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MULTI REMOTE SENSING DATA IN LANDSLIDE DETECTION AND MODELLING

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chair: Associate Professor Biswajeet Pradhan, PhD
Faculty: Engineering

Landslide is one of the disasters that threaten the human's lives and properties in mountainous environments like Malaysia with high elevation and steep terrain. Mitigation and prediction of this phenomenon can be done through the detection of landslide areas. Therefore, an appropriate landslide analysis method is needed in order to map and consequently understand the characteristics of landslide disaster. This reasearch adopted several approaches to investigate, analyze, and assess landsliding in terms of detection, modeling and optimization of the landslides conditioning factors. Remote sensing (RS) and geographic information system (GIS) techniques can support overall landslides management as they can produce rapid data collection and analysis for hazard studies. Therefore, current research is divided into two general aspects.

The first aspect which mainly utilized RS technology is to detect the landslides areas using active microwave sensor of ALOS Palsar sensor. Active radar data have been broadly used for hazard and especially landslides mapping due to its precision in detection of landslide areas. Active remote sensing sensors can provide their own illumination source and they can record data independent of day and night time. Another advantage is their capability to penetrate the cloud cover, making the image recording independent of all weather conditions. Gunung pass area, Malaysia was used as case study to detect the landslides using interferometric synthetic aperture RADAR (InSAR) generated from ALOS-PALSAR repeat pass data. The results were validated using the observed reference point of the landslides and the root mean square error (RMSE) was 0.19. Furthermore, advance 3D processing was performed for measuring the volume of the landslides. Additionaly, the ascending orbit ALOS PALSAR images were acquired from September 2008, January 2009 and December 2009 to generate the DInSAR to model the horizontal movement. Subsequently the displacement measurements of the study site (Gunung Pass) were calculated. The accuracy of the result was evaluated through its comparison with ground truth data using the R2 and RMSE methods. The resulted deformation map showed the landslide locations in the study area from interpretation of the results with 0.84 R2 and 0.151 RMSE. DInSAR

precision was 11.8 cm which proved the efficiency of proposed method in detecting landslides in tropical country like Malaysia.

On the other hand, the data fusion technique are used between LiDAR airborne laser scanner data (high density) and high resolution QuickBird imagery (2.6m spatial resolution) to map the landslide events in Bukit Antarabangsa, Ulu Klang, Malaysia. Wavelet transformer (WT) technique was utilized to perform the fusion. Furthermore, this research employed the Taquchi technique for optimization of the segmentation parameters. Moreover, rule-based technique was performed for object-based classification. Confusion matrix was used to examine the proficiency and reliability of the proposed method. The achieved overall accuracy and kappa coefficient are 90.06% and 0.84 respectively. In addition, the direction of the mass movement was recognized by overlaying the final classification map with LiDAR-derived slope and aspect factors.

The second aspect of the current research is related to the GIS spatial modeling. For all proposed landslide susceptibility methods such as EBF and SVM, landslides inventory was provided and randomly divided into two datasets; 70% for training the models and the remaining 30% was used for validation purpose. Subsequently the related conditioning factors' datasets were constructed and utilized in the analysis. Some researchers assume that as the number of conditioning factors increases, the accuracy of the generated susceptibility map increases. By contrast, other case studies prove that a small number of conditioning factors are sufficient to produce landslide susceptibility maps with a reasonable quality.

This study investigates the effects of conditioning factors on landslide susceptibility mapping. Bukit Antarabangsa, Ulu Klang, Malaysia was selected as the study area, because it is a catchment area with a high potential of landslide occurrence. A spatial database of 31 landslide locations was evaluated to map landslide-susceptible areas. Two datasets of conditioning factors were constructed to be used in the analysis. The first dataset was derived from high-resolution airborne laser scanning data (LiDAR), which contains eight landslide conditioning factors such as altitude, slope, aspect, curvature, stream power index (SPI), topographic wetness index (TWI), topographic roughness index (TRI), and sediment transport index (STI). The second dataset was gathered using the same conditioning factors of the first dataset, but with the addition of other conditioning factors: geological and environmental factors of soil, geology, land use/cover (LULC), distance from river, and distance from road. Two different datasets were constructed to compare the efficiency of one over the other in landslide susceptibility zonation. Three different types of methods were implemented to recognize the importance of different conditioning factors in landslide mapping. weights-of-evidence (WoE) (bivariate statistical analysis (BSA)), logistic regression (LR) (multivariate statistical analysis (MSA)), and data-driven support vector machine (SVM) were used to determine the optimal landslide conditioning factors. The area under curve (AUC) was used to assess the obtained results. The prediction rates of WoE, LR, and SVM obtained from only the LiDAR-derived conditioning factors were 59%, 86%, and 84%, respectively. The prediction rates of the WoE, LR, and SVM obtained from the second dataset were 65%, 66%, and 69%, respectively.

