VEGETATION ANOMALY INDEX FROM REMOTE SENSING FOR LANDSLIDE ACTIVITIES MAPPING

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Specially dedicated to *Ayah, Mama and Adik, and U, Mohd Asraff Asmadi*

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Thank you, Allah for everything you’ve given to me and taken from me. I’m sure there’s a great reason behind every single thing You do.

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ABSTRACT

Remote sensing has long been used for landslide mapping and monitoring. Landslide activity is one of the important parameters for landslide inventory and it can be strongly related to vegetation anomalies. A high-density airborne Light Detection and Ranging (LiDAR), aerial photo and satellite imagery were captured over the landslide prone area along Sungai Mesilau, Kundasang, Sabah. This study aims to evaluate landslide inventory, generate vegetation properties and vegetation anomalies using high density airborne LiDAR and other remotely sensed data. There are four research objectives. The first objective is to delineate and characterize landslide inventory based on different landslide type, depth and activity. Second objective is to generate vegetation properties and vegetation anomalies using high density airborne LiDAR and other remotely sensed data. The third objective is to generate landslide activity probability map and the fourth objective is to analyze the capability of vegetation anomalies in characterizing landslide activity for different landslide type and depth. Landslide identification has been conducted using orthophoto and three terrain-derived raster layers. Series of landslide validations were conducted to ensure the certainty level of the delineated landslide. These validation processes were conducted by visiting the landslide areas and based on expert-knowledge. Remote sensing data have been used in characterizing vegetation into several classes of height, density, types and structures in the study area. There were 13 vegetation anomalies derived from remotely sensed data. To produce a probability map for landslide activity, different combinations of landslide type, activity and depth have been used as the input data together with the vegetation anomalies raster layer. The use of statistical model was based-on data-driven approach which focusing on the bivariate model (hazard index). The capabilities of landslide probability maps are later evaluated using Receiver Operating Characteristic (ROC) curve together with success and prediction rate values. There were 14 scenarios have been modeled in this study by focusing on two landslide depths, three main landslide types, and three landslide activities. All scenarios show that more than 65% of the landslides are captured within 70% of the probability model which indicates high model efficiency. The predictive model rate curve also shows that more than 45% of the independent landslides can be predicted within 30% of the probability model. Indices of vegetation for 13 vegetation anomalies layers were tabulated by conducting statistical analysis on the weightage for each of the model. This study introduces new method that utilizes vegetation anomalies extracted using remote sensing data as a bio-indicator for landslide activity analysis and mapping. In conclusion, this integrated disaster study provides a better understanding into the utilization of advanced remote sensing data for extracting and characterizing vegetation anomalies induced by hillslope geomorphology processes.

ABSTRAK

Penderiaan jarak jauh telah lama digunakan untuk pemetaan dan pemantauan tanah runtuh. Aktiviti gelongsoran tanah adalah salah satu parameter penting bagi inventori tanah runtuh dan ia boleh dikait rapat dengan anomali tumbuhan. Data lidar berketumpatan tinggi, foto udara dan imej satelit dicerap di kawasan tanah runtuh di sepanjang Sungai Mesilau, Kundasang, Sabah. Kajian ini bertujuan untuk menilai inventori tanah runtuh, menjana sifat dan anomali tumbuhan dengan menggunakan data LiDAR dan lain-lain data penderiaan jarak jauh. Terdapat empat objektif bagi kajian ini. Objektif pertama adalah untuk menggambarkan dan mencirikan inventori tanah runtuh berdasarkan jenis, kedalaman dan aktiviti. Objektif kedua ialah untuk menjana ciri dan anomali tumbuhan menggunakan data LiDAR dan lain-lain data penderiaan jarak jauh. Objektif ketiga, adalah untuk menjana peta kebarangkalian aktiviti gelongsoran dan objektif keempat iaitu menganalisa keupayaan anomali tumbuhan dalam mencirikan aktiviti gelongsoran bagi jenis tanah runtuh yang berlainan jenis dan kedalaman. Pengenalpastian tanah runtuh dilakukan dengan menggunakan foto udara dan tiga lapisan raster yang dihasilkan daripada bentuk permukaan bumi. Satu siri pengesahan tanah runtuh telah dilakukan untuk memastikan tahap kepastian tanah runtuh yang dikenalpasti. Proses pengesahan ini dilakukan dengan melawat kawasan tanah runtuh dan berdasarkan pengetahuan pakar. Data penderiaan jarak jauh telah memberikan kefahaman yang lebih baik dalam pencirian tumbuhan mengikut beberapa kelas ketinggian, ketumpatan, jenis dan struktur di kawasan kajian. Terdapat 13 anomali tumbuhan diperolehi dari data penderiaan jarak jauh. Bagi menghasilkan peta kebarangkalian aktiviti tanah runtuh, beberapa gabungan jenis tanah runtuh terpilih, aktiviti dan kedalaman telah digunakan sebagai data bersama dengan lapisan raster anomali tumbuhan. Model statistik yang digunakan adalah berasaskan data yang memfokuskan pada model bivariate (indeks bahaya). Keupayaan model ini seterusnya dinilai menggunakan lengkungan statistik operasi penerima dengan menyatakan kadar keberjayaan dan ramalan. Terdapat 14 senario dimodelkan dalam kajian ini dengan menumpukan pada dua kedalaman tanah longsor, tiga jenis tanah longsor utama, dan tiga aktiviti tanah runtuh. Semua senario menunjukkan bahawa lebih daripada 65% tanah runtuh dikenalpasti dalam 70% model kebarangkalian yang menunjukkan kecekapan model yang tinggi. Kadar ramalan juga menunjukkan bahawa lebih daripada 45% daripada tanah runtuh bebas boleh diramalkan dalam 30% model kebarangkalian. Indeks bagi 13 lapis anomali tumbuhan dinilai dengan menjalankan analisis statistik pada pemberat bagi setiap model. Kajian ini memperkenalkan satu kaedah baru menggunakan anomali tumbuhan dari data penderiaan jarak jauh sebagai penunjuk bio bagi menganalisis aktiviti tanah runtuh dan pemetaan Kesimpulannya, kajian bencana bersepadu ini memberikan pemahaman yang lebih baik kepada penggunaan data penderiaan jarak jauh termasuk mengekstrak dan mencirikan anomali tumbuhan di kawasan terjadinya proses geomorfologi bukit.

