THE USE OF GIS AND RESISTIVITY IMAGING TECHNIQUES TO DETERMINE LANDSLIDE PROBABILITY BASED ON INTERNAL AND EXTERNAL CAUSAL FACTORS

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by

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A	Cross-section area
E	Electric field
I	Current
J	Current density
K	Geometric factor
L	Length between two charge
R	Resistance
r	Position of charge
U	Electric potential
V	Potential difference
x	The length coordinate
y	The width coordinate
z	The depth and elevation coordinate
ρ	Resistivity
ρ_a	Apparent resistivity
ρ_{max}	Maximum resistivity
ρ_{min}	Minimum resistivity
σ	Conductivity

LIST OF ABBREVIATION

a	Distance between adjacent two electrodes
AP	Accurate percentage
BH	Borehole
BH20	Borehole number 20 on the center of Line 2
BH27	Borehole number 27 on the position 70 of Line 2
BH30	Borehole number 30 on the center of Line 3
BH37	Borehole number 37 on the position 70 of Line 3
CCRV	Correct Certainty Resistivity Value
CFLR	Causal Factors of Landslide Ratio
CRP	Classical resistivity Procedure
CRV	Certainty Resistivity Value
D	Dimension
DEM	Digital Elevation Model
DTM	Digital Terrain Model
ECFL	External Causal Factors of Landslide
EP	Error Percentage
GIS	Geographic Information System
GPR	Ground Penetration Radar
GPS	Global Position System
GRASS	geological resources analysis support system (GRASS)
ICFL	Internal Causal Factors of Landslide
log	Logarithm
MEARI	Monitoring to Enhance the Accuracy of Resistivity Imaging
MRR	MEARI Resistivity Ranges
n	Ratio na over a
na	Distance between current and potential electrodes
N_{CCRV}	Number of CCRV
N_{URV}	Number of URV
N_{WCRV}	Number of WCRV
PC	Percentage Change
PC_{ρ}	Percentage Change of Resistivity value
PL	Probability of Landslide
PL_{ECFL}	Probability of Landslide for External Casual Factors of Landslide (ECFL)
PL_{ICFL}	Probability of Landslide for Internal Casual Factors of Landslide (ICFL)
R_{CFL}	Rate of the Causal Factors of Landslide
R_{ECFL}	Rate of the External Casual Factor j
RI	Resistivity Imaging
R_{ICFL}	Rate of the Internal Casual Factor j
RS	Remote Sensing
SRR	Standard Resistivity Ranges
TBHS	Total number of the Borehole Samples
TPL	Total Probability of Landslide
UP	Uncertainty Percentage
URV	Uncertainty Resistivity Value
VL	Vertical Line
WCRV	Wrong Certainty Resistivity Value

PENGGUNAAN KAEDAH GIS DAN PENGIMEJAN RESISTIVITI UNTUK MENENTUKAN KEBARANGKALIAN KEGAGALAN CERUN BERDASARKAN FAKTOR PENYEBAB DALAMAN DAN LUARAN

ABSTRAK

Objektif utama kajian ini adalah untuk menyiasat kebarangkalian kegagalan melalui faktor penyebab dalaman dan luaran. Punca utama faktor dalaman (ICFL) adalah struktur subpermukaan, air bawah tanah, gelinciran subpermukaan dan pergerakan air. Bagi punca utama faktor luaran (ECFL) pula ianya merangkumi sudut lereng, aspek lereng, ketinggian lereng dan liputan tanah. Sebahagian daripada jalan raya Karak di Malaysia telah dipilih dalam kajian ini memandangkan kekerapan berlakunya tanah runtuh di kawasan tersebut. Penggabungan baru antara pengimejan Resistiviti (RI) dan Sistem Informasi Geografi (GIS) telah dilakukan untuk meneliti kawasan sasaran tanah runtuh. RI telah digunakan untuk mengetahui ICFL, manakala GIS digunakan untuk pemetaan factor-faktor tersebut. Theodolite dan GPS digunakan untuk mengetahui ECFL manakala Model Elevasi Digital (DEM) dan GIS digunakan untuk pemataan ECFL. Sebelum menggunakan RI untuk mengetahui ICFL, satu kaedah baru iaitu Monitoring to Enhancing Accuracy of Resistivity Imaging (MEARI) untuk meningkatkan tahap kecekapan RI telah digunakan. Perbandingan antara kelaziman sunsunatur konvensional telah dijalankan untuk mengetahui susunanatur yang paling serasi dalan kes penelitian ini.

Kecekapan RI melalui kaedah MEARI telah meningkat kepada 97% tanpa menggunakan lubang bor atau teknik geofizik yang lain dan susunatur Wenner didapati adalah susunatur yang paling baik dalan kes penelitian ini. Peta kebarangkalian ICFL mendapati kebarangkalian tanah runtuh berjulat antara tahap sangat rendah ke sederhana. Bagi peta kebarangkalian ECFL pula, kebarangkalian tanah runtuh adalah pada tahap sederhana ke tahap tinggi.

THE USE OF GIS AND RESISTIVITY IMAGING TECHNIQUES TO DETERMINE LANDSLIDE PROBABILITY BASED ON INTERNAL AND EXTERNAL CAUSAL FACTORS

ABSTRACT

The main objective of the study is to investigate the landslide probability map through internal and external causal factors. The most important internal causal factors of landslide (ICFL) are subsurface structure, groundwater, sliding subsurface and water movement whereas external causal factors of landslide (ECFL) are slope angle, aspect of the slope, elevation of the slope and the land cover. Part of Karak highway in Malaysia has been selected for the study due to frequent occurrences of landslide. A new integration between Resistivity Imaging (RI), and Geographic Information System (GIS) were carried out to study the landslide in the target area. The RI has been used to find out the ICFL whereas the GIS was used to present the factors. Theodolite and GPS were used to determine the ECFL. Digital Elevation Model (DEM) and GIS were used to map the ECFL. Before applying the RI to find out the ICFL, a new approach called Monitoring and Enhancing Accuracy of Resistivity Imaging (MEARI) was suggested to increase the efficiency of the RI. Moreover, a comparison between the most common conventional arrays has also been carried out to find out the most suitable array for the study.

The efficiency of the RI by using the proposed MEARI approach has been increased to 97% to use RI without other geophysical techniques or boreholes. Wenner array was found to be the best array for the study area and the probability map of ICFL shows that the probability of landslide ranges between very low to medium. Whilst, the probability map of ECFL shows that the probability of landslide ranges between medium to high. The probability map of the integration between the ECFL and the ICFL shows that the probability of landslide ranges between low to high.

