HYBRID MODEL OF SPATIO-TEMPORAL ASSESSMENT OF LANDSLIDE HAZARDS BY USING AIRBORNE LASER ALTIMETRY DATA

TEHMINA BIBI

A thesis submitted in the fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Geoinformatics)

Faculty of Built Environment and Surveying
Universiti Teknologi Malaysia

JULY 2019

DEDICATION

To
My parents
My husband
My little angel Umaima Adnan
&
All the supporting members of my family and friends

ACKNOWLEDGEMENT

First of all, I am thankful to ALLAH (S.W.T) for His countless blessings and spirit offered by Him. Every single thing I have done so far including this exigent task, is just because He wanted me to do. I cannot move forward without acknowledging the guidance of our great Prophet Muhammad (S.A.W.) who enlightened us to ponder upon the monotheism and divinity of ALLAH (S.W.T).

In preparation of this thesis, number of people including researchers, academicians, colleagues and practitioners have helped me to achieve this landmark. They have directly or indirectly contributed towards my conception and thoughts for constructing research framework. In particular, I feel highly obliged to extend my sincere appreciation toward my thesis supervisor, Professor Dr Alias bin Abdul Rahman, for his kind and valuable guidance, encouragement, and constructive critics. I am also grateful to Dr. Khamarrul Azahari Bin Razak for support and motivation. Without the continued support and interest of my supervisors, this thesis would not have been possible in a way as presented here.

I also indebted to Universiti Teknologi Malaysia (UTM) in general and their academic and administrative staff, for providing a priceless opportunity to pursue my Ph.D. study. I owe my special gratitude to Ministry of Higher Education Malaysia (MOHE) for awarding me Malaysian International Scholarship for pursuing my Ph.D. from Universiti Teknologi Malaysia. I may not close it without appreciating the role of Jabatan Mineral dan Geoscience Malaysia (JMG) and especially Mr Mohd Farid bin Abdul Kadir who have great contribution in terms of data and knowledge.

Last but not least, my family, friends, and colleagues remain a major source of motivation and persistence for the accomplishment of this milestone.

My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Unfortunately, it is not possible to list all of them in this limited space.

ABSTRACT

Landslide is a consistent hazard in mountainous terrain, especially in seismically active areas and regions of high rainfall (tropical regions). The key goal of landslide hazard analysis is to observe the location, intensity (magnitude), and occurrence time (prediction) of landslide. Assessment of landslide hazard and future sensitivity prediction are at the infancy level because of the lack of temporal datasets and efficient modelling techniques. Due to the complex nature of landslides, several modeling methods have been applied for the assessment of landslide hazard. This study developed a hybrid modeling approach named weight of evidence based convolutional neural network (WOECNN) using two models, machine learning model which is convolutional neural networks (CNN) and weight of evidence (WOE) technique of bivariate statistical model. In this study the hybrid model was utilized for generating landslide hazard index (LHI) and sensitivity prediction for future using spatio-temporal data (3D). Two study areas having with environmental and physical conditions including seismo-tectonically active region of Sg. Mesilau, Kundasang, Sabah and Gombak Selangor, were selected for this study. The spatial dataset initially constructed landslide inventory maps for these two sample areas through virtual mapping technique. 21 landslide-causative factors which included slope angle, aspect, altitude, TWI, SPI, TST, TSC, TSConv, soil, lithology, land use, rainfall, seismicity and distance to roads, rivers, roads, and faults were derived from different sources including Airborne Laser Altimetry (ALS) data. These results were validated using receiver operating characteristic (ROC) curve. The area under curve (AUC) of ROC for the landslide hazard index of Sg. Mesilau, Kundasang with respect to different scenarios illustrated that there were variations in between the AUC values for all three scenarios. The AUC value of LHI with maximum parameters was higher (0.82) than the other scenarios as it had less parameters based on priority ranking. While in the Gombak Selangor area the situation was reverse as the AUC values were showed an increasing trend with a decrease in the parameters. The highest AUC value (0.89) was obtained with minimum parameters. Moreover, results of sensitivity prediction (0.86) for Quartz Ridge, Selangor area revealed that the greater part of study was within the range of medium to low hazard. In general, the variation of validation results for landslide hazard assessment in both areas depicted the importance of parameters selection. Based on results, the hybrid models can perform better than the individual models. The present study indicates that WOECNN has performed more efficiently for sensitivity prediction as compared to the individual models.