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ALS	-	Airborne Laser Scanning
BRSO	-	Borneo Rectified Skew Orthomorphic
CHM	-	Canopy Height Model
DBH	-	Diameter At Breast Height
DGPS	-	Differential Global Positioning System
DHP	-	Density Of High Points
DSM	-	Digital Surface Model
DTM	-	Digital Terrain Model
DVI	-	Difference Vegetation Index
GDVI	-	Green Difference Vegetation Index
GNDVI	-	Green Normalized Vegetation Index
GNSS	-	Global Navigation And Satellite System
IDW	-	Inverse Distance Method
IMU	-	Inertial Measurement Unit
INSAR	-	Interferometric Synthetic Aperture Radar
LIDAR	-	Light Detection And Ranging
LULC	-	Land Use And Land Cover
NDSM	-	Normalized Digital Surface Model
NDVI	-	Normalized Difference Vegetation Index
NIR	-	Near Infrared
NKVE	-	New Klang Valley Expressway
OSAVI	-	Optimized Soil Adjusted Vegetation Index
SAVI	-	Soil Adjusted Vegetation Index
TLS		Terrestrial Laser Scanner
USGS	-	United State Geological Survey

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Landslides are the main geological hazards in many mountainous areas, where they occur regularly and rapidly at the same area in spatio-temporal way (Lee, 2007a, McKean and Roering, 2004), causing major material loss, environmental damage and loss of life. Landslide occurrences are regularly triggered by several natural phenomena, such as heavy rainfall and earthquake. A landslide will be called rainfall-induced rainfall and earthquake induced landslide, respectively, which are hard to predict unless we have enough data of seismic activity and rainfall distribution (Glenn *et al.*, 2006, Haneberg *et al.*, 2009, Schulz, 2007).

It is essential to obtain an accurate landslide inventory analysis to make sure the accuracy of landslide susceptibility and risk analysis can be maintained (Akgun *et al.*, 2008, Ardizzone *et al.*, 2007, Bai *et al.*, 2010, Guzzetti *et al.*, 2012, Constantin *et al.*, 2011). Figure 1.1 shows the global landslide mortality risk distribution from 1981 to 2000. Figure 1.2 shows the distribution of non-seismic landslide events across the globe that involved fatalities. Landslide incidences in Malaysia are shown in Figure 1.3.

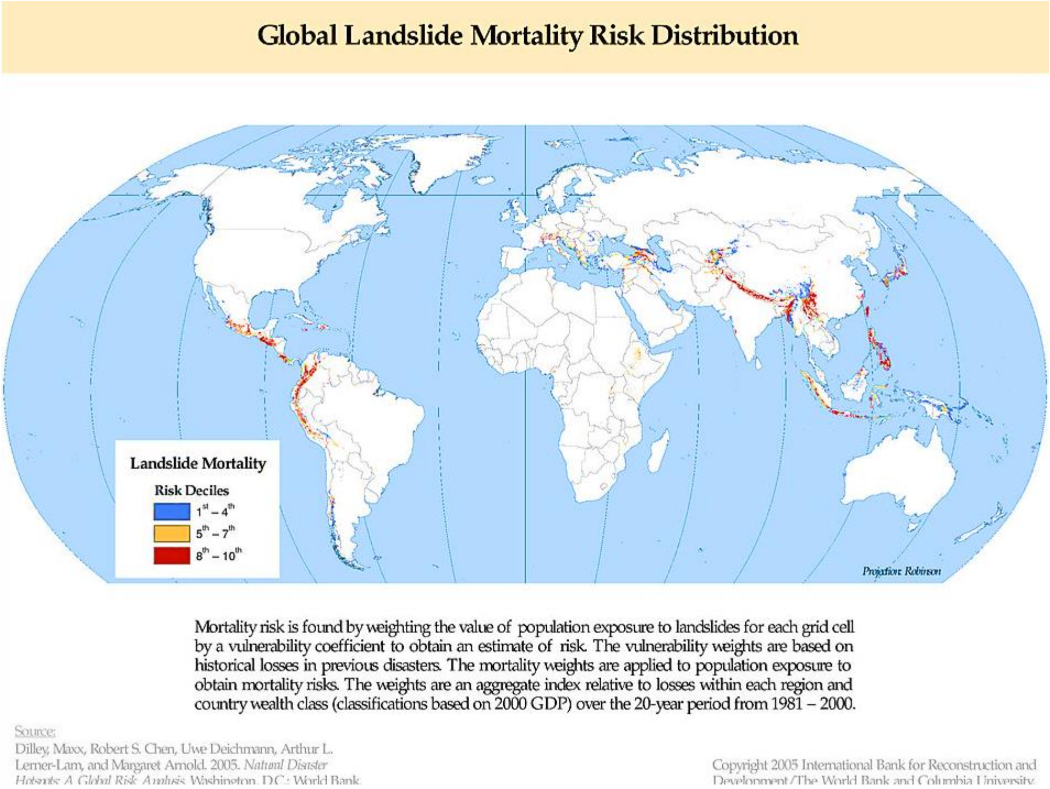

Figure 1.1: Global Mortality Risk Distribution Map (NASA Socioeconomic Data And Applications Center (SEDAC), 2005).

