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LANDSLIDE VULNERABILITY AND RISK ASSESSMENT FOR MULTIHAZARD SCENARIOS USING AIRBORNE LASER SCANNING DATA

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By

WALEED MOHAMMED ABDULWAHID

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

April 2016

DEDICATION

To my daughter, my wife, my parents, all my loving family, and friends, whose genuine love and support are behind my success.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Master of Science

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April 2016

Chairman : Associate Professor Biswajeet Pradhan, PhD
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Landslides are one of the many forms of natural hazards that often cause severe property damages, economic loss, and high maintenance costs. Slope failures are a result of multiple triggering factors, including anthropogenic activities, earthquakes, and intense rainfall, and reactions of a host of unstable surface materials related to geology, land cover, slope geometry, moisture content, and vegetation. In recent decades, numerous people have become the victims of landslides in many regions worldwide. Although there has been a broad exploration into measuring landslide hazard, research into outcome investigation and the appraising of the vulnerability has been constrained and remains in its infancy. An understanding and assessment of the vulnerability of elements exposed to landslide hazard are of key importance to landslide risk assessment. This study presents a semi-quantitative landslide vulnerability and risk assessment for the hazard mapping of rainfall-induced landslides. This approach was tested in the Ringlet area in Malaysia.

This research has three objectives; the first objective focuses on construction of landslide susceptibility map using conditioning factors and probability models for the study area. The logistic regression model was employed. The most significant landslide conditioning factors were prioritized, and the model was validated using success and prediction rate curves. The predicted map yielded higher prediction accuracy and achieved better discrimination of susceptible zones.

The second objective focuses on developing hazard assessment by implementing the temporal probability. Using available precipitation data from 2000 to 2014. Four different antecedent values: average value of any day in the year, and abnormal intensity in the day. And three different average rainfall depth: 5, 10, and 15 years. Finally, hazard maps were developed based on the multiplied results of the spatial and temporal of Ringlet area.

In this study the semi-quantitative risk assessment of landslide hazards and vulnerability map was developed. An integration between the vulnerability and the

hazard maps were accomplished to predict the facilities that are likely to be affected by direct risks. Additionally, an exposure overlay of elements at risk and hazard maps for different duration of intensity were employed to calculate the loss. Results then used to predict area under risk and calculate annualized risk. The expected results proved the capacity of the proposed methods to make valid prediction under landslide risk conditions in a data-scarce environment.

The results are expected not only provide an assessment of future landslide hazards and risks but also serve as a guide for land use planners. The presented methods and information will add a valuable contribution to the landslide hazard and risk assessment at medium scale data analysis.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan Ijazah Master Sains

KELEMAHAN PENILAIAN BAHAYA DAN RISIKO TANAH RUNTUH UNTUK SENARIO PELBAGAI-BAHAYA MENGGUNAKAN DATA IMBASAN LASER BAWAAN UDARA

Oleh

WALEED MOHAMMED ABDULWAHID

April 2016

Pengerusi : Profesor Madya Biswajeet Pradhan, PhD
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Tanah runtuh adalah salah satu di antara banyak kemusnahan semulajadi yang sering menyebabkan kemusnahan hartabenda yang serius, kerugian ekonomi dan kos penyelenggaraan yang tinggi. Kerosakan pada cerun adalah hasil daripada pelbagai faktor penyumbang, termasuk aktiviti antropogenik, gempa bumi, dan hujan yang lebat, dan reaksi beberapa bahan permukaan yang berkait rapat dengan geologi, litupan tanah, geometri cerun, isi kandungan kelembapan dan tumbuh-tumbuhan. Tesis ini membentangkan satu penilaian kelemahan tanah runtuh dan risiko yang bersifat separa kuantitatif untuk pemetaan kemusnahan alam tanah runtuh yang disebabkan oleh hujan. Pendekatan ini telah dikaji dalam kawasan kajian iaitu kawasan Taman Ringlet di Malaysia.

Kajian ini mempunyai beberapa objektif; objektif pertama menjurus kepada pemetaan kelemahan pembangunan tanah runtuh menggunakan faktor penyesuaian dan model kebarangkalian untuk kawasan kajian. Model regresi logistik telah digunakan. Faktor-faktor penyesuaian tanah runtuh diberi keutamaan, dan model disahkan menggunakan lengkok kadar kejayaan dan ramalan. Peta ramalan menghasilkan ketepatan ramalan yang lebih tinggi dan mencapai diskriminasi zon-zon yang terdedah dengan lebih baik.

Objektif kedua memfokus kepada menjalankan kajian kelebatan hujan ke atas kawasan yang dikaji. Empat nilai sebelum ini yang berbeza: nilai purata mana-mana hari dalam setahun, dan keamatan luar biasa dalam sehari. Dan tiga jangkamasa pulangan: 5, 10, dan 15 tahun. Keputusannya mengisi jurang dalam literatur melalui pembentukan peta-peta bahaya berskala sederhana yang dibangunkan berdasarkan keputusan-keputusan ruang dan masa bercampur di kawasan Taman Ringlet menggunakan data pemendakan dari tahun 2000 sehingga tahun 2014.

Objektif ketiga menjurus kepada penilaian risiko separa kuantitatif bahaya tanah runtuh dan indeks kelemahan yang telah dibangunkan. Pergabungan kukuh di antara kelemahan dan pemetaan bahaya telah dicapai untuk meramal elemen-elemen yang

berkemungkinan terjejas oleh risiko-risiko secara langsung. Tambahan pula, satu pendedahan kepada elemen-elemen risiko dan pemetaan bahaya untuk jangkamasa pulangan yang berlainan telah digunakan untuk menghitung kerugian. Keputusan kemudiannya digunakan untuk meramal kawasan-kawasan yang berisiko dan menghitung risiko tahunan. Keputusan yang dijangka membuktikan kapasiti metod yang disarankan untuk membuat ramalan yang sahih di bawah keadaan risiko tanah runtuh dalam persekitaran di mana adalah sukar untuk mendapatkan data. Ciri-ciri yang hilang dari rekod-rekod yang musnah telah membawa kepada kesukaran untuk mengesahkan dapatan-dapatan semasa.

Keputusan-keputusan diharapkan dapat memberikan satu penilaian bahaya dan risiko tanah runtuh di masa akan datang yang cepat dan komprehensif tetapi juga boleh menjadi panduan kepada perancang tanah. Kaedah dan maklumat yang dibentangkan akan memberi satu sumbangan yang bernilai kepada penilaian bahaya dan risiko tanah runtuh pada analisis data berskala sederhana.

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All praise to ALLAH, Most Gracious, and Most Merciful, Who alone brings forgiveness and light and new life to those who call upon Him, and to Him I dedicate this work.

“Read! In the Name of your Lord who has created (all that exists).
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 not.”
Qur’an (Alaq) 96: 1-5.

I wish to thank my parents and my wife, who deserve my sincerest appreciation, for their unselfish love and care as well as for the support and motivation they have always given me. I am grateful for the countless sacrifices they have endured to ensure that I was able to continue pursuing my dream and for always being there for me. May ALLAH always protect them and bless them with long and healthy lives. Words will not be enough to express all my praise and thanks to them.

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I certify that a Thesis Examination Committee has met on 26 April 2016 to conduct the final examination of Waleed Mohammed Abdulwahid on his thesis entitled "Landslide Vulnerability and Risk Assessment for Multihazard Scenarios Using Airborne Laser Scanning Data" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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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 (Master of Science). The members of the Supervisory Committee were as follows:

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Declaration by graduate student

I hereby confirm that:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

LSMs	Landslide susceptibility maps
P_S	Spatial probability
P_T	Temporal probability
TWI	Topographic wetness index
SPI	Stream power index
FR	Frequency ratio
WoE	Weight of evidence
LR	Logistic regression
AUC	Area under curve
TRI	Terrain roughness index
LIDAR	Light Detection and Ranging
LULC	Land use/cover
STI	Sediment Transport Index

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Landslides are one of the most disastrous natural hazards in the world. The total area of land subject to landslides are about 3.7 million square kilometers worldwide, with a total population about 300 million (5% of world population). Around 820,000 square kilometers is relatively classified as high-risk areas, inhabited with a nearly population of 66 million (Dilley, 2005).

As Malaysia keeps on developing in the populace, the burden on residential advancement, in regions that are inclined to landslides, or have conceivably unstable slopes, will expand. More than that Malaysia has continuously led to unmanaged slopes which have contributed to a notable number of shallow landslides (Althuwaynee et al., 2014).

Landslides mechanisms are generally dependent on various factors, such as slope material, geomorphic conditions (i.e., rocks, soil, or artificial fill) and other triggering factors. Landslides result in the downward and outward movement of slope materials (Sidle and Ochiai, 2006). Landslides are classified into many types (e.g., toppling, sliding, flowing, and spreading) depending on the following: (1) types of the mechanisms involved, with mass movement being the most complex, (2) occurrence at different scales (e.g., local scale covering a few square meters and medium or large scale covering several square kilometers of land such as submarine landslides), and (3) velocity (e.g., from creeping failures moving at several millimeters per year to avalanches traveling at several kilometers per hour) (Jibson et al., 1998; Schuster and Wieczorek, 2002).

Landslides are the result of the interplay of two important factors which are predisposing and triggering factors that determine the probability of landslide occurrence. Predisposing factors can cause slope failures at very low speeds and over long durations. These factors are considered as terrain attributes and are used in landslide susceptibility assessment. Furthermore, these factors can lead to slope failure through processes such as stress release, weathering, and erosion (Corominas and Moya, 2008). Triggering factors, such as prolonged or intense rainfall, can cause several landslides over periods of hours or days. Mass slope failure varies in activation time, from a few seconds, such as in the case of a rockfall, to years, such as in the case of large dormant landslides (Guzzetti, 2006).