In InSAR process, the displacement map revealed the strong capability of InSAR to recognize and observe the very small movements (in cm) of the earth surface which occurred due to the landslide. Using DInSAR, it could be found that the large areas that have been moved in a very short time. Selection of proper imagery has a significant impact on the final output of the interferometric processing.

On the other hand, data fusion enhanced the visual appearance of the features and created better view of the topography. Therefore, it facilitated and enhanced the rules generation and the classification performance. Although object-oriented classifications require more time for processing compare to the pixel-based methods, they are capable to overcome the drawbacks of the pixel-based methods. The difficulty in obtaining high accuracy is related to the fact that each kind of landslide has its own set of conditioning factors, which should be evaluated separately. The validation result indicated that the landslide susceptibility maps produced in the current research are of good quality. Therefore, planners and governments can use these landslide susceptibility maps to control and prevent future landslides.

The outcomes of this study prove the ability of the proposed and applied algorithm to make valid detections and predictions for landslide phenomena. The results are expected to not only provide a quick yet comprehensive assessment of future landslide hazards and risks but also serve as a guide for land use planners. The applied algorithms and information will add a worthy contribution to the landslide management in the tropical Malaysia.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KEPELBAGAIAN DATA PENDERIAAN JAUH DALAM PENGESANAN DAN PEMODELAN TANAH RUNTUH

Oleh

MUSTAFA NEAMAH JEBUR

Oktober 2015

Pengerusi: Profesor Madya Biswajeet Pradhan, PhD
Fakulti: kejuruteraan

Tanah runtuh merupakan salah satu bencana yang kebanyakannya mengancam kehidupan manusia dan hartanah di persekitaran pergunungan seperti Malaysia dengan ketinggian yang tinggi dan cerun curam. Mitigasi dan ramalan fenomena ini boleh dilakukan melalui pengesanan tanah runtuh kawasan terdedah. Oleh itu kaedah analisis tanah runtuh yang sesuai diperlukan untuk peta dan seterusnya memahami ciri-ciri bencana tanah runtuh. Reasearch ini mengambil beberapa pendekatan untuk menyiasat, menganalisis, dan menilai landsliding dari segi pengesanan, pemodelan dan pengoptimuman faktor penyaman tanah runtuh. Penderiaan jauh (RS) dan sistem maklumat geografi (GIS) teknik boleh menyokong pengurusan tanah runtuh keseluruhan kerana mereka boleh menghasilkan kutipan data yang cepat dan analisis untuk kajian bahaya. Oleh itu, penyelidikan semasa terbahagi kepada dua aspek umum.

Aspek pertama yang terutama digunakan teknologi RS adalah untuk mengesan kawasan-kawasan tanah runtuh menggunakan sensor gelombang mikro aktif sensor alos Palsar. Data radar aktif telah secara meluas digunakan untuk bahaya dan terutama tanah runtuh pemetaan kerana ketepatan dalam mengesan kawasan tanah runtuh. Aktif sensor remote sensing boleh memberikan sumber pencahayaan mereka sendiri dan mereka boleh merakam data bebas daripada hari dan malam. Kelebihan lain adalah keupayaan mereka untuk menembusi litupan awan, menjadikan bebas rakaman imej semua keadaan cuaca. Pas kawasan Gunung, Malaysia telah digunakan untuk mengesan tanah runtuh menggunakan interferometric aperture sintetik RADAR (InSAR) dihasilkan daripada alos-PALSAR data pas berulang. Keputusan telah disahkan menggunakan titik rujukan yang diperhatikan daripada tanah runtuh dan punca min ralat kuasa dua (RMSE) ialah 0.19. Tambahan pula, pemprosesan 3D terlebih dahulu telah dilakukan untuk mengukur isipadu tanah runtuh. Tambahan pula, menaik orbit imej alos PALSAR diperolehi dari bulan September 2008, Januari 2009 dan Disember 2009 untuk menjana DInSAR untuk memodelkan gerakan mendatar. Selepas pengukuran anjakan tapak kajian (Gunung Pass) telah dikira. Ketepatan keputusan yang telah dinilai melalui perbandingan dengan data yang benar tanah