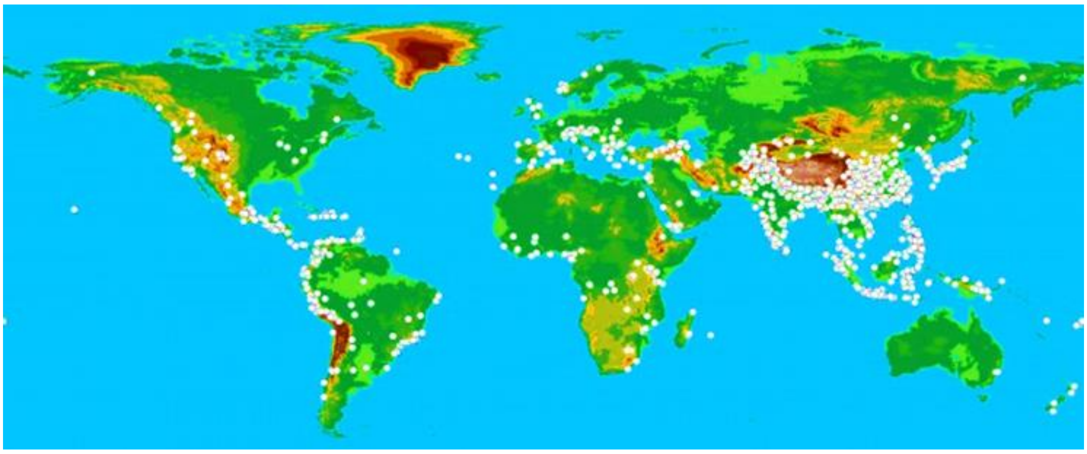

Figure 1.2: Distribution of non-seismic landslide event around the world with fatalities involved (Petley, 2012).

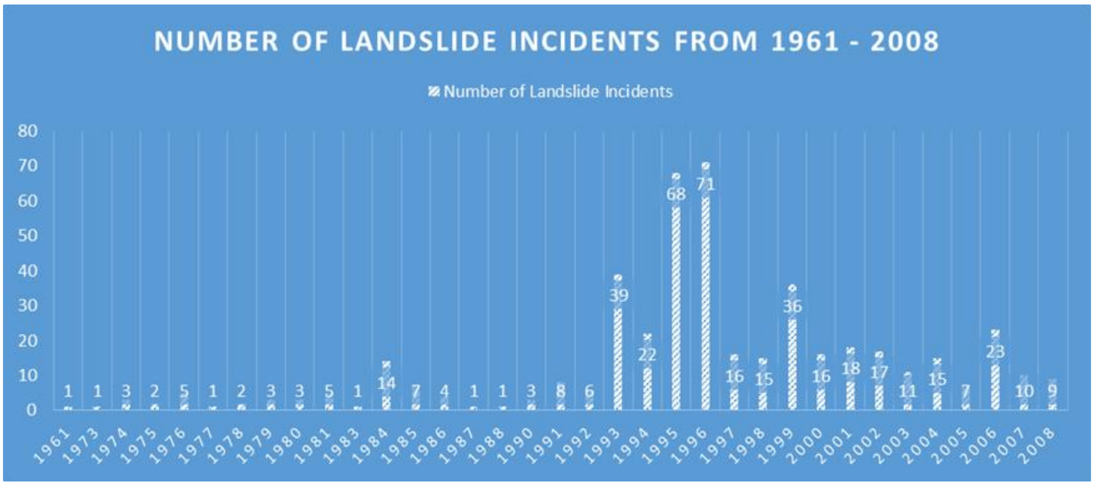

Figure 1.1: No. of landslide incidents in Malaysia from 1961 to 2008 (Gue and Wong, 2012).

Landslide in Malaysia had caused huge amount of damages in terms of property, life and economic losses. It mostly affected mountainous and low stability areas due to rapid movement of soil. Due to modern development in Malaysia since 1980s, only a few low-lying and stable areas remain that are still available for residential or commercial development. This had put the life and property of people in risk of death and destruction. As the result of such environment, the development of highland or hilly terrain has increased to meet the demand for infrastructure, particularly in areas adjacent to high density cities. Such a situation has increased the probability of losses due to landslide phenomenon (Jamaludin and Hussein, 2010). Figure 1.4 shows the landslide occurrence in Malaysia which include the fatalities. Figure 1.4 also implies that it is a must to recognize, analyze and predict the landslide occurrences to make sure proper mitigation can be carried out to prevent severe damage caused by landslide activity.

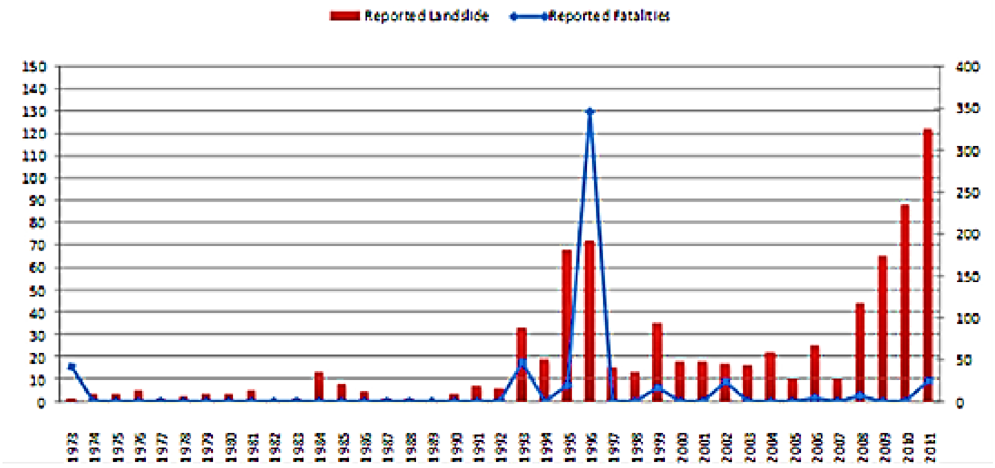

Figure 1.2: Annual landslides and fatalities in Malaysia (Abdullah, 2013).