The sheer variety of the types of landslide phenomena is considered as the major obstacle to the production of a single nationwide landslide hazard map. The number/size and scale of a landslide, as well as terrain complexities, add to the challenge faced by scientists, planners, and decision makers in developing effective methodologies and techniques for landslide hazard and risk mapping.

One of the necessary requirements for making a complete landslide risk assessment is the availability of information about the elements at risk. Elements at risk can be defined as the economic activities, population, civil engineering works, buildings, infrastructure, and utilities, etc. that are under risk of loss or damage in the event of a landslide in a particular area or region (AGSO, 2001). Every element at risk has unique characterization such as temporal (as in the case of a population that varies based on time period and location), spatial (based on the given location from the hazard) and thematic (referring to the age distribution of the population, building types, etc.). Elements at risk inventory are usually time-consuming and varies based on the study requirements. Their uses and applications go beyond landslide risk assessment as they are also useful for cadastral information systems and developmental planning processes (Montoya, 2000). Landslide risk assessment elements at risk employ simple and sometimes complex procedures for classification and inventory collection but are nevertheless, less complex than those of other hazards like flooding or earthquakes (RADIUS, 1999).

IUGS (1997) defines vulnerability as the inability to bear the loss or the risk of loss ascribed to the greater intensity of a phenomenon, be it man-made or naturally occurring. Vulnerability is of four kinds: economic, physical, social and environmental. When carrying out a vulnerability analysis, the aspects at risk are in a curve that depicts the relationship between the hazard's intensity and the extent of harm to the aspects at risk (Fell et al., 2008a). This curve can be stated by observing the historical data and in case it is limited or missing, expert probability/scenarios can be taken into account.

Expressing and computing the vulnerability curves for landslides are seldom discussed in literature though there have been attempts to do so. Wong et al. (1997) investigated the relationship between the magnitude and frequency of the landslide and the vulnerability probability of an infrastructure. For the damage caused by a landslide in several infrastructures, Alexander (1989) developed a database based on zones and the range of damage that occurred. His findings show that the elements at risk in a vulnerability analysis are attributed to people and major infrastructures such as building and roads. Landslide types vary depending on the magnitude of impact and frequency. In some data sets, this has been plotted out using the F-N diagrams (Frequency versus Consequences) to determine the cumulative number of landslides, impact and probability of reoccurrence (Fell and Hartford, 1997).

Landslide vulnerability evaluation maps created by utilizing GIS are renowned and vital in the process of development planning. These have been well established and deployed in many government agencies. Smyth and Royle (2000) assessed the landslide vulnerability in the Niteroi city near Rio de Janeiro by utilizing the census data, satellite images, and field mapping. The intent was to ascertain the vulnerability of the different towns to facilitate the planning and execution of mitigation mechanisms. Liu and Lei (2003) deployed the vulnerability evaluation technique in China to explore the economic, physical and ecological vulnerabilities and ascertain the debris flow for various counties in the Yunnan province.

Risk on one hand is the product of the probability of occurrence of a phenomenon and the magnitude, costs and the degree of damage of the elements at risk (vulnerability). Conducting risk assessment involves taking into account the different types, quantities and qualifications of physical, economic and social factors in the affected area. Much research has been carried out in hazard and risk evaluation processes such as in Hong Kong (Hardingham et al., 1998), California (Blake et al., 2002), Australia (AGSO, 2001; Michael-Leiba et al., 2003), New Zealand (Glassey et al., 2003), Switzerland (Lateltin, 1997) and France (Flageollet, 1989). The National Geohazards Vulnerability of Urban Communities Project (also called as the Cities Project) in Australia has conceived an applied research and technique development programme to scrutinise and explore the risks much common in urban communities (AGSO, 2001). The Cities Project has also been emulated in Australian towns (Cairns, Queensland and Mackay). Measuring the landslide risk is tough since the frequency and intensity have to be taken into consideration, which is different for different areas, particularly if the site of the impacted area is huge. Even when accompanied by GIS, it is tough to determine. In such scenarios, the simplified qualitative measures are deployed (Lateltin, 1997).

This context frames of the work of this thesis, which is conducted on landslide prone area of the study area.

1.2 Problem Statement

Landslide hazard assessment is normally performed by summing up two main independent components: the spatial and temporal probability of the occurrence of the triggering factor that results in a landslide (Guzzetti et al., 2005). Many studies have been conducted to address the relationship between these two components in many areas. Literature review addresses the challenge faced by scientists, planners, and land developers in the application and development of these probabilities geomodells. These reviews also highlight the uncertainties involved in data acquisition and preparation as well as in model selection and calibration techniques.

In recent decades, numerous people have become the victims of landslides in many regions worldwide. Although there has been a broad exploration into measuring landslide hazard, research into outcome investigation and the appraising of the vulnerability has been constrained and remains in its infancy. An understanding and assessment of the vulnerability of elements exposed to landslide hazard are of key importance to landslide risk assessment.

Landslide risk assessments are dependent on some basic assumptions and very complex slope movement data or knowledge popular among earth scientists. These assumptions form the bedrock upon which the conceptual frameworks of slope movements are applied irrespective of the assessment technique employed, the scale of analysis used, the mapping unit or the objective of the study.

However, major constraints such as the systematic identification of deposits of landslides, adequate comprehension of slope failures triggers and causes, collecting enough geological, hydrological, geomorphological and climatological information, choice of the most appropriate predictive model and mapping unit, selection of suitable data analysis and modelling tools and methods, and other instability factors pose a challenge to the assessment of landslide risks (Van Westen, 2004b). Furthermore, the inabilities to recognize and understand the major causes of landslides lead to against successful risk assessments. Nevertheless, whereas some constraints pose more difficult challenges, others can be overcome.

Incomplete information regarding damaged records of elements at risk renders quantitative risk mapping almost difficult to produce an accurate result. Given the scarcity of data on elements at risk for landslides, especially those in landslide prone areas in Malaysia, valid studies based on significant land use maps are rarely conducted (Lee et al., 2014; Pradhan and Lee, 2010c).

1.3 Motivation behind this Research

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 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 phenomenon occurs due to the unexpected variation in the state of natural features due to natural forces. In most of the cases, the human is not capable of controlling and predicting these disasters precisely. Main natural catastrophes such as landslides, earthquakes, and floods when they occur, they lead to affect the human lives, infrastructure, farming, and the 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 affect the social and economic stability of those countries. As stated by (Pradhan, 2010a) approximately 90 percent of the destructions related to natural catastrophes in Malaysia are produced by a landslide. Furthermore, average annual landslide damage is as high as US 10 million. The attention for providing proper landslide management has rose over the last centuries. The recent reasons for recurrent landslides of some regions are mostly due to unplanned urbanization, construction, and deforestation. In spite of all this, it's again human involvement to control landslide disaster by an 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 suitable methodologies to map landslide hazard, vulnerability, and risk prone area location and map the landslide susceptible area using high-resolution airborne laser scanning data (LiDAR). The key motivation of this research is to use the generated maps in order to avoid more urbanization in hazardous areas and have a sustainable environment. 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.

1.4 Aim and Objectives

The general goal of this research is to deliver "medium to long-term early warning" maps that can demonstrate the zones most likely presented to risk. This outcome can bolster the acknowledgment of the frameworks cautioning in advance to alert government and organizations about existing landslide risks keeping in mind the end goal to take suitable measures to control losing lives and damages. The following are the main objective of the thesis:

1. To generate landslide susceptibility map on the basis of conditioning factors and probability models using high-resolution airborne laser scanning data (LIDAR data) for the study area.
2. To develop the temporal and spatial probabilities of landslide events for generating landslide hazard maps.
3. To develop a semi-quantitative landslide risk maps that predicts the elements at risk to be affected by landslides.

1.5 Research Questions

This thesis comprehensively addresses the following research questions:

1. How does the nature of landslide patterns affect the quality of the modeled prediction results?
2. How can the quality and reliability of temporal and spatial probability models be determined, and how can their prediction capability and performance be measured?
3. Could valid rainfall data and landslide susceptibility maps be developed for landslide-prone areas?
4. Could a valid quantitative landslide risk analysis be conducted for medium scale landslide-prone area?
5. What are the elements at risk in the study area?

6. What is the potential damage to the elements at risk?
7. What is the probability of damage?

1.6 Scope of the Study

This research aims to provide insights into the development of a methodology for spatial prediction of medium-scale, rainfall-induced landslides. The methodology tested on the landslide-prone area in tropical Malaysia.

A comprehensive understanding of the landslide hazard phenomenon and its probable effects on society are vital for defining landslide control policies, risk mitigation projects, and other landslide management strategies. Numerous landslides have occurred in Malaysia in recent years. Most of these landslides threatened the lives and properties of the denizens. Generally, landslides often occur near highways or in cut slopes in mountainous areas. Here thesis, aims to perform landslide susceptibility, hazard, vulnerability, and risk mapping in the Ringlet area of Malaysia, since scientific studies still lacks significant complete landslide risk assessments. Comprehensive studies conducted in Malaysia still stop at susceptibility and hazard assessment. This study also focuses on the ability of LIDAR-derived data for the purpose of modeling the landslides. The produced landslide susceptibility map (besides of developing the temporal probability) will be used as the basis for hazard, vulnerability, and risk assessment undertaken in this study.