CHAPTER 1

INTRODUCTION

1.0 Overview

Natural disasters that occur suddenly such as landslides can cause death and economic losses such as damaging buildings, roads and vehicles (Small and Clark, 1982; Abidin and Sujak, 2008). The prediction of landslide before it occurs will reduce or stop these hazards. There are a number of factors that can cause landslide. Some of these factors are external such as elevation, slope angle, aspect of the slope, and land cover of the surface that can be observed on the ground. These factors are the most important factors as they can be used to create a probability image of landslide (Coe et al., 2004). The External Causal Factors of Landslide (ECFL) can be imaged by terrain imaging, Remote Sensing (RS) and Digital Elevation Model (DEM). There are also the internal factors such as internal subsurface structure, the amount of groundwater, sliding subsurface and water movement that can be imaged by geophysical techniques (Monroe and Wicander, 2005). The subsurface structure is a crucial factor which affects slope stability (Heincke et al., 2010). Groundwater, water movement and the sliding subsurface are the most important Internal Causal Factors of Landslide (ICFL) (Heincke et al., 2010; Sharma et al., 2010; Erginal et al., 2009; Jongmans et al., 2009). Therefore, these internal and external factors have been selected to create a probability image of landslide.

Tropical countries which have a high annual rainfall and a high temperature can cause intense weathering and form thick soil and weathered rock layers. Tropical countries face natural disasters such landslide due to this climate and other causative factors such as geological conditions. One of these tropical countries is Malaysia which is facing a lot of landslides since last decade as shown in Table 1.1 (Singh et al., 2009; Abidin and Sujak, 2008). Karak highway is one of the most dangerous areas in Malaysia and it has a large number of cut slopes in residual granitic soil. The landslide problem started in this highway around seven years after the opening of this highway (Moh and Wijemunige, 1990). Thus it was chosen as the study area.

Drilling and laboratory analyses cost a lot of money that affect the area and provide a discontinuous subsurface image with a few accurate data point for the study area (Maganti, 2008). Because of these, geophysical technique is chosen to image and monitor landslide. The development of the geophysical techniques has significantly contributed to landslide studies and recently, these techniques have been used to investigate the soil and groundwater conditions of landslide areas (Friedel et al., 2006).

Resistivity Imaging (RI) technique is chosen for this study since it can monitor the internal structure, water content, depth of bedrock and layer thickness from subsurface image. It is also used in complex geological and noisy areas when other geophysical techniques such as seismic refraction and GPR techniques cannot be used (Cosenza et al., 2006; De Vita et al., 2006; Heincke et al., 2010; Perrone et al., 2004). RI will be used in this study to image the subsurface and determine the Internal Causal Factors of Landslide (ICFL). Geographic Information System (GIS) will also be used to discuss these factors and to create a probability image of landslide for the study area.

The most common arrays in Resistivity Imaging (RI) are Wenner, dipole-dipole and Wenner-Schlumberger (Samouelian et al., 2005; Loke, 2010). Choosing the right array for the resistivity surveys is important for two reasons. The first one is in each array there are advantages and disadvantages compared with the other arrays. The second reason is the geological image created by means of RI for the same structure will be different for each array. In order to obtain the best results, the researcher has made a comparison between the three common conventional arrays, and the most suitable array will be chosen for the study area (Loke, 2010).

Resistivity Imaging (RI) like most geophysical techniques has some error ratio in the results. This is because of the presence of a sharp change in the geology as in the presence of boulders in soil, or because of the water content which affects the results (Loke, 2004). This weakness is not because the resistivity technique that is not effective, but because this technique is very sensitive to water change in the subsurface materials (Niesner and Weidinger, 2008). Therefore, in this study a new approach has been suggested by the researcher to provide more accuracy to the image compared with the actual subsurface material without using other geophysical techniques.

Theodolite and Global Positioning System (GPS) will be used in the field work to create terrain image and can measure the External Causal Factors of Landslide (ECFL). Terrain imaging, Digital Elevation Model (DEM) technique and Geographic Information System (GIS) will be used to represent and create a probability image of landslide. Terrain imaging has been used since it is a useful technique to present the surface and DEM is used because the geological and geomorphological features can be identified clearly by using this technique. Moreover, using DEM will provide additional information than the two dimensional image (Manap et al., 2010).

Geographic Information System (GIS) technique will be applied as the procedures of creating probability imaging of landslide are complex. Therefore, applying GIS technique can provide more manipulation to the data analyses. In addition, by using this technique, the results can become more efficient and economical (Carrara et al., 1999).

The probability image of landslide can be created from the Internal Causal Factors of Landslide (ICFL) by using Resistivity Imaging (RI). Moreover, the probability image of landslide can also be created from the External Causal Factors of Landslide (ECFL) by using terrain image and Digital Elevation Model (DEM). However, the probability image of landslide from either ICFL or ECFL is not sufficient to produce an accurate probability image of landslide as landslide is a complex phenomenon and its casual factors are interconnected (Zaruba and Mencl, 1982). According to Zaruba and Mencl, (1982) the best results of landslide studies can be obtained from the integration between engineering and geological techniques. Hence, in this study, the researcher has suggested a new integration between subsurface image and surface image to determine the internal and external causal factors of landslide. GIS technique has also been used to create an accurate probability image of landslide for the study by combining ICFL and ECFL.

1.1 The study area

Malaysia is located in the Southeast Asia. It consists of two parts, West Malaysia and East Malaysia. The study area is located in West Malaysia which is called Peninsular Malaysia (Abidin and Sujak, 2008). Malaysia is situated in a humid tropical zone with heavy rainfall and high temperatures (Omar et al., 2004; Ramli et al., 2005).

Kuala Lumpur-Karak highway is the major east-west link in the central part of Peninsular Malaysia as shown in Figure 1.1. More than 50 km of this road stretch across a mountainous area thus possessing a large number of cut slopes in the residual granitic soil. The landslide problem started after around seven years after the opening of this highway (Moh and Wijemunige, 1990). This highway is known as a landslide way where it closed for several times in different locations (Omar et al., 2004).