menggunakan R2 dan RMSE kaedah. Menyebabkan ubah bentuk peta menunjukkan lokasi tanah runtuh di kawasan kajian dari tafsiran keputusan dengan 0.84 R2 dan 0,151 RMSE. DInSAR ketepatan adalah 11.8 cm yang terbukti kecekapan kaedah yang dicadangkan dalam mengesan tanah runtuh di negara tropika seperti Malaysia.

Sebaliknya, gabungan data LiDAR data pengimbas laser bawaan udara (kepadatan tinggi) dengan resolusi tinggi imej QuickBird (2.6m resolusi spatial) untuk memetakan peristiwa tanah runtuh di Bukit Antarabangsa, Ulu Klang, Malaysia. Transformer wavelet teknik (WT) telah digunakan untuk melaksanakan gabungan itu. Tambahan pula, kajian ini digunakan teknik Taquchi untuk mengoptimumkan parameter segmentasi. Selain itu, teknik berasaskan peraturan telah dilakukan untuk pengelasan berasaskan objek. Matriks kekeliruan telah digunakan untuk mengkaji kecekapan dan kebolehpercayaan kaedah yang dicadangkan. Ketepatan mencapai keseluruhan dan pekali kappa masing-masing 90,06% dan 0.84. Selain itu, 95,86% dan 95,32% adalah pengeluar dan pengguna diperolehi ketepatan untuk kelas tanah runtuh masing-masing. Di samping itu, arah gerakan rakyat telah diiktiraf oleh melapisi peta klasifikasi akhir dengan LiDAR yang diperolehi cerun dan aspek faktor.

Aspek kedua kajian semasa adalah berkaitan dengan model GIS ruang. Untuk semua kaedah tanah runtuh kecenderungan dicadangkan, inventori tanah runtuh telah disediakan dan secara rawak dibahagikan kepada dua set data; 70% untuk melatih model dan baki 30% itu digunakan untuk tujuan pengesahan. Selepas itu dataset faktor penyaman berkaitan 'telah dibina dan digunakan dalam analisis. Sesetengah penyelidik menganggap ia sebagai bilangan faktor penyaman meningkat, ketepatan kecenderungan yang dijana peta bertambah. Sebaliknya, kajian kes yang lain telah membuktikan bahawa sebilangan kecil faktor penyaman adalah mencukupi untuk menghasilkan peta tanah runtuh kerentanan dengan kualiti yang berpatutan.

Kajian ini mengkaji kesan faktor penyaman pemetaan tanah runtuh kecenderungan. Bukit Antarabangsa, Ulu Klang, Malaysia telah dipilih sebagai kawasan kajian kerana ia merupakan kawasan tadahan yang mempunyai potensi yang tinggi berlakunya tanah runtuh. Pangkalan data spatial 31 lokasi tanah runtuh telah dinilai peta kawasan tanah runtuh mudah. Dua set data faktor penyaman telah dibina untuk digunakan dalam analisis. The dataset pertama telah diperolehi daripada resolusi tinggi laser udara pengimbasan data (LiDAR), yang mengandungi lapan faktor penyaman tanah runtuh seperti ketinggian, cerun, aspek, kelengkungan, indeks kuasa aliran (SPI), indeks kelembapan topografi (TWI), indeks kekasaran topografi (TRI), dan indeks pengangkutan sedimen (STI). The dataset kedua dikumpulkan menggunakan faktor penyaman sama dataset yang pertama, tetapi dengan tambahan faktor penyaman lain: faktor geologi dan alam sekitar tanah, geologi, guna tanah / perlindungan (LULC), jarak dari sungai, dan jarak dari jalan raya. Dua set data yang berbeza telah dibina untuk membandingkan kecekapan berbanding dengan yang lain dalam tanah runtuh kecenderungan penzonan. Tiga kaedah telah dilaksanakan untuk mengenal pasti kepentingan faktor penyaman berbeza dalam pemetaan tanah runtuh. berat-of-bukti (Celakalah) (bivariat analisis statistik (BSA)), regresi logistik (LR) (analisis statistik multivariat (MSA)), dan mesin vektor sokongan yang didorong oleh data (SVM) telah digunakan untuk menentukan faktor-faktor tanah runtuh penyaman optimum . Kawasan di bawah lengkung (AUC) telah digunakan untuk menilai pencapaian yang diperoleh.