1.7 Organization of the Study

This thesis is divided into five chapters, chapter one provides the background of the research problem, the research objective, and the scope of the study. Chapter two reviews the literature on landslide susceptibility, hazard, vulnerability, and risk assessment. This chapter mainly discusses the general principles and methodology of landslide hazard and risk assessment, including landslide types, causes, data sources, modeling approach to spatial and temporal probability, the element at risk, vulnerability assessment, risk analysis, and validation. Chapter three presents the methodology and framework of the thesis. This chapter presents and discusses the data that are necessary for developing landslide hazard, vulnerability, and risk maps. The chapter includes the following: landslide susceptibility prediction mapping, temporal probability, hazard map, the element at risk and vulnerability mapping, and risk map. All proposed models are assessed and validated for accuracy. Chapter four presents the collected information and the results of landslide hazard, vulnerability, and risk mapping, obtained from the analysis conducted in the study area. Chapter five summarizes the research findings, limitations and suggests directions for future work.

REFERENCES

Adams, N. M., & Hand, D. J. (1999). Comparing classifiers when the misallocation costs are uncertain. *Pattern Recognition, 32*(7), 1139-1147.

AGS. (2007). Guideline for landslide susceptibility, hazard and risk zoning for land use management. *Australian Geomechanics Society Landslide Taskforce Landslide Zoning Working Group. Australian Geomechanics, 42*(1), 13–36.

Akgün, A., & Turk, N. (2013). An assessment of conditioning parameter selection efficiency on medium scale erosion susceptibility mapping by gis and remote sensing methodologies: An example from northwest turkey. *EGU General Assembly Conference Abstracts, 15.* pp. 7457.

Alexander, D. (2005). Vulnerability to landslides. *Landslide Hazard and Risk.Wiley, Chichester*, 175-198.

Althuwaynee, O. F., Pradhan, B., & Ahmad, N. (2014a). Estimation of rainfall threshold and its use in landslide hazard mapping of Kuala Lumpur metropolitan and surrounding areas. *Landslides*, 1-15.

Althuwaynee, O. F., Pradhan, B., & Lee, S. (2012). Application of an evidential belief function model in landslide susceptibility mapping. *Computers & Geosciences, 44*, 120-135.

Althuwaynee, O. F., Pradhan, B., Park, H., & Lee, J. H. (2014). A novel ensemble bivariate statistical evidential belief function with knowledge-based analytical hierarchy process and multivariate statistical logistic regression for landslide susceptibility mapping. *Catena, 114*, 21-36.

Ardizzone, F., Cardinali, M., Galli, M., Guzzetti, F., & Reichenbach, P. (2007). Identification and mapping of recent rainfall-induced landslides using elevation data collected by airborne lidar. *Natural Hazards and Earth System Science*, *7*(6), 637-650.

Ayalew, L., & Yamagishi, H. (2005). The application of GIS-based logistic regression for landslide susceptibility mapping in the kakuda-Yahiko mountains, central japan. *Geomorphology, 65*(1), 15-31.

Ayalew, L., Yamagishi, H., & Ugawa, N. (2004). Landslide susceptibility mapping using a GIS-based weighted linear combination, the case in tsugawa area of agano river, Niigata prefecture, japan. *Landslides, 1*(1), 73-81.

Bai, S., Wang, J., Lü, G., Zhou, P., Hou, S., & Xu, S. (2010). GIS-based logistic regression for landslide susceptibility mapping of the zhongxian segment in the three gorges area, china. *Geomorphology, 115*(1), 23-31.

Bai, S., Wang, J., Zhang, Z., & Cheng, C. (2012). Combined landslide susceptibility mapping after Wenchuan earthquake at the zhouqu segment in the bailongjiang basin, china. *Catena, 99*, 18-25.

Bălteanu, D., Chendeş, V., Sima, M., & Enciu, P. (2010). A country-wide spatial assessment of landslide susceptibility in Romania. *Geomorphology, 124*(3), 102-112.

Baltzer, P. A., Dietzel, M., & Kaiser, W. A. (2013). A simple and robust classification tree for differentiation between benign and malignant lesions in MR-mammography. *European Radiology, 23*(8), 2051-2060.

Bates, R., & Jackson, J. (. (1987). Glossary of geology (3rd ed.). *American Geological Institute.Falls Church.VA*, 788.

Bell, R., & Glade, T. (2004). Quantitative risk analysis for landslides–Examples from bíldudalur, NW-Iceland. *Natural Hazards and Earth System Science, 4*(1), 117-131.

Beven, K., & Kirkby, M. (1979). A physically based, variable contributing area model of basin hydrology/Un modèle à base physique de zone d'appel variable de l'hydrologie du bassin versant. *Hydrological Sciences Journal, 24*(1), 43-69.

Birkmann, J. (2007). Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications. *Environmental Hazards, 7*(1), 20-31.

Bonham-Carter, G. (1994). Geographic information systems for geoscientists: Modeling with GIS. (13th ed., pp. 398) Elsevier.

Boots, B. N., & Getis, A. (1985). Point pattern analysis. *SAGE Publications Newbury Park, CA.*,

Borghuis, A., Chang, K., & Lee, H. (2007). Comparison between automated and manual mapping of typhoon-triggered landslides from SPOT-5 imagery. *International Journal of Remote Sensing, 28*(8), 1843-1856.

Bozkir, A. S., & Sezer, E. A. (2013). ADEM: An online decision tree based menu demand prediction tool for food courts. *International Proceedings of Chemical, Biological & Environmental Engineering, 50*, 759-763.

Brabb, E. E., Pampeyan, E. H., & Bonilla, M. G. (1972). Landslide susceptibility in san Mateo county, California. (pp. 360) US Geological Survey.

Brand, E. W. (1985). Relationship between rainfall and landslides in hong kong. *4th Int. Symp. on Landslides, Toronto,* , 377-384.

Brenning, A. (2005). Spatial prediction models for landslide hazards: Review, comparison and evaluation. *Natural Hazards and Earth System Science, 5*(6), 853-862.

Brunetti, M., Peruccacci, S., Rossi, M., Luciani, S., Valigi, D., & Guzzetti, F. (2010). Rainfall thresholds for the possible occurrence of landslides in Italy. *Natural Hazards and Earth System Science, 10*(3), 447-458.

Budimir, M., Atkinson, P., & Lewis, H. (2015). A systematic review of landslide probability mapping using logistic regression. *Landslides,* , 1-18.

Bui, D. T., Ho, T. C., Revhaug, I., Pradhan, B., & Nguyen, D. B. (2014). Landslide susceptibility mapping along the national road 32 of Vietnam using GIS-based J48 decision tree classifier and its ensembles. *Cartography from pole to pole* (pp. 303-317) Springer.

Bui, D. T., Lofman, O., Revhaug, I., & Dick, O. (2011). Landslide susceptibility analysis in the Hoa Binh province of Vietnam using statistical index and logistic regression. *Natural Hazards, 59*(3), 1413-1444.

Bui, D. T., Pradhan, B., Lofman, O., Revhaug, I., & Dick, O. B. (2012). Landslide susceptibility mapping at Hoa Binh province (Vietnam) using an adaptive neuro-fuzzy inference system and GIS. *Computers & Geosciences, 45*, 199-211.

Bui, D. T., Pradhan, B., Lofman, O., Revhaug, I., & Dick, Ø. B. (2013a). Regional prediction of landslide hazard using probability analysis of intense rainfall in the Hoa Binh province, Vietnam. *Natural Hazards, 66*(2), 707-730.

Burns, W. J., Mickelson, K. A., Jones, C. B., Pickner, S. G., Hughes, K. L., & Sleeter, R. (2013). Landslide hazard and risk study of northwestern Clackamas county, Oregon.

by Date, Rev Deliverable Responsible Controlled. (2011). Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies.

Caniani, D., Pascale, S., Sdao, F., & Sole, A. (2008). Neural networks and landslide susceptibility: A case study of the urban area of Potenza. *Natural Hazards, 45*(1), 55-72.

Cardinali, M., Galli, M., Guzzetti, F., Ardizzone, F., Reichenbach, P., & Bartoccini, P. (2006). Rainfall induced landslides in December 2004 in southwestern Umbria, central Italy: Types, extent, damage and risk assessment. *Natural Hazards and Earth System Science, 6*(2), 237-260.

Cardinali, M., Antonini, G., Reichenbach, P., & Guzzetti, F. (2001). Photo-geological and landslide inventory map for the upper Tiber river basin. *CNR, Gruppo Nazionale Per La Difesa Dalle Catastrofi Idrogeologiche, Publication,* (2154)

Carranza, E. J. M. (2009). Controls on mineral deposit occurrence inferred from analysis of their spatial pattern and spatial association with geological features. *Ore Geology Reviews, 35*(3), 383-400.

Carrara, A., Cardinali, M., Detti, R., Guzzetti, F., Pasqui, V., & Reichenbach, P. (1991a). GIS techniques and statistical models in evaluating landslide hazard. *Earth Surface Processes and Landforms, 16*(5), 427-445.

Carrara, A., Cardinali, M., & Guzzetti, F. (1992). Uncertainty in assessing landslide hazard and risk. *ITC Journal, 2,* 172-183.

Carrara, A., Bitelli, G., & Carla, R. (1997). Comparison of techniques for generating digital terrain models from contour lines. *International Journal of Geographical Information Science, 11*(5), 451-473.

Carrara, A., Cardinali, M., Detti, R., GuzzettI, F., Pasqui, V., & Reichenbach, P. (1990). Geographical information systems and multivariate models in landslide hazard evaluation. *Alps, 90*, 17-28.

Carrara, A., & Pike, R. J. (2008). GIS technology and models for assessing landslide hazard and risk. *Geomorphology, 94*(3), 257-260.