Table 1.1: Series of major landslide occurrences in Malaysia [adopted from Singh et al., 2009]

Date	Location	Number of Deaths
November 1993	Karak Highway	2
December 1993	Ulu Klang, Selangor	48
June 1995	Karak Highway	22
January 1996	Gunung Tempurung, Kampar, Perak	1
August 1996	Orang Asli settlement, Kampar Perak	44
January 1999	Squatters settlement, Sandakan	13
January 2000	Vegetable farm, Cameron Highlands	6
January 2001	Simunjan, Sarawak	16
December 2001	Gunung Pulai, Johor	5
November 2002	Hillview, Ulu Klang, Selangor	8
September 2003	Gunung Raya Road, Langkawi	1
November 2004	Taman Harmonis, Gombak, Selangor	1
December 2004	Bercham, Ipoh, Perak	2
May 2006	Ulu Klang, Selangor	4
Jan 2008	Cameron Highlands	2
September 2008	Balik Pulau, Penang	0
October 2008	Hulu Langat, Selangor	2
November 2008	Ulu Yam Perdana, Selangor	2
December 2008	Bukit Antarabangsa, Selangor	4

1.1.1 Location

The center of the study area is located on latitude 03˚ 22′ 9″ N and longitude 101˚ 52′ 03″E between kilometer 48.6 and 48.8 on the Kuala Lumpur-Karak highway near Bukit Tinggi in Pahang State. Pahang State is located on the east coast side of the Peninsula Malaysia.

Kuala Lumpur-Karak Highway as shown in see Figure 1.1 and in Appendix E is located in the mountainous areas and consists of a large number of high residual granite cut slopes. This highway is very susceptible to failures especially during rainy seasons since it is constructed on highland areas and it is located in tropical region. In addition, the annual rainfall of this region is over 2500 mm which is relatively higher rainfall compared to other regions in Peninsular Malaysia (Omar et al., 2007). Two wet seasons occurs in this area which starts from September to December and the second one starts from February to May (Mansor et al., 2007; Pradhan and Youssef, 2009).

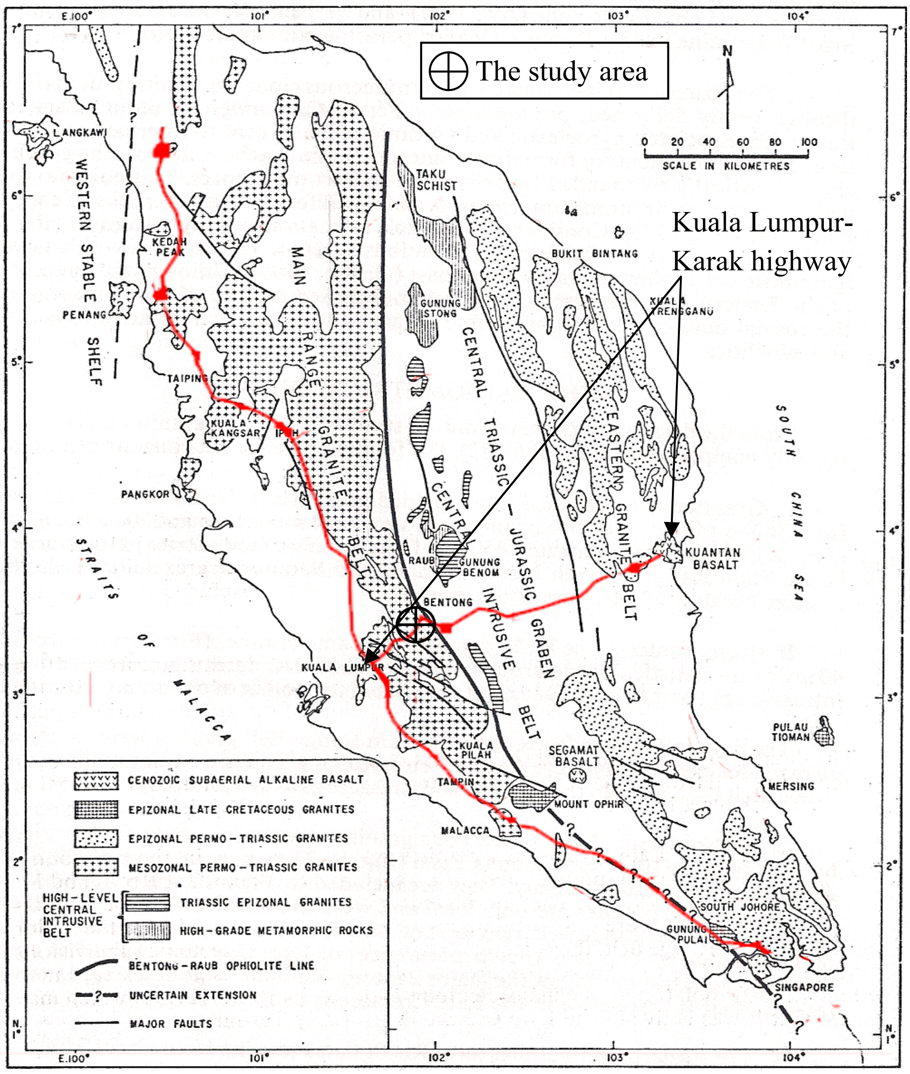


Figure 1.1: The granite distribution in Peninsular Malaysia [adopted from Hutchison, 1977].

1.1.2 Geology

The study area as shown in Figures 1.1 and 1.2 is located on the Mesozoic Post-Triassic age which is responsible for the position of the Main Range granite batholiths and also of the major Bentom (Raj, 1998; Alexander, 1968). Granite porphyry occurs particularly as large masses and huge boulders. The granite is greenish-gray in colour and contains phenocrysts of quartz, orthoclase, plagioclase, brown, strongly pleochroic biotite, light-colour pyroxene, apatite, magnetite and a little pyrite (Alexander, 1968; Rafek and Amin, 1996).

The material of bedrock mass beneath the weathering profile is seen to be grey coloured, medium to coarse grained and porphyritic with large alkali feldspar phenocrysts (Raj, 1998).

The most distinguished fault in Peninsular Malaysia is Bukit Tinggi Fault Zone. The Bukit Tinggi Fault has produced a zone of porphyrocastic mylonitic granite up to 4 km in width and is the only major zone of highly deformed granite in the area (Fatt and Beng, 2007).

The granite bedrock of this area is covered with residual granite soil (gravel, sand, silt and clay) with various thicknesses which range from 6 m to 45 m and the covered soil properties vary with the depth. The soil cover is divided into three layers namely topsoil layer, middle layer and bottom layer where their average thickness is 12 m, 3 - 20 m and 7 m respectively. The amount of the fine fraction of the soil decreases when the depth increases. The quantities and the size of the boulders vary in the subsurface soil. The boulders shape are round with variant diameters (0.5 – 6 m) and located on the ground surface or near the bedrock (Moh and Wijemunige, 1990).