For the last decade, method of detecting landslide under forested area has been dependent on geological, geomorphological feature and drainage pattern of the area (Glenn *et al.*, 2006, Hutchinson, 2009, McKean and Roering, 2004). Although this method would give a reliable landslide area, using tree condition as an indicator of landslide activity can lead to new methods of predicting and providing enough details about landslide activity (Razak *et al.*, 2013a, Razak *et al.*, 2013c, Harker, 1996). Trees play significant role in environment, for example oxygen source, prevention of climate change, habitat of flora and fauna, bio-pharmaceutical, tourism and so on. It can also be used to analyze the activity of the landslide by observing the pattern and irregularities of the vegetation characteristics.

Remote sensing techniques for landslides investigations have undergone rapid development over the past few decades. The possibility of acquiring 3D information of the terrain with high accuracy and high spatial resolution is opening new ways of investigating the landslide phenomena. Recent advances in sensor electronics and data treatment make these techniques more affordable. The two major remote sensing techniques that are exponentially developing in landslide investigation are interferometric synthetic aperture radar (InSAR) , and light detection and ranging (LIDAR) (Jaboyedoff *et al.*, 2012). With the current remote sensing technology such as laser scanning, it had become easier for the authorities or stakeholders to determine the landslide area prior to the event.

LiDAR data is currently being used for the delineation and analysis of landslide polygons that can be interpreted based on colour composite, hillshade, topographic openness or digital terrain model raster layer (Razak, 2014). There are still lack of landslide activity analysis that rely solely on the bio-indicator that had been derived from remotely-sensed data. There are many advantages of using topographic laser scanning data in detecting and predicting landslide, i.e.; it is a very accurate technique requiring less labor needed, and the ability to cover large areas, including areas previously deemed inaccessible. In addition, it has been acknowledged for its contribution in developing and implementing forest inventory and monitoring program. This method allowed extraction of several vegetation anomalies from LiDAR data, which include tree height, abrupt change in tree height, crown width, vegetation density, different vegetation type and many more.

This research aims in estimating and mapping different landslide type, depth and activity probability area together with producing vegetation anomaly indices along a tectonically active region, Kundasang. Vegetation anomaly maps used in generating probability maps were derived from both LiDAR and satellite image data. It is important toanalyze the vegetation pattern on each landslide type, depth and activityas it gave us a newunderstanding about how vegetation characteristics differed from one landslide type, depth and activity to another. Furthermore, the output from this research can be used in future landslide susceptibility analysis as a supporting detail in characterizing landslide polygons based on their current vegetation characteristics. Also, current global and national projects, for example, Sendai Framework, Peta Bahaya Risiko Cerun, National Slope Master Plan etc. can fully-utilize the result from this research to suit the purpose of their projects.

1.2 Problem Statement

Kundasang area is located on a large-scale landslide complex known as "Kundasang Landslide Complex" that consists of number of km-scale, active, landslide systems. This area also had been identified as the first natural large-scale landslide phenomena ever reported in Malaysia (Jamaluddin, 2015). It is worsened by the landslide that struck Ranau on June 5th, 2015 with a moment magnitude of 6.0, which lasted for 30 seconds. Landslide inventory maps had been produced for a various reasons (Brabb, 1991), i.e.; (i) documenting the landslide phenomena in the areas varying from small to large watersheds (Cardinali *et al.*, 2001), (ii) documenting landslide occurrences on region, state and national level (Brabb and Pampeyan, 1972, Antonini *et al.*, 1993, Duman *et al.*, 2005, Cardinali *et al.*, 1990), (iii) as a precursory detail in producing landslide susceptibility, hazard and risk assessment (Van Westen *et al.*, 2006), and (iv) analyzing the landslide distribution, types and patterns in relation to drainage, morphological and vegetation characteristics (Guzzetti *et al.*, 1996, Soeters and Van Westen, 1996).

Conventionally, landslide inventory mapping had undergone the process of visual interpretation based on stereoscopic images and verified with field verification. Next, image analysis by using aerial photographs, satellite and radar images had successfully emerged as it is efficiently capable in covering large areas; however, it is less accurate in mapping the landslide in forested terrain (Will and McCrink, 2002, Van *et al.*, 2007). This is because reflectance spectra of vegetation conceal the spectra of underlying soils and rocks and vegetation, which is the most critical barrier for geologic identification and mapping (Arie Naftali Hawu Hede *et al.*, 2015). Despite its ability in concealing the below canopy data, this reason can be used to utilize vegetation in generating bio-indicators of landslide activity as trees can be a good indicator in recognizing local deformation and different episodes of soil displacement (Mario Parise, 2003).

However, most of the research had not focusedon vegetation anomalies due to the low accuracy and density of point clouds and lack of field data validation (Razak *et al.*, 2013c). This has caused many researchers to neglect the LiDAR point clouds which represent the vegetation structures for landslide recognition (Mackey and Roering, 2011). Disrupted vegetation is often used as an indicator for landslide activity in forested region and to relate tree anomalies to landslides occurrence and its activity, the identification of disrupted trees in forested landslide is crucial (Razak *et al.*, 2013a).