Cascini, L., Bonnard, C., Corominas, J., Jibson, R., & Montero-Olarte, J. (2005). Landslide hazard and risk zoning for urban planning and development. *Landslide Risk Management.Taylor and Francis, London*, 199-235.

Cascini, L. (2008). Applicability of landslide susceptibility and hazard zoning at different scales. *Engineering Geology, 102*(3), 164-177.

Cascini, L., Calvello, M., & Grimaldi, G. M. (2010). Groundwater modeling for the analysis of active slow-moving landslides. *Journal of Geotechnical and Geoenvironmental Engineering, 136*(9), 1220-1230.

Cascini, L., Cuomo, S., & Della Sala, M. (2011). Spatial and temporal occurrence of rainfall-induced shallow landslides of flow type: A case of sarno-quindici, Italy. *Geomorphology, 126*(1), 148-158.

Cascini, L., Cuomo, S., Pastor, M., & Sorbino, G. (2009). Modeling of rainfall-induced shallow landslides of the flow-type. *Journal of Geotechnical and Geoenvironmental Engineering, 136*(1), 85-98.

Cassidy, M. J., Uzielli, M., & Lacasse, S. (2008). Probability risk assessment of landslides: A case study at finneidfjord. *Canadian Geotechnical Journal, 45*(9), 1250-1267.

Chacón, J., Irigaray, C., Fernandez, T., & El Hamdouni, R. (2006). Engineering geology maps: Landslides and geographical information systems. *Bulletin of Engineering Geology and the Environment, 65*(4), 341-411.

Chau, K., Sze, Y., Fung, M., Wong, W., Fong, E., & Chan, L. (2004). Landslide hazard analysis for hong kong using landslide inventory and GIS. *Computers & Geosciences, 30*(4), 429-443.

Chauhan, S., Sharma, M., & Arora, M. K. (2010). Landslide susceptibility zonation of the Chamoli region, Garhwal Himalayas, using logistic regression model. *Landslides, 7*(4), 411-423.

Cheng, K., Wei, C., & Chang, S. (2004). Locating landslides using multi-temporal satellite images. *Advances in Space Research, 33*(3), 296-301.

Chung, C. F., & Fabbri, A. G. (1999). Probabilistic prediction models for landslide hazard mapping. *Photogrammetric Engineering and Remote Sensing, 65*(12), 1389-1399.

Chung, C. F., & Fabbri, A. G. (2003). Validation of spatial prediction models for landslide hazard mapping. *Natural Hazards, 30*(3), 451-472.

Claessens, L., Heuvelink, G., Schoorl, J., & Veldkamp, A. (2005). DEM resolution effects on shallow landslide hazard and soil redistribution modeling. *Earth Surface Processes and Landforms, 30*(4), 461-477.

Claessens, L., Lowe, D. J., Hayward, B., Schaap, B., Schoorl, J., & Veldkamp, A. (2006). Reconstructing high-magnitude/low-frequency landslide events based on soil redistribution modeling and a late-Holocene sediment record from new Zealand. *Geomorphology, 74*(1), 29-49.

Conforti, M., Pascale, S., Robustelli, G., & Sdao, F. (2014). Evaluation of prediction capability of the artificial neural networks for mapping landslide susceptibility in the turbolo river catchment (northern Calabria, Italy). *Catena, 113*, 236-250.

Corominas, J., Copons, R., Moya, J., Vilaplana, J. M., Altimir, J., & Amigó, J. (2005). Quantitative assessment of the residual risk in a rockfall protected area. *Landslides, 2*(4), 343-357.

Corominas, J., & Moya, J. (2010). Contribution of dendrochronology to the determination of magnitude–frequency relationships for landslides. *Geomorphology, 124*(3), 137-149.

Corominas, J., & Moya, J. (2008). A review of assessing landslide frequency for hazard zoning purposes. *Engineering Geology, 102*(3), 193-213.

Cotecchia, F., Santaloia, F., Lollino, P., Vitone, C., & Mitaritonna, G. (2010). Deterministic landslide hazard assessment at regional scale. *GeoFlorida 2010@ sAdvances in Analysis, Modeling & Design,* pp. 3130-3139.

Crozier, M. J., & Glade, T. (2006). Landslide hazard and risk: Issues, concepts and approach. *Landslide Hazard and Risk.Wiley, West Sussex,* , 1-40.

Cruden, D. M., & Varnes, D. J. (1996). Landslides: Investigation and mitigation. chapter 3-landslide types and processes. *Transportation Research Board Special Report,* (247)

D'Haen, J., Van den Poel, D., & Thorleuchter, D. (2013). Predicting customer profitability during acquisition: Finding the optimal combination of data source and data mining technique. *Expert Systems with Applications, 40*(6), 2007-2012.

Dahal, R. K., Hasegawa, S., Yamanaka, M., Dhakal, S., Bhandary, N. P., & Yatabe, R. (2009). Comparative analysis of contributing parameters for rainfall-triggered landslides in the lesser Himalaya of Nepal. *Environmental Geology, 58*(3), 567-586.

Dai, F., & Lee, C. (2002). Landslide characteristics and slope instability modeling using GIS, Lantau island, hong kong. *Geomorphology, 42*(3), 213-228.

Dai, F., Lee, C., & Ngai, Y. Y. (2002). Landslide risk assessment and management: An overview. *Engineering Geology, 64*(1), 65-87.

Das, I., Kumar, G., Stein, A., Bagchi, A., & Dadhwal, V. K. (2011). Stochastic landslide vulnerability modeling in space and time in a part of the northern Himalayas, India. *Environmental Monitoring and Assessment, 178*(1-4), 25-37.

De Vita, P. (2000). Fenomeni di instabilità delle coperture piroclastiche dei monti lattari, di sarno e di salerno (campania) ed analisi degli eventi pluviometrici determinanti. *Quaderni Di Geologia Applicata, 7*(2), 213-235.

Dempster, A. P. (1968). Upper and lower probabilities generated by a random closed interval. *The Annals of Mathematical Statistics,* , 957-966.

Dilley, M. (2005). *Natural disaster hotspots: A global risk analysis* World Bank Publications.

Dimri, S., Lakhera, R., & Sati, S. (2007). Fuzzy-based method for landslide hazard assessment in active seismic zone of Himalaya. *Landslides, 4*(2), 101-111.

Domínguez-Cuesta, M. J., Jiménez-Sánchez, M., & Berrezueta, E. (2007). Landslides in the central coalfield (Cantabrian mountains, NW Spain): Geomorphological features, conditioning factors and methodological implications in susceptibility assessment. *Geomorphology, 89*(3), 358-369.

Donati, L., & Turrini, M. (2002). An objective method to rank the importance of the factors predisposing to landslides with the GIS methodology: Application to an area of the Apennines (valnerina; Perugia, Italy). *Engineering Geology, 63*(3), 277-289.

Dou, J., Oguchi, T., Hayakawa, Y. S., Uchiyama, S., Saito, H., & Paudel, U. (2014). GIS-based landslide susceptibility mapping using a certainty factor model and its validation in the chuetsu area, central japan. *Landslide science for a safer geoenvironment* (pp. 419-424) Springer.

Duman, T. Y., Çan, T., Emre, Ö., Keçer, M., Doğan, A., Ateş, Ş., et al. (2005). Landslide inventory of northwestern Anatolia, turkey. *Engineering Geology, 77*(1), 99-114.

Düzgün, H., & Lacasse, S. (2005). Vulnerability and acceptable risk in integrated risk assessment framework. *F.Edited by Hunger, Couture and Emberhardt.(Ed.), Landslide Risk Management,* , 505-515.

Egan, J. (1975). Signal detection theory and ROC analysis (academic, new york). *EganSignal Detection Theory and ROC Analysis1975,*

Elbers, C., & Gunning, J. W. (2003). *Vulnerability in a Stochastic Dynamic Model,*

Ercanoglu, M., Kasmer, O., & Temiz, N. (2008). Adaptation and comparison of expert opinion to analytical hierarchy process for landslide susceptibility mapping. *Bulletin of Engineering Geology and the Environment, 67*(4), 565-578.

Ercanoglu, M., & Gokceoglu, C. (2004). Use of fuzzy relations to produce landslide susceptibility map of a landslide prone area (west black sea region, turkey). *Engineering Geology, 75*(3), 229-250.

Erener, A., & Düzgün, H. S. B. (2010). Improvement of statistical landslide susceptibility mapping by using spatial and global regression methods in the case of more and Romsdal (Norway). *Landslides, 7*(1), 55-68.

Erener, A., & Düzgün, H. S. (2013). A regional scale quantitative risk assessment for landslides: Case of kumluca watershed in bartin, turkey. *Landslides, 10*(1), 55-73.

Erenera, A., & Düzgünb, H. (2009). A GIS and RS-based quantitative vulnerability assessment for rainfall triggered landslides. *Isprs.Org,*

Ermini, L., Catani, F., & Casagli, N. (2005). Artificial neural networks applied to landslide susceptibility assessment. *Geomorphology, 66*(1), 327-343.

Falaschi, F., Giacomelli, F., Federici, P., Puccinelli, A., Avanzi, G., Pochini, A., et al. (2009). Logistic regression versus artificial neural networks: Landslide susceptibility evaluation in a sample area of the serchio river valley, Italy. *Natural Hazards, 50*(3), 551-569.

Felicísimo, Á. M., Cuartero, A., Remondo, J., & Quirós, E. (2013). Mapping landslide susceptibility with logistic regression, multiple adaptive regression splines, classification and regression trees, and maximum entropy methods: A comparative study. *Landslides, 10*(2), 175-189.