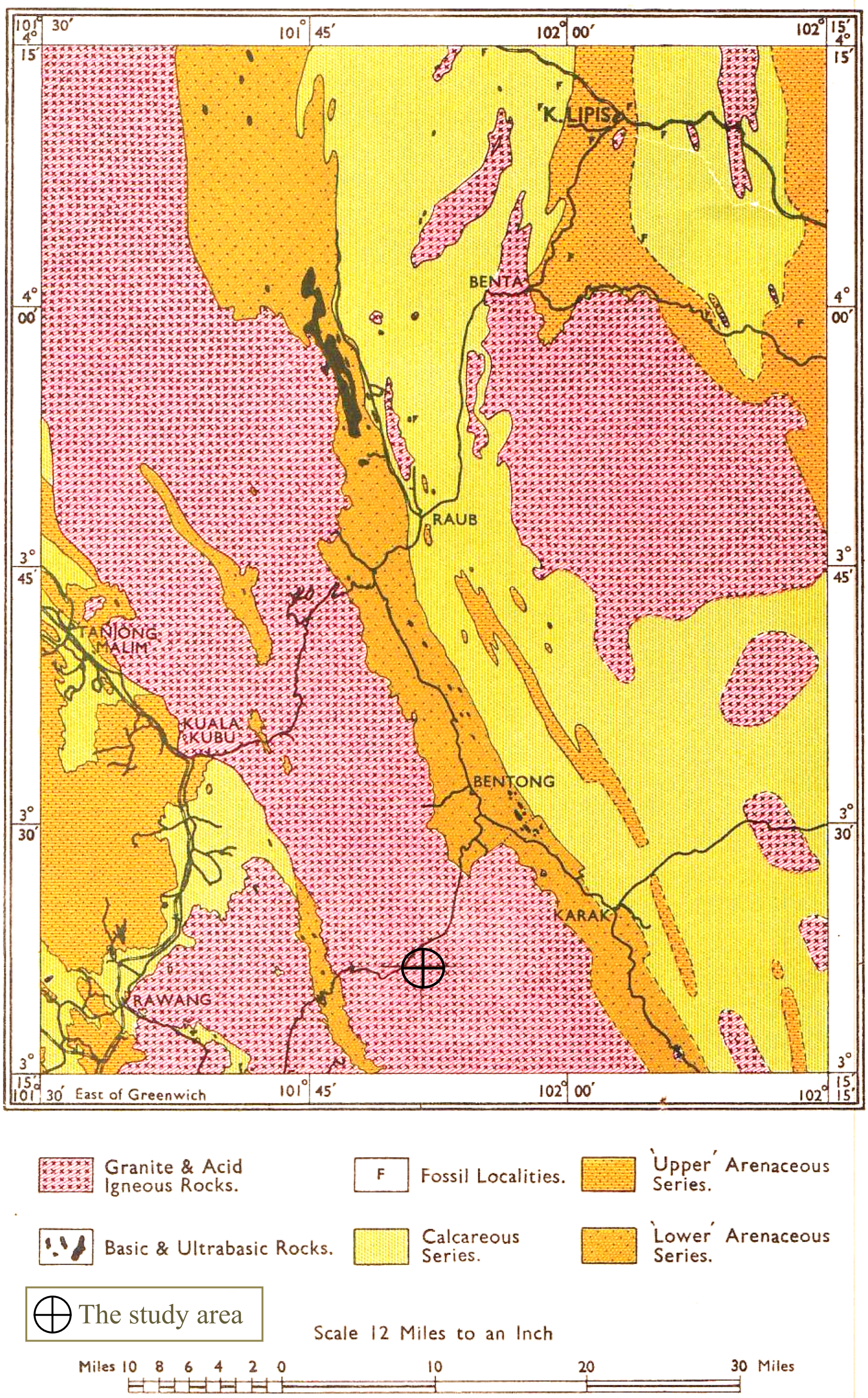


Figure 1.2: Geological image of the study area [adopted from Alexander, 1968].

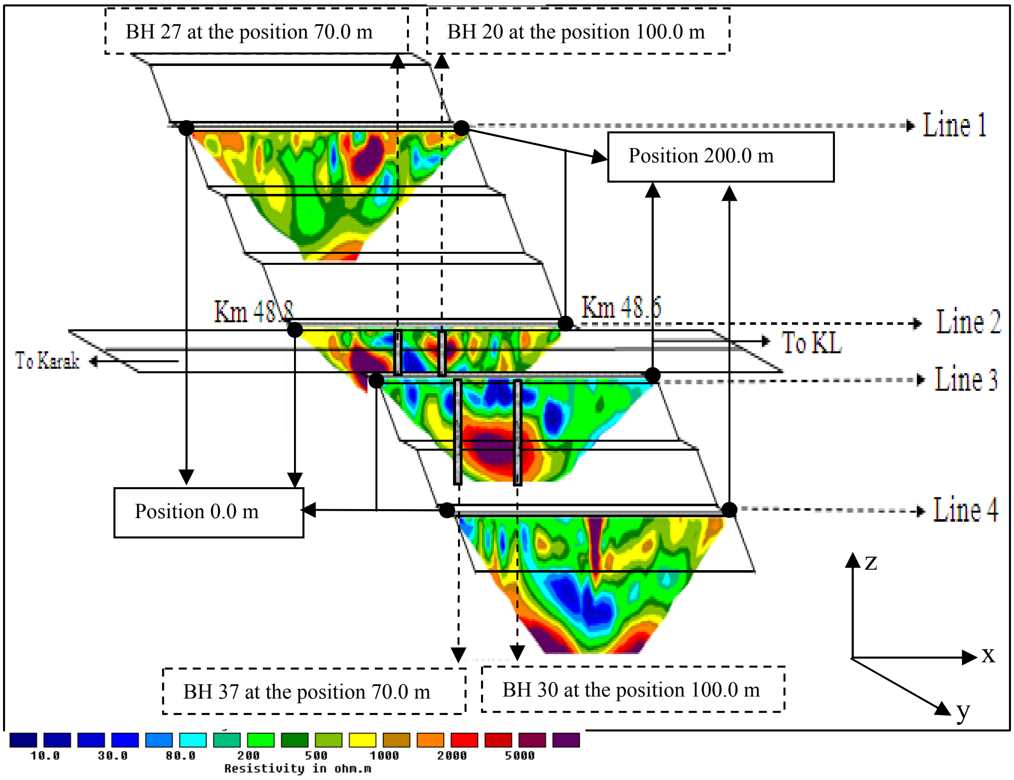
1.1.3 Boreholes (BHs)

Boreholes data are considered accurate, give the best results and provide accurate details for the subsurface structure. However, there are disadvantages using boreholes data because it provide information for a limited area, require a longer time, distract the study area, and cannot use them in all the terrain (Maganti, 2008). However, boreholes data are needed to confirm and tie the results of the geological and geophysical interpretations.