Kadar ramalan Celaka, LR, dan SVM diperolehi daripada hanya faktor penyaman LiDAR yang diperolehi adalah 59%, 86%, dan 84% masing-masing. Kadar ramalan Celaka, LR, dan SVM diperolehi daripada dataset yang kedua ialah 65%, 66%, dan 69% masing-masing.

Dalam proses InSAR, Peta anjakan mendedahkan keupayaan yang kuat InSAR untuk mengenali dan memerhati pergerakan yang sangat kecil (dalam cm) permukaan bumi yang berlaku akibat kejadian tanah runtuh itu. Menggunakan DInSAR, ia boleh didapati bahawa kawasan-kawasan yang telah bergerak dalam masa yang singkat. Pemilihan imej yang betul mempunyai kesan signi fi cant kepada pengeluaran fi nal pemprosesan interferometric. Sebahagian besar tanah runtuh berlaku di kawasan yang diliputi oleh tumbuh-tumbuhan dan litupan awan.

Sebaliknya, gabungan data yang dipertingkatkan penampilan visual ciri-ciri dan mencipta pandangan yang lebih baik daripada topografi. Oleh itu, ia memudahkan dan meningkatkan generasi peraturan dan prestasi klasifikasi. Walaupun klasifikasi berasaskan objek memerlukan lebih banyak masa untuk diproses berbanding dengan kaedah yang berpusat pixel-itu, mereka mampu untuk mengatasi kelemahan kaedah berasaskan piksel-the. Kesukaran memperoleh ketepatan yang tinggi adalah berkaitan dengan hakikat bahawa setiap jenis tanah runtuh telah menetapkan sendiri faktor dingin, yang perlu dinilai secara berasingan. Keputusan pengesahan menunjukkan bahawa kejadian tanah runtuh itu peta kecenderungan dihasilkan dalam kajian semasa adalah berkualiti baik. Oleh itu, perancang dan kerajaan boleh menggunakan peta tanah runtuh kecenderungan untuk mengawal dan mencegah tanah runtuh di masa depan.

Hasil kajian ini membuktikan keupayaan algoritma yang dicadangkan dan digunakan untuk membuat pengesanan sah dan ramalan untuk fenomena tanah runtuh. Keputusan dijangka bukan sahaja menyediakan penilaian komprehensif lagi cepat bahaya tanah runtuh di masa hadapan dan risiko tetapi juga berfungsi sebagai panduan kepada perancang penggunaan tanah. Algoritma yang digunakan dan maklumat yang akan menambah sumbangan layak untuk pengurusan tanah runtuh di Malaysia tropika.

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All praise to ALLAH, Most Gracious, Most Merciful, Who, Alone brings forgiveness and light and new life to those who call upon Him; and to Him is the dedication of this work.