Fell, R., Glastonbury, J., & Hunter, G. (2007). Rapid landslides: The importance of understanding mechanisms and rupture surface mechanics. *Quarterly Journal of Engineering Geology and Hydrogeology, 40*(1), 9-27.

Fell, R., Ho, K., Lacasse, S., & Leroi, E. (2005). State of the art paper 1-A framework for landslide risk assessment and management. *Proceedings of the International Conference on Landslide Risk Management, Vancouver, Canada, , 31.*

Fell, R., Corominas, J., Bonnard, C., Cascini, L., Leroi, E., & Savage, W. Z. (2008a). Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. *Engineering Geology, 102*(3), 85-98.

Fielding, A. H., & Bell, J. F. (1997). A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation, 24*(01), 38-49.

Fiorucci, F., Cardinali, M., Carlà, R., Rossi, M., Mondini, A., Santurri, L., et al. (2011). Seasonal landslide mapping and estimation of landslide mobilization rates using aerial and satellite images. *Geomorphology, 129*(1), 59-70.

Floris, M., Iafelice, M., Squarzoni, C., Zorzi, L., Agostini, A. D., & Genevois, R. (2011). Using online databases for landslide susceptibility assessment: An example from the veneto region (northeastern italy). *Natural Hazards and Earth System Science, 11*(7), 1915-1925.

Fotopoulou, S., Pitilakis, K., & Anagnostopoulos, C. (2011). Vulnerability assessment of RC buildings due to earthquake induced slow moving slides. *Proceedings of 5th International Conference on Earthquake Geotechnical Engineering, Santiago,* pp. 10-13.

Fuchs, S., Heiss, K., & Hübl, J. (2007). Towards an empirical vulnerability function for use in debris flow risk assessment. *Natural Hazards and Earth System Science, 7*(5), 495-506.

Gallant, J. C. (2000). *Terrain analysis: Principles and applications* New York: John Wiley & Sons.

Galli, M., Ardizzone, F., Cardinali, M., Guzzetti, F., & Reichenbach, P. (2008). Comparing landslide inventory maps. *Geomorphology, 94*(3), 268-289.

Galli, M., & Guzzetti, F. (2007). Landslide vulnerability criteria: A case study from umbria, central italy. *Environmental Management, 40*(4), 649-665.

Gao, J., & Maro, J. (2010). Topographic controls on evolution of shallow landslides in pastoral wairarapa, new zealand, 1979–2003. *Geomorphology, 114*(3), 373-381.

Gee, M. D. (1992). Classification of landslide hazard zonation methods and a test of predictive capability. *Proc. 6th International Symposium on Landslides, Christchurch, New Zealand, , 2.* pp. 947-952.

Ghosh, S., van Westen, C. J., Carranza, E. J. M., & Jetten, V. G. (2012). Integrating spatial, temporal, and magnitude probabilities for medium-scale landslide risk analysis in darjeeling himalayas, india. *Landslides, 9*(3), 371-384.

Glade, T. (2003). Vulnerability assessment in landslide risk analysis. *Erde, 134*(2), 123-146.

Glade, T., & Crozier, M. J. (2005). The nature of landslide hazard impact. *Landslide Hazard and Risk.Wiley, Chichester,* , 43-74.

Glenn, N. F., Streutker, D. R., Chadwick, D. J., Thackray, G. D., & Dorsch, S. J. (2006). Analysis of LiDAR-derived topographic information for characterizing and differentiating landslide morphology and activity. *Geomorphology, 73*(1), 131-148.

Goh, A. T., & Goh, S. (2007). Support vector machines: Their use in geotechnical engineering as illustrated using seismic liquefaction data. *Computers and Geotechnics, 34*(5), 410-421.

Gokceoglu, C., & Sezer, E. (2009). A statistical assessment on international landslide literature (1945–2008). *Landslides, 6*(4), 345-351.

Goodenough, D. J., Rossmann, K., & Lusted, L. B. (1974). Radiographic applications of receiver operating characteristic (ROC) curves 1. *Radiology, 110*(1), 89-95.

Granger, K., Hayne, M., & Australia, A. (2001). *Natural hazards and the risks they pose to south east queensland* ASGO-Geoscience Australia.

Guillard-Gonçalves, C., Cutter, S. L., Emrich, C. T., & Zêzere, J. L. (2014). Application of social vulnerability index (SoVI) and delineation of natural risk zones in greater lisbon, portugal. *Journal of Risk Research,* (ahead-of-print), 1-24.

Guzzetti, F., Cardinali, M., Reichenbach, P., & Carrara, A. (2000). Comparing landslide maps: A case study in the upper tiber river basin, central italy. *Environmental Management, 25*(3), 247-263.

Guzzetti, F., Galli, M., Reichenbach, P., Ardizzone, F., & Cardinali, M. (2006). Landslide hazard assessment in the collazzone area, umbria, central italy. *Natural Hazards and Earth System Science, 6*(1), 115-131.

Guzzetti, F. (2006). *Landslide Hazard and Risk Assessment,*

Guzzetti, F., Cardinali, M., & Reichenbach, P. (1996). The influence of structural setting and lithology on landslide type and pattern. *Environmental & Engineering Geoscience, 2*(4), 531-555.

Guzzetti, F., Carrara, A., Cardinali, M., & Reichenbach, P. (1999). Landslide hazard evaluation: A review of current techniques and their application in a multi-scale study, central italy. *Geomorphology, 31*(1), 181-216.

Guzzetti, F., Manunta, M., Ardizzone, F., Pepe, A., Cardinali, M., Zeni, G., et al. (2009). Analysis of ground deformation detected using the SBAS-DInSAR technique in umbria, central italy. *Pure and Applied Geophysics, 166*(8-9), 1425-1459.

Guzzetti, F., Mondini, A. C., Cardinali, M., Fiorucci, F., Santangelo, M., & Chang, K. (2012). Landslide inventory maps: New tools for an old problem. *Earth-Science Reviews, 112*(1), 42-66.

Guzzetti, F., Peruccacci, S., Rossi, M., & Stark, C. P. (2007). Rainfall thresholds for the initiation of landslides in central and southern europe. *Meteorology and Atmospheric Physics, 98*(3-4), 239-267.

Guzzetti, F., Peruccacci, S., Rossi, M., & Stark, C. P. (2008a). The rainfall intensity–duration control of shallow landslides and debris flows: An update. *Landslides, 5*(1), 3-17.

Guzzetti, F., Reichenbach, P., Cardinali, M., Galli, M., & Ardizzone, F. (2005). Probabilistic landslide hazard assessment at the basin scale. *Geomorphology, 72*(1), 272-299.

Hagen, A. (2003). Fuzzy set approach to assessing similarity of categorical maps. *International Journal of Geographical Information Science, 17*(3), 235-249.

Haneberg, W. (2005). The ins and outs of airborne LIDAR: An introduction for practicing engineering geologists. *AEG News, 48*, 16-19.

Haneberg, W. C., Cole, W. F., & Kasali, G. (2009). High-resolution lidar-based landslide hazard mapping and modeling, UCSF parnassus campus, san francisco, USA. *Bulletin of Engineering Geology and the Environment, 68*(2), 263-276.

Hanley, J. A., & McNeil, B. J. (1982). The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology, 143*(1), 29-36.

Harvey, A., Hinkel, J., Horrocks, L., Klein, R., Lasage, R., Hodgson, N., et al. (2009). Preliminary assessment and roadmap for the elaboration of climate change vulnerability indicators at regional level. *Not Published Yet, but Available at DG ENV.Final Report to the European Commission (Restricted Commercial, ED45669, Issue Number: 3),*

He, X., Hong, Y., Yu, X., Cerato, A. B., Zhang, X., & Komac, M. (2014). Landslides susceptibility mapping in oklahoma state using GIS-based weighted linear combination method. *Landslide science for a safer geoenvironment* (pp. 371-377) Springer.

Hengl, T. (2006). Finding the right pixel size. *Computers & Geosciences, 32*(9), 1283-1298.

Hiremagalur, J., Yen, K. S., Akin, K., Bui, T., Lasky, T. A., & Ravani, B. (2007). Creating standards and specifications for the use of laser scanning in caltrans projects. *Technical Report no F/CA/RI/2006/46, California Department of Transportation, US,*

Huat, B. B., Ali, F. H., & Mariappan, S. (2005). Effect of surface cover on water infiltration rate and stability of cut slope in residual soils. *Electronic J Geotech Eng, 10*

Hungr, O., McDougall, S., Wise, M., & Cullen, M. (2008). Magnitude–frequency relationships of debris flows and debris avalanches in relation to slope relief. *Geomorphology, 96*(3), 355-365.

Hwang, S., Guevarra, I. F., & Yu, B. (2009). Slope failure prediction using a decision tree: A case of engineered slopes in south korea. *Engineering Geology, 104*(1), 126-134.

Ibsen, M., & Brunsden, D. (1996). The nature, use and problems of historical archives for the temporal occurrence of landslides, with specific reference to the south coast of britain, ventnor, isle of wight. *Geomorphology, 15*(3), 241-258.

IUGS Working Group on Landslides. (1997). Committee on risk assessment. *Quantitative Risk Assessment for Slopes and Landslides– the State of the Art. in D,*

Iverson, R. M. (2000). Landslide triggering by rain infiltration. *Water Resources Research, 36*(7), 1897-1910.

Jaiswal, P., van Westen, C. J., & Jetten, V. (2010). Quantitative landslide hazard assessment along a transportation corridor in southern india. *Engineering Geology, 116*(3), 236-250.

Jakob, M., Stein, D., & Ulmi, M. (2012). Vulnerability of buildings to debris flow impact. *Natural Hazards, 60*(2), 241-261.