Four boreholes were drilled in the study area. Two boreholes (BH27 and BH20) were drilled on Line 2 and the other two boreholes (BH37 and BH30) were drilled on Line 3 as shown in Figure 1.3. In each line, one borehole was drilled in the centre of the line (at position 100 m) and the other borehole was drilled on the position 70 m. The researcher could not drill any borehole on Line 1 and Line 4 because the terrain is complicated and limited space.

In general, the geology of the study area consists of sand and weathered granite as shown in Appendix A. In this study, silty sand and sandy silt was found in boreholes results. In all the boreholes, the first layer is sand and the second layer is granite with different thicknesses.

A



B

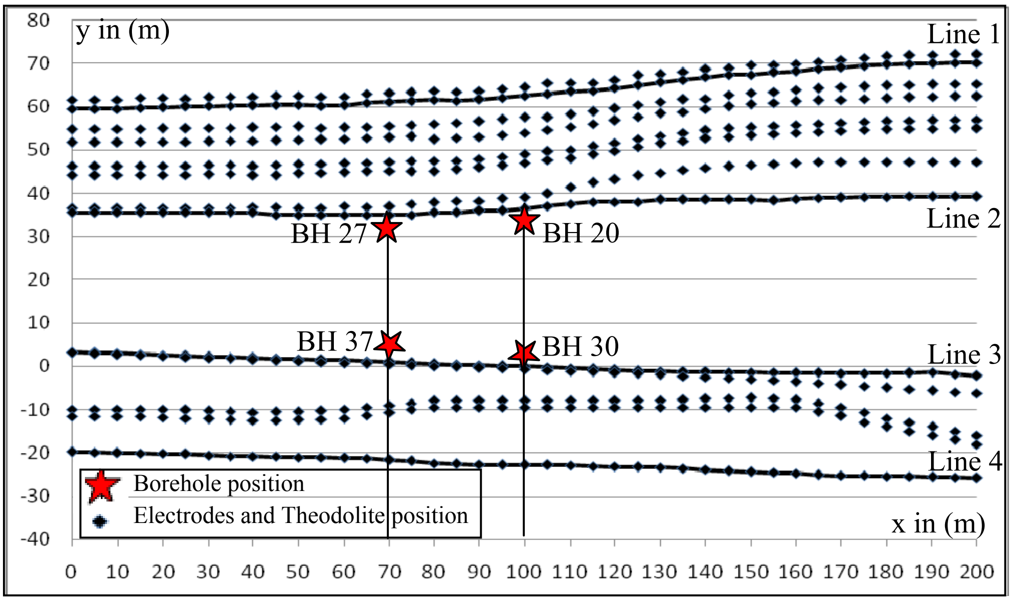


Figure 1.3: Boreholes locations in the study area.

1.2 Problems Statement

The resistivity imaging method has uncertainty in the results therefore it requires borehole or other techniques to confirm the obtained results (Reynolds, 1997; Loke, 2010; Sass et al., 2008).

There are many arrays used for resistivity imaging where each array has advantages and disadvantages depending on the nature of the study area (Saad, 2009; Jongmans and Garambois, 2007).

There are internal and external causal factors causing the landslide. However, either ICFL or ECFL are not enough to create accurate image of probability to landslide (Jongmans and Garambois, 2007).

1.3 Research objectives

The objectives of the study are summed up as follows:

To suggest a new interpretation approach to ensure the efficiency of Resistivity Imaging (RI) technique. To determine the most suitable array for the study area by making a comparison between the three conventional arrays (Wenner, Wenner-Schlumberger and dipole-dipole arrays).

To analyse the internal causal factors of landslide (ICFL) namely subsurface structure, groundwater, sliding subsurface and water movement by using Resistivity Imaging (RI) technique.

To analyse the external causal factors of landslide (ICFL) namely elevation, slope angle, aspect of the slope and land cover using Theodolite, field work and GPS.

To create a total probability images of the study area for the internal and external causal factors of landslide using GIS.

1.2 Organisation of the dissertation

This dissertation consists of five chapters which are described in brief as follows:

Chapter 1 Provide an overview of this study, the techniques which will be used in this research and the target study area. This chapter presents a brief background to the study area in terms of geology and location. In addition, statement of the problem and the objectives of this study are also presented in this chapter.

Chapter 2 consists of two parts. The first part presents a brief summary of the causal factors of landslide. The second part reviews the previous studies on landslide by using RI, DEM and GIS techniques.

Chapter 3 is devoted to techniques, materials and methodology. This chapter discusses the basic principles and the programs of the three techniques RI, DEM and GIS which are used in this study.

Chapter 4 consists of four parts. The first part discusses the results of this study and the outcome of using the proposed approach in Resistivity Imaging (RI) technique. The efficiency of the new approach is also considered in this part. It includes a comparison between the three conventional arrays namely Wenner, Wenner-Schlumberger and dipole-dipole arrays. The second part presents and discusses the results of the internal causal factors of landslide (ICFL). In this part, the RI is used to determine the ICFL and GIS is used to present the results. The third part presents and discusses the results of the external causal factors of landslide (ECFL). In this part Theodolite, GPS, and DEM are used to determine the ECFL and GIS is used to represent the results. The forth part presents and discusses the results of the landslide probability of the ICFL, ECFL and the total probability through the integration between the ICFL and ECFL.

Chapter 5 consists of two sections. The first section presents the conclusions of this study. The second section involves some suggestions for future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Causal factors of landslide

Landslide is “the movement of a mass of rock, debris or earth down a slope” (Sassa, 2007). Landslide has been studied in many countries and areas, in many fields of science and engineering because it occurs almost in most parts of the world (Monroe and Wicander, 2005). Landside occurs in high mountainous areas, in coastal areas or even in marine geologic units. It can happen in heavy rainfall areas. Landslide can be classified depending on the movement of the material (rapid and slow), the material type (rock, debris (coarse soil), fine soil) or the movement type (fall, topple, slide, spread, flow) (Monroe and Wicander, 2005).