Previous studies have shown that the conventional method of producing landslide inventory analysis is undoubtedly time consuming, dangerous and expensive (Guzzetti *et al.*, 2012). Using this study, problems arising from implementing conventional methods can be kept to a minimum, as utilizing remote sensing technology enables the researcher to obtain vegetation anomalies as a bio-indicator of landslide activity mapping and analysis. In Malaysia,landslide analysistends to have frequent site visit, and real-time monitoring of the deformation that cancause lots of budget to be put on, and potential hazard to property and life once the landslide struck. Thus, by using the result of this study, itcan contribute to the thorough analysis of vegetation anomalies suitability as a bio-indicator to landslide activity analysis. In addition, this studies also capable in defining the method to produce vegetation anomalies from remote sensing data and analyze the performance of geospatial-based approach.

This research used high density point clouds, high resolution orthophoto and recent satellite image. By using this dataset, a framework to define different landslide activity probability map for different type and depth of landslide based on vegetation anomalies will be carried out. From the probability map, a matrices for each of the scenarios has been tabulated to identify the most and the least significance vegetation anomaly characteristics in each landslide scenario. A vegetation anomaly characteristics library has been developed as a guideline to landslide activity monitoring and mapping in Malaysia, and Kundasang in particular. This is because, despite its use as one of the slope strengthening methods, it can be used as a bio-indicator of defining landslides in different type, depth and activity. There were only a few studies about this in Malaysia and most of the studies were using spectral reflectance to indicate the vegetation cover characteristics (Lee, 2007b, Lee and Abdul Talib, 2005, Jaewon *et al.*, 2012, Pradhan *et al.*, 2010).

1.3 Research Objectives

The aim of this study is to map and analyze landslide activity based on vegetation anomalies from remote sensing data. This aim is supported by the following specific objectives:

1. To delineate and characterize landslide inventory based on different landslide type, depth and activity.
2. To generate vegetation properties and vegetation anomalies using high density airborne LiDAR and other remotely sensed data
3. To generate landslide activity probability map for different landslide type and depth occurred in tectonically active region.
4. To analyze the capability of vegetation anomalies in characterizing landslide activity for different landslide type and depth.

1.4 Research Questions

1. To delineate and characterize landslide inventory based on different landslide type, depth and activity.

    a. What are the morphological layers that can be used for landslide delineation?

    b. How can landslide properties (type, depth, activity) be characterized using remote sensing data?

    c. How many landslide types, depths and activities can be derived from the landslide inventory polygons?

    d. What is the quality of the delineated landslide using LiDAR data?

2. To generate vegetation properties and vegetation anomalies using remotely sensed data.

    a. How many vegetation anomalies have been derived from remote sensing data?

    b. Do the vegetation anomalies extracted portray the true state of the vegetation on site?

    c. Do each of the vegetation indices generated from satellite image have their own capabilities in differentiating the landslide area and non-landslide area?

3. To generate landslide activity probability map for different landslide type and depth occurred in tectonically active region.

    a. What are the parametersused to create the probability map?

    b. Can every landslide type, depth and activity be used to generate probability map?

    c. What is the highest Success Rate and Prediction Rate value among the scenarios tested?

4. To analyze the capability of vegetation anomalies in characterizing landslide activity for different landslide type and depth.

    a. What are the common vegetation anomalies of active landslide?

    b. What are the common vegetation anomalies of inactive landslide i.e. dormant and relict?

1.5 Significance of Study

According to the research, landslide source areas occurred mostly in "no vegetation" zones (Reichenbach *et al.*, 2014). While vegetation growth may be an indicator of monitoring ground stability, soil moisture conditions (which can change dramatically over short periods of time) may conceal the brightness properties of the underlying ground, especially on satellite images (Hervás *et al.*, 2003). For detecting landside in forested area, the best results are obtained in zones with a closed vegetation cover and affected by landslides, as in this research study area, where there is a strong contrast between mobilized zones, where loss of vegetation cover and non-mobilized zones that conserve the vegetation cover can be clearly seen (Fernández *et al.*, 2008). In addition, vegetation indices are very useful in order to identify landslide scarps and body, especially in zones with a dense vegetation cover which enhance the landslide boundary (Chang and Liu, 2004).

This study will promote remotely sensed data as a viable option for a fast and accurate method for generating landslide activity analysis by using vegetation as an indicator. Local agencies such as Department of Mineral and Geoscience, which is actively involved with landslide inventory in Peninsular Malaysia and Borneo region, can be exposed to this technology and utilize it in landslide inventory analysis. Public Works Department and Forest Research Institute Malaysia can also be part of the organization which use this approach to gain understanding of how vegetation react on different landslide activity, type and depth. Data of vegetation anomalies can be used later to assess, predict and mitigate the landside state by monitoring the changes of vegetation pattern on the landslides area. In disaster management workflow, this study can be used as preparedness and mitigation measure to avoid any casualties or damages when landslide happen (Stojic, 2013). Besides that, the vegetation anomalies can also be used as the input features to generate landslide susceptibility, hazard and risk analysis. This study is also capable in provingremotely sensed data can be used effectively in monitoringand analyzing growth andactivity of the landslide features; dormant, active or relict. The change in vegetation pattern from one landslide activity to another can. This technology will provide a natural-based indicator in landslide activity analysis. Therefore, the output of this study, which is the vegetation anomalyindices in the activity level using remotely sensed technology, can be seen as a future potential in assisting the decision of landslide activity analysis in Malaysia.

1.6 Scope of Study

This study is conducted along debris flow channel located in Kundasang, which is one of the districts in Sabah, Malaysia. Primary data collected for this study is high density of airborne laser scanning data that covered the whole debris flow channel from Mount Kinabalu Golf Club to Ranau district. This point cloud data covered ±17 km^2 which includes landslide area with various sizes and types of dominant vegetation. However, only 321 landslide polygons were used in this study due to restricted data,hardware limitation and time constraint.