Jakob, M., Hungr, O., & Jakob, D. M. (2005). *Debris-flow hazards and related phenomena* Springer.

Jebur, M. N., Pradhan, B., & Tehrany, M. S. (2014a). Optimization of landslide conditioning factors using very high-resolution airborne laser scanning (LiDAR) data at catchment scale. *Remote Sensing of Environment, 152*, 150-165.

Jiang, H., & Eastman, J. R. (2000). Application of fuzzy measures in multi-criteria evaluation in GIS. *International Journal of Geographical Information Science, 14*(2), 173-184.

Jibson, R. W., Harp, E. L., & Michael, J. A. (1998). *A method for producing digital probabilistic seismic landslide hazard maps: An example from the los angeles, california, area* US Department of the Interior, US Geological Survey.

Jiménez-Perálvarez, J., Irigaray, C., El Hamdouni, R., & Chacón, J. (2009). Building models for automatic landslide-susceptibility analysis, mapping and validation in ArcGIS. *Natural Hazards, 50*(3), 571-590.

Joyce, K., Samsonov, S., Levick, S., Engelbrecht, J., & Belliss, S. (2014). Mapping and monitoring geological hazards using optical, LiDAR, and synthetic aperture RADAR image data. *Natural Hazards,* , 1-27.

Kanungo, D., Arora, M., Gupta, R., & Sarkar, S. (2008). Landslide risk assessment using concepts of danger pixels and fuzzy set theory in darjeeling himalayas. *Landslides, 5*(4), 407-416.

Kanungo, D., Arora, M., Sarkar, S., & Gupta, R. (2006a). A comparative study of conventional, ANN black box, fuzzy and combined neural and fuzzy weighting procedures for landslide susceptibility zonation in darjeeling himalayas. *Engineering Geology, 85*(3), 347-366.

Kanungo, D., Arora, M., Sarkar, S., & Gupta, R. (2009). A fuzzy set based approach for integration of thematic maps for landslide susceptibility zonation. *Georisk, 3*(1), 30-43.

Kasai, M., Ikeda, M., Asahina, T., & Fujisawa, K. (2009). LiDAR-derived DEM evaluation of deep-seated landslides in a steep and rocky region of japan. *Geomorphology, 113*(1), 57-69.

Kavzoglu, T., Sahin, E. K., & Colkesen, I. (2014). Landslide susceptibility mapping using GIS-based multi-criteria decision analysis, support vector machines, and logistic regression. *Landslides, 11*(3), 425-439.

Kaynia, A., Papathoma-Köhle, M., Neuhäuser, B., Ratzinger, K., Wenzel, H., & Medina-Cetina, Z. (2008). Probabilistic assessment of vulnerability to landslide: Application to the village of lichtenstein, baden-württemberg, germany. *Engineering Geology, 101*(1), 33-48.

Keefer, D. K., Wilson, R. C., Mark, R. K., Brabb, E. E., Brown, W. M.,3rd, Ellen, S. D., et al. (1987). Real-time landslide warning during heavy rainfall. *Science (New York, N.Y.), 238*(4829), 921-925.

King, D., & MacGregor, C. (2000). Using social indicators to measure community vulnerability to natural hazards. *Australian Journal of Emergency Management, the, 15*(3), 52.

Komac, M. (2005). Napoved verjetnosti pojavljanja plazov z analizo satelitskih in drugih prostorskih podatkov (landslide occurrence prediction with analysis of satellite images and other spatial data). *Geological Survey of Slovenia, Ljubljana,* , 136-138.

Komac, M. (2003). Geohazard map of the central slovenia-the mathematical approach to landslide prediction. *Geologija, 46*(2), 367-372.

Komac, M. (2006). A landslide susceptibility model using the analytical hierarchy process method and multivariate statistics in perialpine slovenia. *Geomorphology, 74*(1), 17-28.

Kussul, N., Shelestov, A., & Skakun, S. (2008). Grid system for flood extent extraction from satellite images. *Earth Science Informatics, 1*(3-4), 105-117.

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics,* , 159-174.

Lauknes, T., Piyush Shanker, A., Dehls, J., Zebker, H., Henderson, I., & Larsen, Y. (2010). Detailed rockslide mapping in northern norway with small baseline and persistent scatterer interferometric SAR time series methods. *Remote Sensing of Environment, 114*(9), 2097-2109.

Lee, E. M., & Jones, D. K. (2004a). *Landslide risk assessment* Thomas Telford.

Lee, M. L., Ng, K. Y., Huang, Y. F., & Li, W. C. (2014). Rainfall-induced landslides in hulu kelang area, malaysia. *Natural Hazards, 70*(1), 353-375.

Lee, S., & Evangelista, D. (2008). Landslide susceptibility mapping using probability and statistics models in baguio city, philippines. *Department of Environment and Natural Resources, North Avenue, Diliman, Quezon City, Philippines,*

Lee, S., Hwang, J., & Park, I. (2013). Application of data-driven evidential belief functions to landslide susceptibility mapping in jinbu, korea. *Catena, 100*, 15-30.

Lee, S., & Pradhan, B. (2007). Landslide hazard mapping at selangor, malaysia using frequency ratio and logistic regression models. *Landslides, 4*(1), 33-41.

Lee, S., Ryu, J., & Kim, I. (2007). Landslide susceptibility analysis and its verification using likelihood ratio, logistic regression, and artificial neural network models: Case study of youngin, korea. *Landslides, 4*(4), 327-338.

Leone, F., Asté, J., & Leroi, E. (1996). L'évaluation de la vulnérabilité aux mouvements de terrains: Pour une meilleure quantification du risque/The evaluation of vulnerability to mass movements: Towards a better quantification of landslide risks. *Revue De Géographie Alpine, 84*(1), 35-46.

Leroueil, S., Locat, J., Vaunat, J., Picarelli, L., Lee, H., & Faure, R. (1996). Geotechnical characterization of slope movements. *Proceedings of the 7th International Symposium on Landslides, Trondheim, Norway, , 1.* pp. 53-74.

Levine, C. (2004). The concept of vulnerability in disaster research. *Journal of Traumatic Stress, 17*(5), 395-402.

Li, Z., Nadim, F., Huang, H., Uzielli, M., & Lacasse, S. (2010). Quantitative vulnerability estimation for scenario-based landslide hazards. *Landslides, 7*(2), 125-134.

Lifeng, Y., & Youshui, Z. (2006). Debris flow hazard assessment based on support vector machine. *Wuhan University Journal of Natural Sciences, 11*(4), 897-900.

Liu, X. (2006). Site-specific vulnerability assessment for debris flows: Two case studies. *Journal of Mountain Science, 3*(1), 20-27.

Liu, X., Yue, Z. Q., Tham, L. G., & Lee, C. F. (2002). Empirical assessment of debris flow risk on a regional scale in yunnan province, southwestern china. *Environmental Management, 30*(2), 249-264.

Lu, P., Stumpf, A., Kerle, N., & Casagli, N. (2011). Object-oriented change detection for landslide rapid mapping. *Geoscience and Remote Sensing Letters, IEEE, 8*(4), 701-705.

Lucà, F., D'Ambrosio, D., Robustelli, G., Rongo, R., & Spataro, W. (2014). Integrating geomorphology, statistic and numerical simulations for landslide invasion hazard scenarios mapping: An example in the sorrento peninsula (italy). *Computers & Geosciences, 67*, 163-172.

Malamud, B. D., Turcotte, D. L., Guzzetti, F., & Reichenbach, P. (2004). Landslide inventories and their statistical properties. *Earth Surface Processes and Landforms, 29*(6), 687-711.

Manzo, G., Tofani, V., Segoni, S., Battistini, A., & Catani, F. (2013). GIS techniques for regional-scale landslide susceptibility assessment: The sicily (italy) case study. *International Journal of Geographical Information Science, 27*(7), 1433-1452.

Marjanović, M. (2013). Comparing the performance of different landslide susceptibility models in ROC space. *Landslide science and practice* (pp. 579-584) Springer.

Marjanović, M., Kovačević, M., Bajat, B., & Voženílek, V. (2011). Landslide susceptibility assessment using SVM machine learning algorithm. *Engineering Geology, 123*(3), 225-234.

Mavrouli, O., Corominas, J., & Wartman, J. (2009). Methodology to evaluate rock slope stability under seismic conditions at sola de santa coloma, andorra. *Natural Hazards and Earth System Science, 9*(6), 1763-1773.

Menard, S. (2000). Coefficients of determination for multiple logistic regression analysis. *The American Statistician, 54*(1), 17-24.

Mondini, A., Guzzetti, F., Reichenbach, P., Rossi, M., Cardinali, M., & Ardizzone, F. (2011). Semi-automatic recognition and mapping of rainfall induced shallow landslides using optical satellite images. *Remote Sensing of Environment, 115*(7), 1743-1757.

Montgomery, D. R., & Dietrich, W. E. (1994). A physically based model for the topographic control on shallow landsliding. *Water Resources Research, 30*(4), 1153-1171.

Moreiras, S. M. (2005). Landslide susceptibility zonation in the Rio Mendoza valley, Argentina. *Geomorphology, 66*(1), 345-357.

Morris, S., Robida, C., Zarikian, L., Kearns, D., Rose, N., Pacheco, A., et al. (2013). *Methods and Systems for Segmentation using Multiple Dependent Variables,*

Murillo-García, F., Rossi, M., Fiorucci, F., & Alcántara-Ayala, I. (2015). Population landslide vulnerability evaluation: The case of the indigenous population of pahuatlán-puebla, Mexico. *Engineering geology for society and territory-volume 2* (pp. 1793-1797) Springer.