Slopes can occur either naturally or artificially. Embankment is a type of artificial slopes and it is found along highways, railways and canals (Norris and Greenwood, 2008). The stability of the slopes or embankments can be affected by internal and external factors. It is necessary to obtain sufficient information on each factor to predict slope stability (Sassa, 2007; Gao and Lo, 1995). The ability to identify and understand these factors assist to find ways to reduce the hazards of landside. The Internal Causal Factors of Landslide (ICFL) are related to subsurface physical properties such as the subsurface structure, groundwater, sliding surface and water movement. The External Causal Factors of Landslide are related to the surface such as elevation, slope angle, aspect of the slope, and land cover (Norris and Greenwood, 2008).

2.1.1 Internal Causal Factors of Landslide (ICFL)

The most important Internal Causal Factors of Landslide (ICFL) are subsurface structure, groundwater, sliding subsurface and water movement. These factors will be discussed in detail in the following sub-subsections.

2.1.1.1 Subsurface structure factor

One of the most important causal and intrinsic contributing factors to landslide is the geology of the subsurface (Kouli et al., 2010; Ramli et al., 2010).

Landslide is more probable to happen in loose or poorly consolidated slope materials than in bedrock. In tropical area such as in Malaysia, high temperatures and rainfall worsen the effects of weathering to an extend of several tens of meters deep; this weathered layer become more probability to landslide (Monroe and Wicander, 2005).

2.1.1.2 Groundwater factor

Water is a significant factor that causes landslide because the amount of water on the surface and in the subsurface greatly affects slope stability. Water can aid landslide depending on the amount of water in the soil. For example, slope is stable when the amount of water is little. This stability comes from surface tension between sand grains. When the slope contains, this wet sand means that the area can experience sliding because of the spacing between the grains will be full of water which in turn causes the grains to slide easily on each other (Plummer et al., 2007; Small and Clark, 1982). Moreover, Small and Clark (1982) and Monroe and Wicander, (2005) found that water will increase the weight of the slope as well as the gravity force.

2.1.1.3 Sliding subsurface factor

The presence of sand and clay layer in the subsurface causes the upper layer to slide especially when the sand or clay layer is saturated with water. The penetration of water through soil grains decreases the friction between the grains until their cohesion is lost. Clay can hold large amounts of water, and that the grains will easily slide over each other. The clay layer beneath the rocks is the most slippery layer (Monroe and Wicander, 2005).

When rocks in the subsurface are placed in the same direction as the slope, water can penetrate between the layers and decrease the cohesiveness and friction between the adjacent rock layers. Moreover, if the subsurface is placed in the opposite direction to the slope, water will affect the subsurface. Subsequently, water will penetrate through the rocks and aid to weather the rocks (Monroe and Wicander, 2005).

2.1.1.4 Water movement factor

Rainfall, infiltration and runoff are the major water sources for landslide. Infiltration of rainfall affects the slope stability. The correlation between the rainfall and the infiltration to the slope stability consists of a large number of factors. Some of these factors, such as rainfall duration and intensity, slope surface cover, degree of saturation, slope angle, are extremely difficult to be evaluated (Huat, 2005; Zaruba and Mencl, 1982).

Slopes are only stable within a certain range of water saturation. Suction and shear resistance reduce significantly when the saturation is above crucial value. This means after heavy rainfall, water saturation may exceed the critical limit in certain parts of the slope, initiating failure which leads to landslide or debris flow (Friedel et al., 2006).

2.1.2 External Causal Factors of Landslide (ECFL)

There are a lot of External Causal Factors of Landslide (ECFL). However, the major ECFL are elevation, slope angle, aspect of the slope and land cover. The results obtained from these factors can give enough information about the occurrence of landslide (Coe et al., 2004). These factors will be presented in detail in the next sub-subsections.

2.1.2.1 Elevation of the slope factor

Elevation of the slope above the sea level is one of the important causal factors and an intrinsic contributing factor to landslide (Gao and Lo, 1995; Ramli et al., 2010). The best probability of landslide can be achieved when the elevation is considered (Coe et al., 2004). The probability of occurrence of landslide in a high elevation area is more than that of the lower elevation. This higher probability comes from the effect of gravity which is the force that drives landslide to move down (Pipkin et al., 2008).

2.1.2.2 Slope angle factor

Slope angle is the angle between the horizontal and the surface of the slope which is represented by the gradient of the slope. This is the second major factor that causes the landslide (Kouli et al., 2010; Coe et al., 2004; Ramli et al.,2010). In general, the steeper slope has less stability. Therefore, steep slopes are more likely to fail than the gentle ones (Monroe and Wicander, 2005).

2.1.2.3 Aspect of the slope factor

Aspect of the slope is the third intrinsic contributing factor to landslide (Ramli et al., 2010). It is the direction of the slope towards the sun. The measurement unit of the aspect is degree from the north and clockwise, and its value starts from 0 to 360 degrees (Kouli et al., 2010). The temperature of the soil is higher and the moisture of the soil is lower when the slope faces the afternoon sun.

2.1.2.4 Land cover factor

Land cover is the fourth intrinsic contributing factor to landslide (Kouli et al., 2010; Ramli et al., 2010). This factor shows the presence or absence of vegetation on the surface which can be observed directly through the field work (Donati and Turrini, 2002; Shafri et al., 2010). The vegetation can affect the slope stability in different ways where the presence of vegetation can decrease the water saturation from the subsurface material and the root system can help to stabilize the slope by binding the soil (Monroe and Wicander, 2005).

2.2 Previous Works

The dangers of sudden disasters such as landslide promoted the researcher to try to predict landslide before it occurs. Landslide can be predicted through the causal factors of landslide. Many studies have been carried out to predict landslide by using various interpretation techniques, data source and causal factors. Geophysical techniques were used to predict landslide by monitoring the Internal Causal Factors of landslide (ICFL) (Friedel et al., 2006; Lebourg et al., 2005). Whereas remote sensing (RS) and GIS techniques were used to predict landslide by monitoring External Causal Factors of Landslide (ECFL) (Pradhan, 2010; Gahgah et al., 2009).