This study is still elusive in tropical rainforest where most of the study of analyzing landslides activity was solely based on morphological features and drainage pattern. The point clouds were projected to ground coordinate system with the average point spacing of ±0.3 m. There are 25 tiles with average size 1 km^2 per tile. Each tile was located along Sungai Mesilau area where debris flow events occurred. Vegetation extractions were done according to tile due to high density of point clouds with average of ±100,000,000 number of points for each tile. Dealing with high density of point clouds required advanced hardware.

Previous studieshave shown that point cloud generated from airborne laser scanning is capable of extracting several vegetation anomalies; vegetation height, vegetation gap, vegetation peak value, vegetation type, vegetation density, percentage of vegetation covered, vegetation distribution etc. However, these studies were only focusing on measuring the crucial parameters for landslide activity which can differentiate the vegetation characteristics on the landslide area and non-landslide area based on the literature study. The parameters used include irregularity in vegetation height, canopy gap, vegetation density of 4 vegetation layers, vegetation type distribution. Using satellite image QuickBird satellite image, with spatial resolution 2.4m, Normalized Difference Vegetation Index (NDVI, Difference Vegetation Index (DVI), Green Difference Vegetation Index (GDVI), Green Normalized Vegetation Index (GNDVI), Soil Adjusted Vegetation Index (SAVI) and Optimized Soil Adjusted Vegetation Index (OSAVI) value were calculated. Then, different landslide activity probability map was produced using Hazard Index algorithm together with the aforementioned parameters. The generated probability map come together with weightage for each vegetation anomaly. Then, the weightage had been used to produce vegetation anomalies indices which show the rank from most important vegetation anomaly to the least important vegetation anomaly.

1.7 Description of Study Area

Figure 1.5 shows the study area map along debris flow area Kundasang with focus on source zone, transport zone and deposition zone. Kundasang area is located in the district of Ranau in Sabah, Malaysia that lies along the bank of Kundasang Valley.

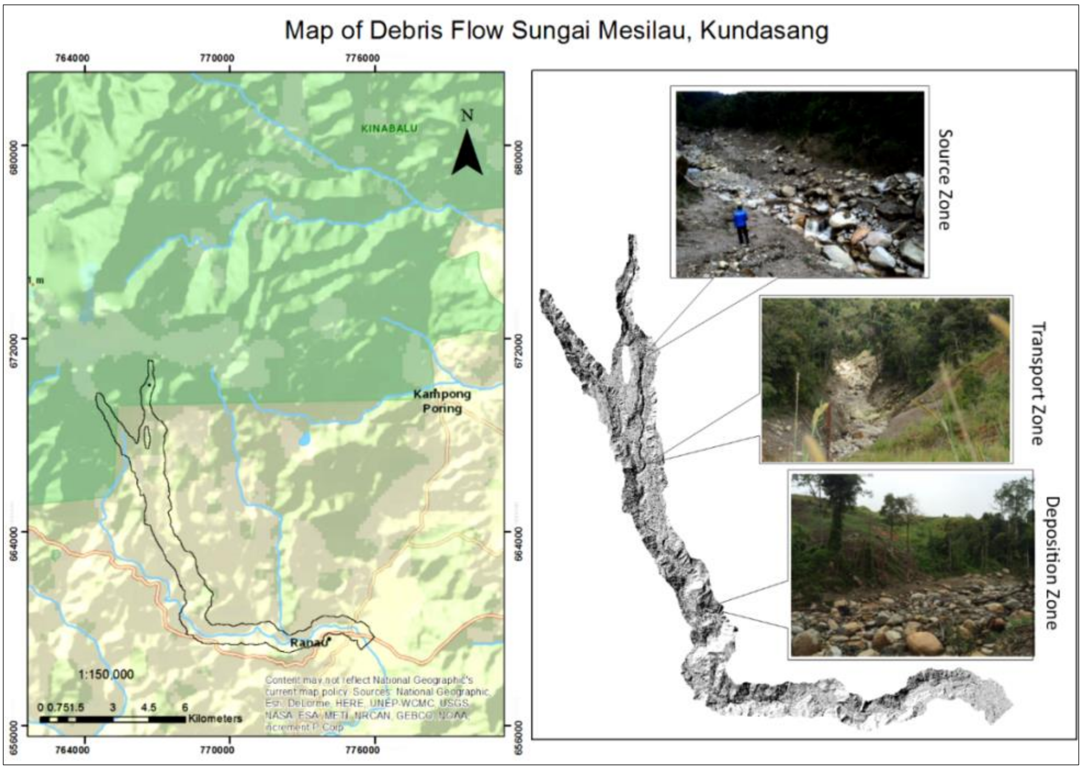

Figure 1.3: Study area map of debris flow along Sungai Mesilau, Kundasang

As of 2010, the total population of Kundasang area is 5008 within the area of Ranau district, which is 3555.51 km^2. With an elevation of about 1200 to 1600 metres above sea level, it is one of the coolest places in Sabah with temperatures dropping to 13ºC at night (Wikitravel, 2015, BeautifulKK, 2010). Kundasang has a tropical climate. There are large amount of rainfall all year, even during the driest month (ClimateData.ORG, 2015). The average annual rainfall is ±2189 mm.

Kundasang area consists of 3 types of lithology; Pinasouk gravel, Trusmadi formation and Crocker formation. On 5 June, an earthquake measuring 6.0 Mw occurred in Sabah that had triggered the debris flow which caused the disruption of roads, houses and the vegetation along the channel (Tongkul, 2016). It is said that the earthquake was caused by movement on a SW-NE trending normal fault and the epicenter was near Mount Kinabalu. The shaking caused massive landslides around the mountain (Tongkul, 2015). Rocks located beneath Kundasang vary in age and type, which are the rock starting from Paleocene-Eocene rocks to alluvial rock. Three formations are present and include Trusmadi Formation, Crocker Formation and Quaternary sediment (Tongkul, 1987).Mensaban fault zone is located on the eastern side of Kundasang area which intersects with Crocker fault. The mass movements in Kundasang area can be the result of active movement in Crocker and Mensaban fault zones.