"Read! In the Name of your Lord who has created (all that exist).
He has Created man from a clot.
Read! And your Lord as the Most Generous.
Who has taught (the writing) by the pen.
He has taught man that which he knew no."
Qur'an (AIaq) 96: 1-5

I praise ALLAH for his great loving kindness, which has brought all of us to tell and encourage each other and who has pulled us from the darkness to the light. All respect for our holy prophet (Peace be upon him), who guided us to identify our creator. I also thank all my brothers and sister who answered ALLAH's call and have made their choice to be in the straight path of ALLAH.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

RS	Remote Sensing
GIS	Geographic Information Systems
RADAR	Radio Detection And Ranging
SAR	Syntactic Aperture RADAR
InSAR	Interferometric Synthetic Aperture RADAR
DInSAR	Differential Interferometric Synthetic Aperture RADAR
LiDAR	Light Detection and Ranging
LULC	land use/cover
BSA	Bivariate Statistical Analysis
MSA	Multivariate Statistical Analysis
AUC	The area under curve
ROC	Relative Operating Characteristic
WoE	Weights-of-Evidence
LR	Logistic regression
SVM	Support Vector Machine

EBF	Evidential Belief Function
SPI	Stream Power Index
TWI	Topographic Wetness Index
TRI	Topographic Roughness Index
STI	Sediment Transport Index

CHAPTER 1

INTRODUCTION

1.1 General

Natural disasters, such as floods, earthquakes, tsunamis, and landslides, are potential concerns for governments worldwide because they cost lives and properties. Particularly, landslides cause huge damages to properties, agricultural lands, and infrastructures (Promper et al., 2012). Owing to extensive urban expansion and deforestation actions, the trend of landslide occurrence will continue in the next eras due to climate change (Bellugi et al., 2011). Considering the wide coverage of landslide damages, planners and decision makers need to identify landslide prone areas to plan mitigation actions (Pradhan, 2011). Landslide susceptibility mapping depends on the method employed and the quality and scale of the conditioning factors (Cortes and Vapnik, 1995). The efficiency of landslide susceptibility maps strongly relies on the quantity and quality of dataset and the choice of proper analysis method (Ayalew and Yamagishi, 2005).

Landslides are a catastrophic phenomenon and a dynamic process that contributes to the destruction and transformation of a given landscape (Lee Saro and Pradhan Biswajeet, 2006). Various natural and man-made factors trigger landslides (Guzzetti et al., 2005). Meteorological variations, such as strong precipitation, and tectonic forces, such as earthquakes, are the main factors that trigger landslides (Huang et al., 2012), although natural forces, such as rainfall, and human activities also trigger them (Guadagno et al., 2003). Given the many possible causes of landslides, mapping landslide susceptibility, hazards, and risks is essential to implementing mitigation strategies (Chen and Lee, 2003; Pradhan and Buchroithner, 2010; Ray et al., 2010). The landslide susceptibility map is the first stage of hazard and risk mapping, which determines the regions with the specific probability value of landslide occurrence in a given period of time (Pradhan et al., 2011; Pradhan and Youssef, 2010). Landslide susceptibility mapping is the evaluation of the proneness of the ground to landslides and the possibility that a landslide might take place at a specific terrain or under the influence of certain factors (Pourghasemi HR et al., 2012a). Landslide susceptibility is specified using comparative qualitative and quantitative analyses of the conditioning factors observed in previously landslide occurred regions (Domínguez-Cuesta et al., 2007). Differences between the characteristics of the factors should be evaluated to produce a landslide susceptibility map that employs various conditioning factors. The characteristics of conditioning factors vary from area to area, therefore, the first stage in generating susceptibility map is to assess the importance of each factor (Nefeslioglu et al., 2010). Constructing the conditioning factors is a difficult task (Jibson and Keefer, 1989), and no specific rule exists to define how many conditioning factors are sufficient for a specific susceptibility analysis. Furthermore, no framework exists for the selection of conditioning factors. These factors are mostly chosen based on the opinions of experts.

The advent of geographical information systems (GISs) and remote sensing techniques has greatly facilitated the development of various methods in landslide susceptibility mapping (Yao et al., 2008). The preparation of the dataset of landslide conditioning factors is an essential requirement for any susceptibility analysis. Therefore, a landslide-related spatial database should first be created. In this regard, different types of conditioning factors have been used in various studies. The selection of these factors can be implemented based on the knowledge attained from literature and field investigations (Smith and Ward, 1998.). This process is critical because some conditioning factors may be effective in landslide occurrence for a specific area, whereas the same factors may not be influential for other environments. The precision of derived maps depends not only on the methodology adopted but also on the quality of the conditioning factors. If the quality of the data increases, then the performance of the landslide susceptibility maps can increase (Pradhan, 2013b). In several countries having access to full datasets which contain topological, environmental, geological, and hydrological information is likely impossible. Therefore, this study aims to use only light detection and ranging (LiDAR)-derived conditioning factors in landslide susceptibility mapping to examine the efficiency of high-precision conditioning factors in modeling.