This section is divided into four subsections to present some of the previous studies on landslide. The first subsection presents some of the landslide studies which were done by using monitoring Resistivity Imaging (RI) technique. The second subsection presents some of the landslide studies which were done by using Remote

Sensing (RS) and GIS techniques in Malaysia. The third subsection presents some of the studies which were done by integrating RI and (RS or GIS) techniques. The fourth subsection presents the major differences and the novelty of this study.

2.2.1 Resistivity imaging technique, monitoring and landslide

Field investigation (RI technique is one of the field investigatory techniques in this field) is the foremost major technique to study landslide. 36% of landslide studies used field investigations. Moreover, 9% of landslide studies techniques used monitoring to study landslide because it is a useful technique (Sassa et al., 2009). Researchers give different names to resistivity imaging (RI) technique such as electrical imaging (Marescot et al., 2008), resistivity imaging (Yang et al., 2004), 2D or 3D electrical resistivity (Sharma et al., 2010), electrical resistivity topography (Mol and Velis, 2010) electrical technique (Bichler et al., 2004) and DC resistivity (Heincke et al., 2010). In this thesis, the name Resistivity Imaging (RI) technique will be used.

This section presents some of landslide studies which were done by monitoring RI in different locations as shown in Table 2.1. RI has been used since 1977 to study the landslide where Bogoslovsky and Ogilvy (1977) were the first researchers who studied landslide via RI technique. They integrated two geophysical techniques (electrical and seismic techniques) to predict landslide in various regions of the Soviet Union by investigating the structure of the slope (thickness of landslide body and slip zone), water saturation and the properties and status of the soil comprising the slope (Bogoslovsky and Ogilvy, 1977). The survey was repeated two times in two different seasons in a year (summer and winter) to monitor the physical properties of soil. The results showed that the RI technique is more effective to observe the change in water content. Moreover, water saturation and the physical properties have also been examined.

Suzuki and Higashi (2001) used 2D RI technique via using pole-pole array and laboratory experiment to monitor landslide in Japan. Groundwater flow as a causal factor of landslide was monitored for 42 days. Changing in resistivity values associated with heavy rainfall was also observed. The results suggested that there was a connection between the 2D RI and the infiltration of the rain. Their results showed the effect of the groundwater flow on landslide.

In Italy, 2D RI via using dipole-dipole array and self-potential were carried out to monitor landslide by (Lapenna et al., 2003). Summer and winter seasons were chosen in this study. Thickness and depth of the sliding surface and geometry of landslide (underground water) were studied as causal factors of landslide. The RI indicated that there was a sliding surface. They found that the RI is cheap, can perform fast field survey procedures and can produce high resolution images. They detected the sliding subsurface in their results at depth 25 m.

Supper and Romer (2004) did their monitoring in Austria by using RI. They used a new kind of arrays for two years of monitoring to study the internal change of the structure which caused landslide. They found that the principle structure and the water saturation of the study area during monitoring remained without change.

In French Alps, 3D and 2D RI via using pole-pole and dipole-dipole arrays have been used to monitor the sliding surface and water drain system as causal factors of landslide for six months (Lebourg et al., 2005). There were no additional techniques and no borehole data or laboratory test. Their study showed that RI technique is an effective technique to evaluate the ground water and geological structure. They detected the slipping subsurface and water drainage system of the study area.

2D and 3D RI technique using three arrays (Wenner, Schlumberger and dipole-dipole) were integrated with boreholes data and laboratory analysis to derive a detailed subsurface image and to determine the structure and thickness of the sliding layer. Friedel et al. (2006) conducted their study in a dry and a wet season to determine the impact of rainfall on the slope. The 2D and 3D RI technique provided a detailed image of the subsurface which was in very good agreement with drilling and sampling data. They found in their results that the silty sand can be saturated very fast after the rainfall and can be a sliding subsurface.

Niesner and Weidinger (2008) integrated RI and seismic techniques to image water saturation as a causal factor of landslide in the Alpine area. Their study has continued for three years. The results showed that RI technique was suitable for long-term monitoring of potentially hazardous slopes. They have detected mass movement early.

Sjodahl et al. (2008) did of landslide probability for nine years. They used Wenner, Wenner-Schlumberger and dipole-dipole arrays in their monitoring to study the internal erosion of the embankment subsurface. They found that RI may detect the early erosion.

From the previous studies above, one can see that the previous studies examined the internal causal factors of landslide (ICFL) such as sliding subsurface, water saturation, subsurface structure and thickness of the subsurface layers. Moreover, most of the researchers used more than one array or created new arrays to ensure the accuracy of the results. In addition, most of the studies used other geophysical or engineering techniques to confirm the results. However, previous studies examined the presence of the ICFL without giving probability percentage or image and they did not take ECFL in their account. Most of the results of the previous studies have been presented in 2D image or in 3D image.

Table 2.1: A comparison between previous studies on landslide using RI tchnique

Researcher	Study Area	Arrays	Other techniques	Causal factors of landslide	Monitoring time	Results
Bogoslovsky and Ogilvy, 1977	USSR	-	Seismic	Thickness, Slipping zone, Groundwater	Summer & Winter	Determined the physical properties, water saturation, motion of landslide
Suzuki and Higashi, 2001	Japan	Wenner	Boreholes	groundwater	42 days	groundwater flow
Lappena et al., 2003	Italy	Dipole-dipole	Self-potential	Sliding surface	Summer & Winter	the sliding subsurface, surface boundaries
Supper and Römer, 2004	Austria	new	System Innovation	Saturation, Subsurface structure	2 years	Structure stay same, full saturation stay same
Lebourg et al., 2005	France	Pole–pole, dipole–dipole	seismic	weathered zones, slipping surface, network of water drainage.	6 months	slipping subsurface and water drainage system
Friedel et al., 2006	Swiss	Wenner, dipole-dipole, Schlumberger	Seismic, GPR, Laboratory analysis, boreholes	Subsurface structure, sliding subsurface, water saturation	dry and wet period	Detect sliding subsurface
Niesner and Weidinger, 2008	Australia	-	Seismic	Water saturation	2 years	Detect mass movement
Sjodahl et al., 2008	Swiss	Pole-dipole, Wenner-Schlumberger	-	Internal erosion	9 years	RI may has chance to detect the early erosion
The current study includes only the ICFL part	Malaysia	New approach, Wenner, dipole-dipole, Wenner-Schlumberger	Boreholes	Geology, Sliding subsurface, Groundwater, Water movement	21 months	Probability image has been created from ICFL.