Based on Figure 1.6, it is clearly seen that Kundasang experiences heavy rainfall almost every month. This heavy rainfall is capable of inducing landslides in Kundasang area. On 15th and 16th July 2013, heavy rainfall had triggered landslides in Kampung Mesilau that killed one resident and damaged concrete bridge. Heavy rainfall on 10th April 2011 triggered landslide in Kampung Mohiboyan and the landslide was worsened by the eroded riverbank. The landslide event damaged 19 houses and villagers were evacuated. Landslides in Kampung Pinausok were also triggered by heavy rainfall that had caused electric power outage and damaged houses.

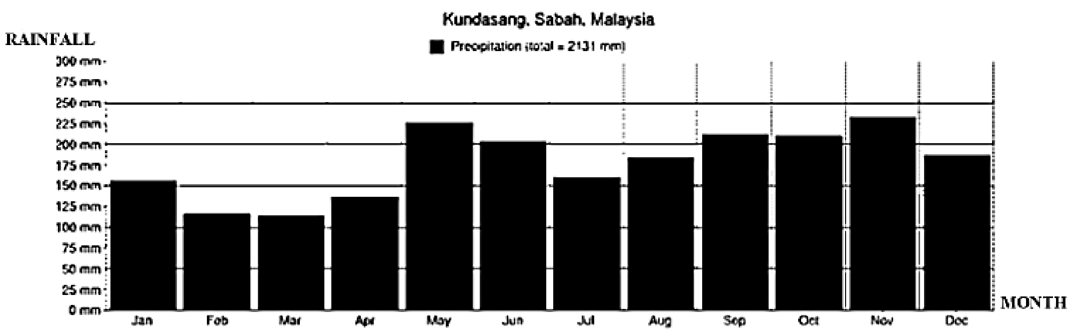

Figure 1.4: Rainfall distribution in Kundasang, Sabah (SamSamWater Climate Tool., 2016)

Previous research has stated that in Kundasang, there have been more than 20 landslide occurrences from 1996 to 2015 (UTM PBRC, 2016). Figure 1.7 shows the distribution of landslide for the past 20 years in Kundasang district.

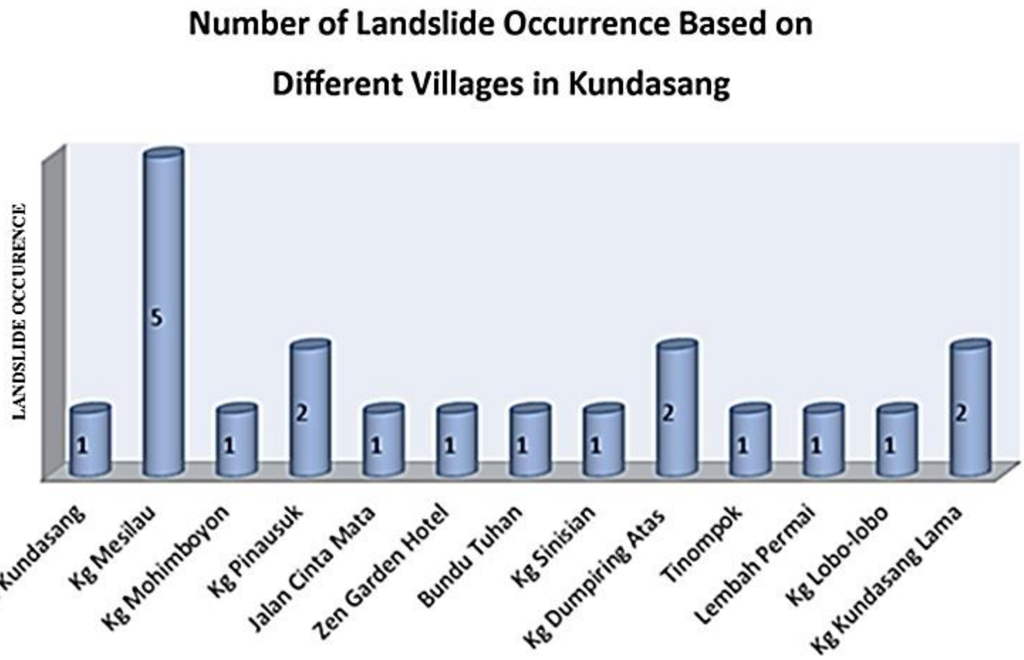

Figure 1.5: Landslide occurrence in Kundasang district based on area and villages.

The movement of two large-scale landslide systems had caused continuous landslide episodes at SMK Kundasang with creeping movements on the landslide area. The movement had caused severe damages on roads, bridges and buildings. Landslide at Jalan Cinta Mata was caused by the post-glacial deposit movement and damaged road pavement, drainage and distressed water pump house.

Figure 1.8 shows infrastructure damaged due to debris flow in Sg Mesilau channel. Along Sungai Mesilau channel, at least 5 events were recorded from 2008 to 2015. Most of the landslides occurred in this area due to heavy rainfall and the recent landslide that occurred was due to earthquake that occurred in Sabah, which lasted for 30 seconds. The earthquake was the strongest to affect Malaysia since 1976 (The Borneo Post, 2015, Tongkul, 2016).

Figure 1.6: (a) Mud floods triggered by heavy rainfall in Kampung (Daily Express., 2015) (b)search and rescue operation (c) Damaged house in debris-flow channel of Sungai Mesilau (Ismayatim, 2015).

Figure 1.7: Vegetation distribution on the landslide body of Sungai Mesilau.