1.2 Problem Statement

The use of remote sensing and GIS techniques in monitoring the earth movment has been widly explored. Monetoring the movment is one of the parameters in detecting the landslide prone areas. However, the problems below still shown in the research.

1. There are some limitations in the performance of Interferometric Synthetic Aperture RADAR (InSAR) to detect the landslides in dense vegetated regions (Granica et al., 2005).
2. Different techniques can be used for a purpose of mass movement monitoring; however, Landslides inventory map is not always there to be used in the risk and hazard assessment.
3. There are different active and passive sensors which can represent a lot of information in terms of mass movement; however, they have still not been integrated to enhance the detection of mass movement detection and modeling.
4. Not much work has been done in tropics especially on landslide detection using fusion of active and passive sensors.
5. Recognition and mapping of an appropriate set of conditioning factors having a correlation with the landslide require specific knowledge of the main motives of landslides (Pradhan and Lee, 2010c).
6. Some conditioning factors, such as DEM, geology, slope, vegetative cover, and soil type, are more important and effective than others (Miller, 2011).
7. However, some conditioning factors may be effective in landslide occurrence for a specific area, while the same factors may not be influential for other environments
8. The accessibility to these dataset is different, based on the type, scale, and technique of data collection. However acquisition an ideal landslide related database on a suitable scale with high precision is often a costly and difficult task (Alfieri et al., 2013).

9. The ensemble method is expected to increase the processing speed and the precision of the results. Furthermore, Lidar data is expected to give precise information about the earth terrain which can enhance the models' capability. However, using both of these two advantages not yet been done.

1.3 Motivation Behind this Reserach

Nowadays, natural hazards are common in today's life. Increasing amounts of natural catastrophes have proved to the human the vital importance of the natural hazards issues for the safety of the environment, and the populations. Rapid urbanization and climate change are expected to raise the amount of landslide. The dramatic landslide of which occur in tropical countries, especially Malaysia, emphasize the extreme in climatic variations. That is why, the topic of landslide monitoring, mapping, modeling and mitigation are among priority tasks in governments schedule (Kussul et al., 2008). This phenomena occur due to the unexpected variation in state of natural features due to natural forces. In most of the cases human is not capable to control and predict these disasters precisely. Main natural catastrophes such as landslide, earthquakes, floods and land subsidence when they occur, they lead to affect the human lives, belongings, infrastructure, farming and environment. The influence of natural hazards is varying based on its amount and coverage region.

Landslides are the most common occurring natural catastrophes that influence human and its adjacent environment. It is more vulnerable to Asia and the Pacific regions which affects social and economic stability of a those countries. As stated by Pradhan (2010a), approximately 90 percent of the destructions related to natural catastrophes in Malaysia are produced by landslide. Furthermore, average annual landslide damage is as high as US10 millions. The attention for providing proper landslide management has rose over the last centuries. The recent reasons for recurrent landsliding of some regions are mostly due to un-planned urbanization, construction and deforestation. In spite of all this its again human involvement to control landslide disaster by immense use of various technology. The use of technology can facilitate landslide prevention actions to detect the landslide areas and to have an early warning for this catastrophe.

Here thesis attempts to propose novel techniques to map the landslide prone areas locations and map the landslide susceptible areas using untested methods. The key motivation of this research is to use the generated maps in order to avoid more urbanization in hazardous areas and have sustainable environment. To reduce the damage and victims in case of a landslide occurrence, it is critical to locate the susceptible areas. To recognize those susceptible regions, landslide inventory map should be generated as a basis of landslide susceptibility mapping. Besides the landslide inventory and susceptibility mapping, optimization of conditioning factors is of great interest as well. Governments and planners can utilize the produced results by this study to recognize safe regions for citizens, support first responders in emergencies, and update the urban planning strategies. Such data can decrease the requirement to perform field surveys by agencies such as departments of surveying.