ABSTRAK

Tanah runtuh merupakan situasi berbahaya yang konsisten di kawasan aktif secara seismic di pergunungan dan kawasan kepadatan hujan tinggi (wilayah tropika). Matlamat utama analisis risiko bahaya tanah runtuh adalah untuk melihat lokasi, intensiti (magnitud), dan masa berlakunya (ramalan) tanah runtuh. Penilaian berbahaya tanah runtuh dan ramalan kepekaan masa depan berada pada peringkat awal kerana kekurangan data temporal dan teknik pemodelan yang cekap. Disebabkan sifat tanah runtuh yang kompleks, beberapa kaedah pemodelan telah digunakan untuk penilaian bahaya tanah longsor. Kajian ini menghasilkan pendekatan pemodelan hibrid yang dinamakan konvolusi rangkaian neural berasaskan pemberat bukti (WOECNN) dengan menggunakan dua model, model pembelajaran mesin yang merupakan rangkaian neural konvensional (CNN) dan teknik pemberatan bukti (WOE) daripada teknik model statistik dwiperubah. Dalam kajian ini, model hibrid telah digunakan untuk menghasilkan indeks bahaya tanah runtuh (LHI) dan ramalan kepekaan untuk masa depan menggunakan data ruang masa (3D). Dua kawasan kajian yang mempunyai keadaan alam sekitar dan fizikal termasuk wilayah aktif seismik-tektonik Sg. Mesilau, Kundasang, Sabah dan Gombak Selangor, Selangor dipilih untuk kajian ini. Dataset ruang pada mulanya dibina peta inventori tanah runtuh untuk kedua-dua kawasan sampel melalui teknik pemetaan maya. 21 faktor penyebab tanah runtuh termasuk sudut cerun, aspek, ketinggian, TWI, SPI, TST, TSC, TSConv, tanah, litologi, penggunaan tanah, hujan, seismik dan jarak ke jalan raya, sungai, jalan raya dan gelinciran telah diperoleh dari sumber yang berbeza termasuk data Altimetri Laser Udara (ALS). Keputusan ini telah disahkan menggunakan lenkung ciri operasi penerima (ROC). Kawasan di bawah lengkung (AUC) daripada ROC untuk indeks bahaya tanah runtuh Sg. Mesilau, Kundasang berhubung dengan daripada senario yang berbeza menggambarkan bahawa terdapat variasi di antara nilai AUC untuk ketiga-tiga senario ini. Nilai AUC LHI dengan parameter maksimum adalah lebih tinggi (0.82) daripada senario yang lain kerana parameternya kurang berdasarkan kedudukan utama. Manakala di kawasan batas kuarza Gombak Selangor, keadaan itu berlaku sebaliknya kerana nilai AUC menunjukkan trend yang semakin meningkat dengan penurunan parameter. Nilai AUC tertinggi (0.89) diperoleh dengan parameter minimum. Selain itu, hasil ramalan sensitiviti (0.86) untuk kawasan batas kuarza, Selangor mendedahkan bahawa sebahagian besar kajian berada dalam lingkungan bahaya sederhana hingga rendah. Secara umumnya, variasi keputusan pengesahan untuk penilaian bahaya tanah runtuh di kedua-dua kawasan menggambarkan kepentingan pemilihan parameter. Berdasarkan keputusan, model hibrid adalah lebih baik daripada model individu. Kajian ini menunjukkan bahawa WOECNN lebih cekap untuk ramalan kepekaan dibandingkan dengan model individu.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	**ii**
	DEDICATION	**iii**
	ACKNOWLEDGEMENT	**iv**
	ABSTRACT	**v**
	ABSTRAK	**vi**
	TABLE OF CONTENTS	**vii**
	LIST OF TABLES	**xi**
	LIST OF FIGURES	**xiii**
	LIST OF ABBREVIATIONS	**xvi**
	LIST OF APPENDICES	**xviii**
CHAPTER 1	**INTRODUCTION**	**1**
1.1	Problem Background	1
1.2	Research Problem	5
1.3	Research Questions	8
1.4	Research Objectives	9
1.5	Scope of the Study	9
1.6	Significance of Study	10
1.7	Thesis Outline	11
CHAPTER 2	**OVERVIEW OF THE PREVIOUS WORKS**	**13**
2.1	Introduction	13
2.2	Conceptual framework of landslide hazard	14
	2.2.1 Brief History	14
	2.2.2 Landslide definitions	15
	2.2.3 Landslide Classification	15
	2.2.4 Definitions of Landslide Types and Features	18