National Research Council (US). Committee on the Review of National Landslide Hazards Mitigation Strategy, & National Research Council. (2004). *Partnerships for reducing landslide risk: Assessment of the national landslide hazards mitigation strategy* Grove/Atlantic, Inc.

Nefeslioglu, H., & Gokceoglu, C. (2011a). Probabilistic risk assessment in medium scale for rainfall-induced earthflows: Catakli catchment area (cayeli, rize, turkey). *Mathematical Problems in Engineering, 2011*

Nefeslioglu, H., & Gokceoglu, C. (2011b). Probabilistic risk assessment in medium scale for rainfall-induced earthflows: Catakli catchment area (cayeli, rize, turkey). *Mathematical Problems in Engineering, 2011*

Nefeslioglu, H., Gokceoglu, C., & Sonmez, H. (2008). An assessment on the use of logistic regression and artificial neural networks with different sampling strategies for the preparation of landslide susceptibility maps. *Engineering Geology, 97*(3), 171-191.

Oh, H., & Pradhan, B. (2011). Application of a neuro-fuzzy model to landslide-susceptibility mapping for shallow landslides in a tropical hilly area. *Computers & Geosciences, 37*(9), 1264-1276.

Ohlmacher, G. C., & Davis, J. C. (2003). Using multiple logistic regression and GIS technology to predict landslide hazard in northeast Kansas, USA. *Engineering Geology, 69*(3), 331-343.

Pan, W. S., Lu, Y. D., & Guo, J. Y. (2014). Risk assessment and management of geological disaster based on risk period analysis and GIS in loess areas. *Applied Mechanics and Materials, , 675.* pp. 1184-1191.

Papathoma-Köhle, M., Neuhäuser, B., Ratzinger, K., Wenzel, H., & Dominey-Howes, D. (2007). Elements at risk as a framework for assessing the vulnerability of communities to landslides. *Natural Hazards and Earth System Science, 7*(6), 765-779.

Papathoma-Köhle, M., Zischg, A., Fuchs, S., Glade, T., & Keiler, M. (2015). Loss estimation for landslides in mountain areas–An integrated toolbox for vulnerability assessment and damage documentation. *Environmental Modelling & Software, 63*, 156-169.

Papoulis, A., & Pillai, S. (2002). Probability, random variables, and stochastic processes (; McGraw-hill, Boston).

Park, N. (2011). Application of dempster-shafer theory of evidence to GIS-based landslide susceptibility analysis. *Environmental Earth Sciences, 62*(2), 367-376.

Pasuto, A., & Silvano, S. (1998). Rainfall as a trigger of shallow mass movements. A case study in the dolomites, Italy. *Environmental Geology, 35*(2-3), 184-189.

Pedrazzini, A., Humair, F., Jaboyedoff, M., & Tonini, M. (2015). Characterisation and spatial distribution of gravitational slope deformation in the upper rhone catchment (western swiss alps). *Landslides,* , 1-19.

Pesci, A., Teza, G., & Ventura, G. (2008). Remote sensing of volcanic terrains by terrestrial laser scanner: Preliminary reflectance and RGB implications for studying Vesuvius crater (Italy). *Annals of Geophysics, 51*(4), 633-653.

Poiraud, A. (2014). Landslide susceptibility–certainty mapping by a multi-method approach: A case study in the tertiary basin of puy-en-Velay (massif central, France). *Geomorphology, 216*, 208-224.

Pourghasemi, H. R., Pradhan, B., & Gokceoglu, C. (2012). Application of fuzzy logic and analytical hierarchy process (AHP) to landslide susceptibility mapping at haraz watershed, Iran. *Natural Hazards, 63*(2), 965-996.

Pradhan, B. (2010a). Flood susceptible mapping and risk area delineation using logistic regression, GIS and remote sensing. *Journal of Spatial Hydrology, 9*(2)

Pradhan, B. (2010b). Remote sensing and GIS-based landslide hazard analysis and cross-validation using multivariate logistic regression model on three test areas in Malaysia. *Advances in Space Research, 45*(10), 1244-1256.

Pradhan, B. (2011). Manifestation of an advanced fuzzy logic model coupled with geo-information techniques to landslide susceptibility mapping and their comparison with logistic regression modeling. *Environmental and Ecological Statistics, 18*(3), 471-493.

Pradhan, B. (2013). A comparative study on the predictive ability of the decision tree, support vector machine and neuro-fuzzy models in landslide susceptibility mapping using GIS. *Computers & Geosciences, 51*, 350-365.

Pradhan, B., & Lee, S. (2010a). Delineation of landslide hazard areas on Penang island, Malaysia, by using frequency ratio, logistic regression, and artificial neural network models. *Environmental Earth Sciences, 60*(5), 1037-1054.

Pradhan, B., & Lee, S. (2010c). Landslide susceptibility assessment and factor effect analysis: Backpropagation artificial neural networks and their comparison with frequency ratio and bivariate logistic regression modeling. *Environmental Modelling & Software, 25*(6), 747-759.

Pradhan, B., & Lee, S. (2010d). Regional landslide susceptibility analysis using back-propagation neural network model at Cameron highland, Malaysia. *Landslides, 7*(1), 13-30.

Pradhan, B., Oh, H., & Buchroithner, M. (2010). Weights-of-evidence model applied to landslide susceptibility mapping in a tropical hilly area. *Geomatics, Natural Hazards and Risk, 1*(3), 199-223.

Pradhan, B., Sezer, E. A., Gokceoglu, C., & Buchroithner, M. F. (2010). Landslide susceptibility mapping by neuro-fuzzy approach in a landslide-prone area (Cameron highlands, Malaysia). *Geoscience and Remote Sensing, IEEE Transactions on, 48*(12), 4164-4177.

Pradhan, B., & Youssef, A. M. (2010). Manifestation of remote sensing data and GIS on landslide hazard analysis using spatial-based statistical models. *Arabian Journal of Geosciences, 3*(3), 319-326.

Premchitt, J., Brand, E., & Phillipson, H. (1986). Landslides caused by rapid groundwater changes. *Geological Society, London, Engineering Geology Special Publications, 3*(1), 87-94.

Provost, F., & Fawcett, T. (2001). Robust classification for imprecise environments. *Machine Learning, 42*(3), 203-231.

PWD, P. W. D. (2008). Kajian pelan induk langkah-langkah pembaikan cerun di Malaysia. *Kajian Pelan Induk Cerun Negara - National Slope Master Plan Study,*

Rahardjo, H., Rezaur, R., & Leong, E. (2009). Mechanism of rainfall-induced slope failures in tropical regions. *1st Italian Workshop on Landslides, , 1.*

Razak, K. A., Straatsma, M., Van Westen, C., Malet, J., & De Jong, S. (2011). Airborne laser scanning of forested landslides characterization: Terrain model quality and visualization. *Geomorphology, 126*(1), 186-200.

Regmi, N. R., Giardino, J. R., & Vitek, J. D. (2010). Assessing susceptibility to landslides: Using models to understand observed changes in slopes. *Geomorphology, 122*(1), 25-38.

Remondo, J., Bonachea, J., & Cendrero, A. (2008). Quantitative landslide risk assessment and mapping on the basis of recent occurrences. *Geomorphology, 94*(3), 496-507.

Roberds, W. (2005a). Estimating temporal and spatial variability and vulnerability. *Landslide Risk Management. Edited by Hungr, O., Fell, R., Couture, R., Eberhardt, E. Proceedings of the International Conference on Landslide Risk Management, Vancouver, London: Taylor and Francis,* pp. 129-157.

Roberds, W. (2005b). Estimating temporal and spatial variability and vulnerability. *Landslide Risk Management.Taylor & Francis, London,* , 129-158.

Rosin, P., & Hervas, J. (2005). Remote sensing image thresholding methods for determining landslide activity. *International Journal of Remote Sensing, 26*(6), 1075-1092.

Rossi, M., Guzzetti, F., Reichenbach, P., Mondini, A. C., & Peruccacci, S. (2010). Optimal landslide susceptibility zonation based on multiple forecasts. *Geomorphology, 114*(3), 129-142.

Saito, H., Nakayama, D., & Matsuyama, H. (2009). Comparison of landslide susceptibility based on a decision-tree model and actual landslide occurrence: The akaishi mountains, japan. *Geomorphology, 109*(3), 108-121.

Santangelo, M., Cardinali, M., Rossi, M., Mondini, A., & Guzzetti, F. (2010). Remote landslide mapping using a laser rangefinder binocular and GPS. *Natural Hazards and Earth System Science, 10*(12), 2539-2546.

Sarkar, A., Benabbou, N., & Ghanem, R. (2009). Domain decomposition of stochastic PDEs: Theoretical formulations. *International Journal for Numerical Methods in Engineering, 77*(5), 689-701.

Sassa, K., & Canuti, P. (2008). *Landslides-disaster risk reduction: Disaster risk reduction* Springer.

Schuster, R. L., & Wieczorek, G. F. (2002). Landslide triggers and types. *Landslides: Proceedings of the First European Conference on Landslides, Taylor & Francis, Prague,* pp. 59-78.

Sezer, E. A., Pradhan, B., & Gokceoglu, C. (2011). Manifestation of an adaptive neuro-fuzzy model on landslide susceptibility mapping: Klang valley, Malaysia. *Expert Systems with Applications, 38*(7), 8208-8219.

Shafer, G. (1976). *A mathematical theory of evidence* Princeton university press Princeton.

Shaharom, S., Huat, L. T., & Othman, M. A. (2014). Area based landslide hazard and risk assessment for Penang island Malaysia. *Landslide science for a safer geoenvironment* (pp. 513-519) Springer.