Table 2.1 shows some of the studies on landslide using resistivity imaging (RI) technique in different countries. Most of these studies used other geophysics or engineering techniques along with RI technique using different arrays. The monitoring time varies in these studies, but most of them focused on two seasons (wet and dry).

2.2.2 Landslide and GIS

GIS is the second important technique after field investigations to study landslide because the results of this technique are more reliable if they are supported with other techniques (Sassa et al., 2009). Therefore, landslide studies using remote sensing (RS), GIS, DEM have been carried out in different countries such as Greece (Kouli et al., 2010), Italy (Cascini et al., 2010; Donati and Turrini, 2002; Turrini and Visintainer, 1998; Chelli et al., 2006), Iran (Jadda et al., 2009), Turkey (Akgun et al., 2008), India (Sarkar and Anbalagan, 2008; Anbalagan and Singh, 1996; Sarkar et al., 2008), Nepal (Dhakal et al., 2000), USA (Coe et al., 2004; Gao and Lo, 1995; Nandi and Shakoor, 2009), Thailand (Patanakanog, 2002) , Sweden (Erener et al., 2007) and Ethiopia (Temesgen et al., 2001).

Some states in Malaysia such as Penang, Selangor and Pahang face landslide problems. Therefore, there were some landslide studies that were carried out to study this phenomenon using RS, GIS and DEM. Most of the these studies were concentrated in Penang as in Pradhan 2010; Pradhan et al., 2009; Abedini et al., 2009; El-Fadil and Gofar, 2008; Ahmad et al., 2007; Pradhan et al., 2006; Lee and Pradhan, 2006; Ahmad et al., 2005; and Lee and Talib, 2004. Selangor state received less focus by some researchers such as Pradhan, 2010; Manap et al., 2009; Lee and Pradhan, 2006; and Talib, 2000. With regard to Pahang state, there were few studies on landslide in this state.

The target study area is Pahang state which has been facing a lot of landslide as shown in Table 1.1. Most of landslide studies which used GIS in Pahang focused on Cameron Highland as in Pradhan 2010; Pradhan and Lee, 2010; Pradhan and Youssef, 2009; Pradhan et al., 2008; Mansor et al., 2007; Ghahgah et al., 2009; Omar et al, 2004; Ramli et al., 2005 and Mansor et al., 2004. Very few studies were carried out in other locations in Pahang such as Fraser's Hill (Shafri et al., 2010), Genting Sempah (Ahmad et al., 2004) and Karak highway (Omar et al., 2007).

Based on the above previous studies, there are few studies on landslide which used GIS. Hence the researcher has chosen Karak highway because there is little information and reporting on this area even through it is considered a very dangerous area. Moreover, the previous studies which were carried out in Pahang, have low probability to landslide in most of their study area and also high probability to landslide in few places. In addition, the previous studies focused on ECFL where only the surface geology was considered, but not the subsurface geology. One can conclude from most of the previous studies that the researchers only considered the elevation (+z) where the produced image was 2.5D. These studies did not consider the depth below the surface.

Table 2.2: An overview of the varies studies on landslide using GIS in Pahang state

The source	Study area	sources of data	Causal factors of landslide	Analysis techniques	Type of results	Results
Ahmad et al., 2004	Genting Sempah	TM, Aerial photo	Surface temperature, land use, slope angle, groundwater	Simple algorithm, Spatial analysis	Risk image	No evidence to prove that these areas are risky.
Mansor et al., 2004	Cameron Highland	Remote sensing, Site observation	Weathered ability, homogenous. Slope, aspect, elevation, aperture. Land cover, drainage	Special algorithm	Risk map	Most of the risk image is low and very few places are high
Omar et al., 2004	Cameron Highland	TM, Topographic map	Land use Slope angle Elevation, aspect	Special algorithm	Risk map	Most of the map is low risk and very few places are high
Ramli et al., 2005	Cameron Highland	Topographic map, Geological map, Land cover map	Slope angle, geology Land cove, distance from river and lineaments.	GRASS	Hazard map	Most of the area (93%) is low risk
Mansor et al., 2007	Cameron Highland	Aerial photo, Site observation, Topographic map, Geological map, TM, SPOT	Slope angle, aspect, curvature, drainage, geology, lineaments, land use, soil, vegetation, precipitation	ANNM	Hazard map	Most of the area is low risk. The higher is 20%
Omar et al., 2007	**Karak highway**	TM, Radar sat SAR	Soil cohesion Internal friction Soil unit weight Slope angle	Infinite slope stability Factor of safety	Susceptibility map	Most of the low risk
Pradhan et al., 2008	Cameron Highland	Aerial photo, Site observation, Topographic map, Geological map, TM, SPOT	Slope angle, aspect, curvature, drainage, geology, lineament, land use, soil, vegetation, precipitation	Logistic regression	Hazard map	Most of the area is low risk.
Gahgah et al., 2009	Cameron Highland	TM, Site observation, Aerial photo	Lineament, Soil, geology, drainage,rainfall, angle, elevation	Heuristic technique	Hazard map	Very low:17.27 Low: 39.35 Medium: 25.1 High: 15.35 Very high: 2.93
Pradhan and Youssef, 2009	Cameron Highland	Aerial photo, Site observation, Topographic map, Geological map, TM, SPOT	Slope angle, aspect, curvature, drainage, geology, lineament, land use, soil, vegetation, precipitation	Logistic regression, frequency ratio	Hazard map	Most of the area is low risk.
Pradhan and Lee, 2010	Cameron Highland	Aerial photo, Site observation, Topographic map, Geological map, TM, SPOT	Slope angle, aspect, curvature, drainage, geology, lineament, land use, soil, vegetation, precipitation	ANNM	Susceptibility map	Most of the area is low risk.
Pradhan, 2010	Cameron Highland , Selangor, Penang	Aerial photo, Site observation, Topographic map, Geological map, TM, SPOT	Slope angle, aspect, curvature, drainage, geology, lineament, land use, soil, vegetation, precipitation	Multivariate logistic regression	Hazard map	Most of the area is low risk.
Shafri et al., 2010	Fraser's Hill	Site observation, Satellite image,	Vegetation, land cover, precipitation, geology	Heuristic technique	Susceptibility map	Most of the area is low risk.
This current study	Karak Highway	Field work (Theodolite, GPS, Resistivity imaging)	Angle, aspect, elevation, land cover, geology, groundwater, water movement, sliding subsurface	Simple algorithm	Probability map	Most of the area is low risk.