Figure 1.9 shows the landslide on the Sungai Mesilau channel. This landslide began in 2009 (Google Earth Pro, 2009). From the landslide area, it is shown that the landslide body is mainly covered by shrubs, which indicated the presence of water and active movement of the terrain (A.B. Orodho, 2006). The figure shows the current image of one of the active landslides that caused damage to the roads, agricultural terraces and residential area. This landslide was characterized as one of the largest landslides to have occurred along the Sungai Mesilau area

1.8 Thesis Structure

The overall structure of this thesis is shown in Figure 1.10. The first chapter gives an overview of the study, background of study, a statement of problem, aim, objectives, significance of study, scope of the study as well as explanation of the study area.

Chapter two describes a literature review focusing on topics and fields that are related to this study. Eight (8) main subtopics have been created which include; natural disaster, landslide processes and analysis, triggering factor of landslide, type of landslides, landslide inventory mapping and analysis, airborne laser scanning and vegetation anomalies as bio-indicator for landslide analysis The first subtopic contains detailed explanation of several natural disasters frequently occurred in Malaysia and its example. The second subtopic covers the detailed explanation of landslide process and analysis such as landslide figure and features Next subtopic continues with an explanation of common triggering factor. Next, several type of landslide types were discussed and illustrated in the next subtopic. Landslide depth; deep-seated and shallow landslide were explained in the next subtopics. In the sixth subtopics, the process of landslide inventory mapping and analysis were explained by visualizing the different characteristics of landslide in different type and activity. Next topic explained about airborne laser scanning capability in capturing details in forested area. Last topic discussed about the method can be used in analysing different bio-indicators reside on the landslide area.

Chapter three discusses the approaches used in this study. This chapter started with an explanation of data used in this study. Airborne LiDAR dataset, satellite data, orthophoto and individual tree measurement were acquired to conduct this study. This chapter also explains detailed procedures in evaluating the capabilities of vegetation anomalies in generating vegetation anomalies index for different landslide type, activity and depth. This chapter reveals the procedure and technique used in producing vegetation anomalies based on remote sensing data, landslide activity probability map and vegetation anomalies index.

Chapter four contains analysis of landslide activity probability map and vegetation anomalies index produced. The analysis started with the discussion of the performance of the vegetation anomalies derived from remote sensing data followed by the analysis of probability map. Further assessment is conducted in investigating the output from probability map which is the weightage by using Pair-Wise comparison, vegetation anomalies index were tabulated. The conclusion of the study along with recommendations on future directions for analysing vegetation as a bio-indicator in analysing landslide type and activity by using remote sensing data data are presented in chapter five.

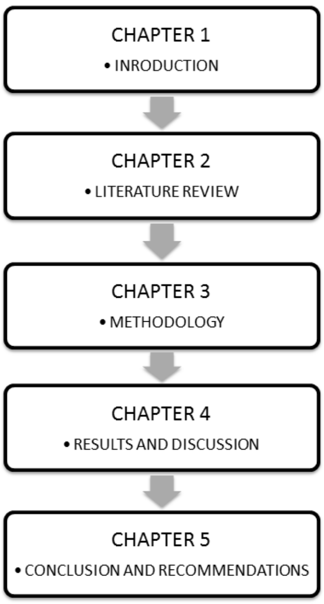

Figure 1.10: The outline of the thesis

APPENDIX C

LIST OF PUBLICATIONS

Ishak, N.I., Razak, K. A., Abd Rahman, M.Z., Latif, Z.A., Asmadi, M.A., (2016). A Bioindicator Assessment for Understanding Geological Hazard in a Tectonically Active Region. In: 4th AUN/SEED-Net Regional Conference On Natural Disaster, 06-07 September 2016, Kuala Lumpur.

Asmadi, M. A., Razak, K. A., Abdul Rahman, M. Z. & Ishak, N. I. Assessing Landslide Spatial Probability in A Scarcely Data Region. 4TH AUN/SEED-NET Regional Conference on Natural Disaster 2016, 06-07 September 2016 Seri Pacific Hotel, Kuala Lumpur, Malaysia.

Ishak, N.I., Asmadi, M.A., Razak, K. A., Abd Rahman, M.Z., (2016). LIDAR-Derived Vegetation Anomalies Induced by Geological Hazards for Activity Analysis. In: RRPG 7th International Conference and Field Study in Malaysia, 15-16 August 2016, Johor Bahru, Johor.

Asmadi, M. A., Ishak, N. I., Razak, K. A. & Abdul Rahman, M. Z. An Improved Method for Characterizing Element-At-Risk for Landslides in Scarcely Data Region. RRPG 7th International Conference and Field Study in Malaysia, 15-16 August 2016 Faculty of Built Environment, Universiti Teknologi Malaysia Johor Bahru, Johor, Malaysia.

Ishak, N.I., Asmadi, M.A., Abd Rahman, M.Z., Razak, K. A., (2015). Extracting Vegetation Anomalies Induced by Landslide. In: Proceeding of the Natural Disaster Seminar 2015, 01-02 December 2015, Kota Kinabalu, Sabah.

Asmadi, M. A., Ishak, N. I., Abdul Rahman, M. Z. & Razak, K. A. Mapping and Characterization of Complex Landslides: Multi-Scale LiDAR Approach. In: Tahir, S., Tongkul, F., Musta, B., Bidin, K., Roslee, R., Pungut, H., Mohd Husin, M. A. Y. & Asis, J., eds. Natural Disaster Seminar 2015, 01-02 December 2015 Kota Kinabalu, Sabah, Malaysia.

Ishak, N.I., Abu Bakar, M.A., Abd Rahman, M.Z., Rasib, A.W., Kanniah, K.D., Shin, A., Razak, K.A., (2015) Estimating Single Tree Stem And Branch Biomass Using Terrestrial Laser Scanning. In: 77:26 (2015) 59– 67| www.jurnalteknologi.utm.my | eISSN 2180–3722 |