and obtain cartographic visualization of the results. The maximum benefit of GIS is when the causative factor is revealed by the study of parameters terrain in relation to the occurrence of landslide.

Based on the analysis produce by the author using GIS, the high risk area are contributed by:

- The aspect factor mainly on: **east**, **southeast**, **south** and **west** direction.
- Elevation that more than **1003 m** above sea level.
- Degree of slope between **7.766789157** until 15.23485565.
- **Arenaceous** (Coal, Calcareous bed) type of soil.

Therefore, the results of the application of model in GIS-based hazard zonation are positive on condition that the data quality is good and have sufficient amount of data relation with the occurrence of the triggering factor in relation to the occurrence of landslides (Westen, 2000).

5.3 RECOMMENDATION

From the figure 8, there are the location of the rainfall station that are surrounding the location of study which is Murum dam reservoir. The inventory list of rainfall gauges installed in Sarawak were provided also from real-time based data provided by DID Sarawak. The location between each of the rainfall station are far almost 50 kilometers.

In order to improve the precipitation rainfall distribution values, increase the number of installation of rainfall gauge. The area surrounding study location known as hilly and sloppy area, it can be knowledgeable known that the gauge are difficult to install in those area. For further research to be conducted, it is recommended to get as much details on precipitation rainfall from DID Sarawak as the author only using the precipitation data collected for two weeks from 1 November 2016 until 14 November 2016.

REFERENCES

S. L. K. Tyng, "GIS Based Determination of Landslide Location," Bachelor of Engineering, Civil Engineering, Universiti Teknologi Petronas, 2014.

Jordan, (2000). "Mapping of Landslide Hazard Zones in Jordan Using Remote Sensing and GIS," Journal of Urban Planning and Development, 126(1), 1-17.

M. Guinau, I. Vilajosana, and J. M. Vilaplana, "GIS-based debris flow source and runout susceptibility assessment from DEM data – a case study in NW Nicaragua," *Natural Hazards and Earth System Science*, 7, pp 703-716, 2007.

C. J. V. Westen, "The Modelling of Landslide Hazards Using GIS," *Surveys in Geophysics*, 21, pp. 241-255, 2000.

A. S. Dhakal, T, Amada, and M. Aniyu, "Landslide Hazard Mapping and its Evaluation Using GIS: An Investigation of Sampling Schemes for a Grid-Cell Based Quantitative Method," 2000.

H. Shahabi & M. Hashim, "Landslide susceptibility mapping using GIS-based statistical models and Remote sensing data in tropical environment," *Scientific Reports*, 2015.

A. N. Matori, A. Basith, and I. S. H. Harahap, "Study of regional monsoonal effect on landslide hazard zonation in Cameron Highlands, Malaysia," *Arabian Journal of Geosciences*, vol. 5, pp. 1069-1084, 2011.

M. H. Amiruzan, "Development of GIS Based Landslide Hazard Assessment," Bachelor of Engineering, Civil Engineering, Universiti Teknologi Petronas, 2006.

N. Saadatkhah, A. Kassim, and L. M. Lee, "Hulu Kelang, Malaysia regional mapping of rainfall-induced landslides using TRIGRS model," *Saudi Society for Geosciences*, 2014.

V. Vozenilek, "Landslide modelling for natural risk/hazard assessment with GIS," *Acta Universitatis Caroline*, vol. 35, pp. 145-155, 2000.

R. K. Dahal, S. Hasegawa, A. Nonomura, M. Yamanaka, T. Masuda, and K. Nishino, "GIS-based weights-of-evidence modelling of rainfall-induced landslides in small catchments for landslide susceptibility mapping," *Springer- Verlag*, 2007.

B. Pradhan & A. M. Youssef, "Manifestation of remote sensing data and GIS on landslide hazard analysis using spatial-based statistical models," *Saudi Society for Geosciences*, 2009.

H. X. Lan, C. H. Zhou, L. J. Wang, H. Y. Zhang & R. H. Li, "Landslide hazard spatial analysis and prediction using GIS in the Xiaujiang watershed, Yunnan, China", *Engineering Geology*, 76, pp. 109-128, 2004.

L. Turi (Water Resources Management and Hydrology Division). 'Inventory Stations in Sarawak'. Available: h2o.water.gov.my/v2/fail/rhnc/index.html.

M. Mendez & L. Calvo-Valverde, "Assessing the performance of several rainfall interpolation methods as evaluated by conceptual hydrological model", *Procedia Engineering*, 154, pp. 1050-1057, 2016.

C. Chalkias, M. Ferentinou, and C. Polykretis, "GIS-Based Landslide Susceptibility Mapping on the Peloponnese Peninsula, Greece," *Geosciences*, vol. 4, pp. 176-190, 2014.

K. T. Chau, Y. L. Sze, M. K. Fung, W. Y. Wong, E. L. Fong & L. C. P. Chan, "Landslide hazard analysis for Hong Kong using landslide inventory and GIS", *Computers & Geosciences*, vol. 30, pp. 429-443, 2004.