1.3 Research Objectives

The present thesis proposes and applied various new methodologies that clearly contributes to the gap in the literature. The method is simple, repeatable, and comprehensive. The following are the main objectives of the thesis:

1. To detect and monitor terrigenous mass movement using Interferometry SAR (InSAR) and DInSAR in tropical forest.
2. To fuse active sensor data (Lidar) and passive sensor data (QuickBird) for improvement of landslides detection.
3. To optimize landslide conditioning factors using very high-resolution airborne laser scanning data.
4. To combine different models for utilizing only the pure LiDAR derived conditioning factors in landslide prediction using GIS modeling.

1.4 Research Questions

This thesis comprehensively addresses the following research questions:

1. How valid InSAR technique is in detecting the vertical movement of the ground in tropical forest?
2. Could DInSAR be used for detecting the horizontal movement of ground in tropical forest?
3. What is the result of the fusion of high resolution satellite data with high density LiDAR data? How can this be helpful in landslide detection?
4. How well object oriented classification method in defining the landslide prone areas?
5. Which landslide conditioning factors are most relevant to the mapping of landslide prone areas? What weights should be given to each factor?
6. Do more conditioning factors increase the accuracy of the resulted prediction map?
7. Could a machine learning classification model for landslide conditioning factors be integrated with a bivariate statistical model for selecting and weighing landslide predictors?

1.5 Scope of this Thesis

This study aims only to detect and predict landslide prone areas using remote sensing and GIS techniques in tropical country, such as Malaysia. The developed methodology was applied in the two study areas to test the validity of the conclusions and the applicability of the methodology across a range of areas. However, the proposed methodology for detection and susceptibility modeling may be supplemented in other areas

For detection, this research aims to study the use of SAR techniques in horizontal and vertical movement detection. In addition, the fusion model was developed for high-resolution airborne laser scanning data and optical sensor of QuickBird to detect the occurred landslides. On the other hand, the efficiency of Lidar data was examined to validate its reliability in prediction landslide. Furthermore, an ensemble technique between he bivariate models of evidential belief function (EBF) and support vector machine (SVM) was developed for predicting the landslide prone areas.

1.6 Thesis Organization

This thesis is organized into five chapters. The list of the publication related to this study is listed in page 237. The summary of each chapter is as the following:

i. CHAPTER ONE: INTRODUCTION

This chapter mentioned briefly about the problem statement of the study, goal, objectives and scope of the study. Also this chapter included the research questions. Moreover, the significant contributed to new knowledge and the overall structure of the thesis.

ii. CHAPTER TWO: LITERATURE REVIEW

This chapter provides an overview of landslide status in various regions and previous work of using remote sensing and GIS for landslide detection as well as susceptibility mapping. Next, discussion about traditional and innovative and emerging techniques for detecting the landslide prone area. Then, discussion describing the methodology used for landslide susceptibility mapping using qualitative and quantitative analysis. Finally, validation methods used to assess the accuracy of maps produced are summarized.

iii. CHAPTER 3: MATERIALS AND METHODOLOGY

This chapter describes in detail about the characteristic of the study area. Then followed by the materials, data, methodology, detection, fusion, GIS modelling and model validation used for landslide detection and modeling using various GIS techniques and remote sensing.

iv. CHAPTER 4: RESULTS AND DISCUSSION

This chapter focuses on the results of the study including analysis results of satellite interpretation, GIS modeling techniques integration which supported by diagrams, tables, equations and charts. This chapter also discussed on the comparative analysis of using SAR techniques in landslide movement detection. Next, the result of the fusion between LiDAR and QuickBird data. Furthermore, the optimization of the LiDAR driven parameters and their validity in landslide prediction. Then, the result of ensemble between EBF and SVM. Finally, the accuracies obtained from all the applied models are discussed.

v. CHAPTER 5: CONCLUSION AND FUTURE WORK RECOMMENDATIONS

This chapter provides the overall conclusion from this study, recommendation and further research for the study area.

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