Sidle, R. C., & Ochiai, H. (2006). *Landslides: Processes, prediction, and land use* American Geophysical Union.

Singhroy, V. H. (2014). Landslides. *Encyclopedia of Remote Sensing,* , 328-332.

Slatton, K. C., Carter, W. E., Shrestha, R. L., & Dietrich, W. (2007). Airborne laser swath mapping: Achieving the resolution and accuracy required for geosurficial research. *Geophysical Research Letters, 34*(23)

Smirnoff, A., Boisvert, E., & Paradis, S. J. (2008). Support vector machine for 3D modeling from sparse geological information of various origins. *Computers & Geosciences, 34*(2), 127-143.

Soralump, S. (2010). Rainfall-triggered landslide: From research to mitigation practice in Thailand. *Geotechnical Engineering, 41*(1), 39.

Sorbino, G., Sica, C., & Cascini, L. (2010). Susceptibility analysis of shallow landslides source areas using physically based models. *Natural Hazards, 53*(2), 313-332.

Srivastava, V., Srivastava, H. B., & Lakhera, R. (2010). Fuzzy gamma based geomatic modelling for landslide hazard susceptibility in a part of tons river valley, northwest Himalaya, India. *Geomatics, Natural Hazards and Risk, 1*(3), 225-242.

Swets, J. A. (1988). Measuring the accuracy of diagnostic systems. *Science (New York, N.Y.), 240*(4857), 1285-1293.

Tangestani, M. (2004). Landslide susceptibility mapping using the fuzzy gamma approach in a GIS, kakan catchment area, southwest Iran. *Australian Journal of Earth Sciences, 51*(3), 439-450.

Tarolli, P., Sofia, G., & Dalla Fontana, G. (2012). Geomorphic features extraction from high-resolution topography: Landslide crowns and bank erosion. *Natural Hazards, 61*(1), 65-83.

Taubenböck, H., Post, J., Roth, A., Zosseder, K., Strunz, G., & Dech, S. (2008). A conceptual vulnerability and risk framework as outline to identify capabilities of remote sensing. *Natural Hazards and Earth System Science, 8*(3), 409-420.

Tien Bui, D., Pradhan, B., Lofman, O., Revhaug, I., & Dick, O. B. (2012). Spatial prediction of landslide hazards in the Hoa Binh province (Vietnam): A comparative assessment of the efficacy of evidential belief functions and fuzzy logic models. *Catena, 96*, 28-40.

Tobler, W. (1987). Measuring spatial resolution. *Proceedings, Land Resources Information Systems Conference*, pp. 12-16.

Tournadour, E., Mulder, T., Borgomano, J., Hanquiez, V., Ducassou, E., & Gillet, H. (2015). Origin and architecture of a mass transport complex on the northwest slope of little Bahama bank (Bahamas): Relations between off-bank transport, bottom current sedimentation and submarine landslides. *Sedimentary Geology, 317*, 9-26.

Trigila, A., Iadanza, C., & Spizzichino, D. (2010). Quality assessment of the Italian landslide inventory using GIS processing. *Landslides, 7*(4), 455-470.

Tsang, C. (1991). Coupled hydromechanical-thermochemical processes in rock fractures. *Reviews of Geophysics, 29*(4), 537-551.

Ukhorskiy, A., Sitnov, M., Sharma, A., & Papadopoulos, K. (2002). On the origin of the power-law spectra in magnetospheric dynamics during substorms. *J.Geophys.Res,*

United Nations Development Program. (2004). A human development report 2004. *United Nations, New York,* , 299 pp.

Uzielli, M., Nadim, F., Lacasse, S., & Kaynia, A. M. (2008). A conceptual framework for quantitative estimation of physical vulnerability to landslides. *Engineering Geology, 102*(3), 251-256.

Van Den Eeckhaut, M., Hervas, J., & Montanarella, J. (2010). Validation of landslide inventory, susceptibility and hazard maps for risk management. *URL: Http://globesec. Jrc. Ec. Europa. eu/workshops/valgeo-2010/presentations/session-2/VanDenEeckhaut_al_v4. Pdf, Accessed on December 22nd,*

Van Den Eeckhaut, M., Poesen, J., Verstraeten, G., Vanacker, V., Nyssen, J., Moeyersons, J., et al. (2007). Use of LIDAR-derived images for mapping old landslides under forest. *Earth Surface Processes and Landforms, 32*(5), 754-769.

Van Den Eeckhaut, M., Vanwalleghem, T., Poesen, J., Govers, G., Verstraeten, G., & Vandekerckhove, L. (2006). Prediction of landslide susceptibility using rare events logistic regression: A case-study in the flemish Ardennes (Belgium). *Geomorphology, 76*(3), 392-410.

Van Westen, C. ANALYZING CHANGING RISK AND PLANNING ALTERNATIVES: A CASE STUDY OF A SMALL ISLAND COUNTRY.

Van Westen, C. (2009). Multi-hazard risk assessment. *Distance Education Course Guide Book.Bangkok, United Nations University-ITC,*

Van Westen, C. J., Castellanos, E., & Kuriakose, S. L. (2008). Spatial data for landslide susceptibility, hazard, and vulnerability assessment: An overview. *Engineering Geology, 102*(3), 112-131.

Van Westen, C. (2004a). Geo-information tools for landslide risk assessment: An overview of recent developments. *Landslides: Evaluation and Stabilization, 1*, 39-56.

Van Westen, C., Seijmonsbergen, A., & Mantovani, F. (1999). Comparing landslide hazard maps. *Natural Hazards, 20*(2-3), 137-158.

Van Westen, C., Soeters, R., & Rengers, N. (1993). Geographic information systems as applied to landslide hazard zonation. *Mapping Awareness & GIS in Europe, 7*(5), 9-13.

Van Westen, C., Van Asch, T. W., & Soeters, R. (2006). Landslide hazard and risk zonation—why is it still so difficult? *Bulletin of Engineering Geology and the Environment, 65*(2), 167-184.

Varnes, D. J. (1984). Landslide hazard zonation: A review of principles and practice.

Wang, W. D., Xie, C. M., & Du, X. G. (2009). Landslides susceptibility mapping based on geographical information system, GuiZhou, south-west china. *Environmental Geology, 58*(1), 33-43.

White, I. D., Mottershead, D. N., Harrison, S. J.,. (1996). *Environmental systems* (2nd ed.). London: Chapman & Hall.

White, P., Pelling, M., Sen, K., Seddon, D., Russell, S., & Few, R. (2005). Disaster risk reduction: A development concern. *London: DfID,*

Wieczorek, G. F. (1996). Landslide triggering mechanisms. *AK Turner and RL Schuster, Op.Cit,* , 76-90.

Wieczorek, G. F., Gori, P. L., & Highland, L. M. (2005). Reducing landslide hazards and risk in the united states: The role of the US geological survey. *Landslide Hazard and Risk.Wiley, New York,* , 351-375.

Wilson, J. P., & Gallant, J. C. (2000). Digital terrain analysis. *Terrain Analysis: Principles and Applications,* , 1-27.

Wood, E. F., Sivapalan, M., & Beven, K. (1990). Similarity and scale in catchment storm response. *Reviews of Geophysics, 28*(1), 1-18.

Xu, C., Dai, F., Xu, X., & Lee, Y. H. (2012). GIS-based support vector machine modeling of earthquake-triggered landslide susceptibility in the Jinjiang river watershed, china. *Geomorphology, 145*, 70-80.

Yang, X., & Lo, C. (2000). Relative radiometric normalization performance for change detection from multi-date satellite images. *Photogrammetric Engineering and Remote Sensing, 66*(8), 967-980.

Yao, X., & Dai, F. (2006). Support vector machine modeling of landslide susceptibility using a GIS: A case study. *IAEG2006, 793*

Yao, X., Tham, L., & Dai, F. (2008). Landslide susceptibility mapping based on support vector machine: A case study on natural slopes of hong kong, china. *Geomorphology, 101*(4), 572-582.

Yilmaz, I. (2009). Landslide susceptibility mapping using frequency ratio, logistic regression, artificial neural networks and their comparison: A case study from kat landslides (Tokat—Turkey). *Computers & Geosciences, 35*(6), 1125-1138.

Yilmaz, I. (2010). Comparison of landslide susceptibility mapping methodologies for koyulhisar, turkey: Conditional probability, logistic regression, artificial neural networks, and support vector machine. *Environmental Earth Sciences, 61*(4), 821-836.

Zêzere, J., Garcia, R., Oliveira, S., & Reis, E. (2008). Probabilistic landslide risk analysis considering direct costs in the area north of Lisbon (Portugal). *Geomorphology, 94*(3), 467-495.

Zêzere, J., Trigo, R., & Trigo, I. (2005). Shallow and deep landslides induced by rainfall in the Lisbon region (Portugal): Assessment of relationships with the north Atlantic oscillation. *Natural Hazards and Earth System Science, 5*(3), 331-344.

Zêzere, J. L., de Brum Ferreira, A., & Rodrigues, M. L. (1999). The role of conditioning and triggering factors in the occurrence of landslides: A case study in the area north of Lisbon (Portugal). *Geomorphology, 30*(1), 133-146.

Zhao, H. (2008). Slope reliability analysis using a support vector machine. *Computers and Geotechnics, 35*(3), 459-467.

Zinck, J. A., López, J., Metternicht, G. I., Shrestha, D. P., & Vázquez-Selem, L. (2001). Mapping and modelling mass movements and gullies in mountainous areas using remote sensing and GIS techniques. *International Journal of Applied Earth Observation and Geoinformation, 3*(1), 43-53.