2.2.5 Landslide features 20

2.2.6 Landslide Activity 22

2.2.7 Principles of Slope Stability 24

2.3 Landslide in Malaysia 25

2.4 Spatial Data for landslide 29

2.5 Landslide Inventory Mapping Approaches 31

2.5.1 Direct Method of Mapping 32

2.5.2 Landslide Inventory Mapping through Historical Records 33

2.5.3 Landslide Recognition, Detection and Classification with Remote Sensing Data 34

2.5.4 Automatic and Semi-automatic Mapping Approach 34

2.5.5 Visual Interpretation via Medium to High Resolution Images 38

2.6 The importance of Remote Sensing in Mapping Landslide Predisposing Factors 42

2.6.1 Influence of Vegetation and Land-cover type to Slope Stability 43

2.6.2 Geology and Lithology 44

2.6.3 Topographic / Morphometric Properties 47

2.6.4 Geomorphology 48

2.6.5 Hydrology 48

2.6.6 Anthropogenic Factors 50

2.7 Landslide Triggering Factors: Rainfall 51

2.8 Landslide Hazard Mapping Techniques 54

2.8.1 Geomorphological Field Method 55

2.8.2 Maps Combination Approach 57

2.8.3 Heuristic Methods 57

2.8.4 Process- based Deterministic / Methods 58

2.8.5 Statistical Methods 59

2.8.6 Empirical Analysis Methods 60

2.8.7 Multi-Criteria Decision Making (MCDM) 62

2.8.8 Distribution Free Approaches 63

2.9 The Priority Ranking of Landslide Predisposing Factors through Random Forest Classifier 67
2.10 Valuation and Validation of Performance of Landslide Model 69
2.11 Chapter Summary 70

CHAPTER 3 THE METHODOLOGY 73
3.1 Introduction 73
3.2 Methodology 74
3.3 Datasets 76
3.4 Landslide Inventory Mapping 77
3.5 Predisposing Factor Selection and Prioritization/ Ranking 79
3.6 Hazard Analysis 80
3.7 Landslide Hazard Prediction 85
3.8 Validation of the Results 87
3.9 Tool and Software 89
3.10 Summary 90

CHAPTER 4 DERIVATION OF FACTORS FOR LANDSLIDE MODELLING 91
4.1 Introduction 91
4.2 Intermediate channel of River Mesilau, Kundasang 91
  4.2.1 Geology 92
  4.2.2 Climate 93
4.3 Gombak Selangor Quartz Ridge (Urban Area) 95
  4.3.1 Geology 96
  4.3.2 Climate 97
4.4 Landslide Mapping in Tropical Region 99
4.5 Airborne Laser Scanning (ALS) based Landslide Inventory Mapping (LIM) 100
  4.5.1 LiDAR Processing 103
  4.5.2 Image Visualization and Interpretation 103
  4.5.3 Historical data of landslide 107

4.6 Expert Knowledge and Field verification 107
4.7 Predisposing/ Conditioning Factor Maps 109
  4.7.1 Geomorphological Parameters 110
  4.7.2 Hydro-topographical Parameters 116
  4.7.3 Geological Parameters 118
  4.7.4 Anthropogenic Parameters 121
4.8 Triggering Factors 122
  4.8.1 Earthquake 123
  4.8.2 Rainfall 123
  4.8.3 Distance to Seismic 123
4.9 Prioritization/ Ranking of predisposing factors 124
4.10 Chapter Summary 125

CHAPTER 5 RESULTS AND DISCUSSIONS 127
5.1 Introduction 127
5.2 Landslide inventory mapping (LIM) 128
5.3 Generation of landslide predisposing and triggering factor maps 129
5.4 Landslide Hazard Analyses 130
  5.4.1 Landslide Hazard Index (LHI) 130
  5.4.2 Landslide Sensitivity Prediction based on Convolutional Neural Network (CNN) 137
5.5 Discussion 141

CHAPTER 6 CONCLUSION AND RECOMMENDATION 147
6.1 Contributions 149
6.2 Recommendations 149

REFERENCES 151
Appendices A-G 188-213

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Process, type and material-based classification of mass movement (Cruden and Varnes 1996; Dikau *et al.*, 1996)	16
Table 2.2	Velocity based mass movement classification (after Cruden and Varnes, 1996; Australian Geomechanics Society, 2002)	17
Table 2.3	Description and classification of landslide activity (Soeters and van Westen, 1996)	22
Table 2.4	Schematic representation of basic data sets for landslide susceptibility, hazard and risk assessment (Van Westen *et al.*, 2008)	30
Table 2.5	Contemporary RS systems (after Guzzetti *et al.*, 2012)	40
Table 2.6	Machine Learning Algorithms	65
Table 3.1	List of Datasets of the study area (Source: JMG, Malaysia)	76
Table 4.1	Terrain surface classification classes, (Iwahashi and Pike (2007)	115
Table 5.1	Results of Three Scenarios Based on Parameters Priority Ranking	132
Table 5.2	AUC Values Obtained from different Analysis Scenario of Landslide Hazard Index (LHI)	134
Table 5.3	Results of Three Scenarios based on Parameters Priority Ranking	135
Table 5.4	AUC Values Obtained from different Analysis Scenario of Landslide Hazard Index (LHI)	137
Table 5.5	Results of Sensitivity prediction of landslide hazard in Gombak Selangor Quartz Ridge area	139

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 2.1	Landslide classification modified by Hungr *et al.* (2014), which is based on slope movement and earth material	19
Figure 2.2	Landslide features of deep-seated landslide (Varnes, 1978)	20
Figure 2.3	Landslide activity changes from active (1993), suspended (1998), and dormant (2007) (after Van Westen)	23
Figure 2.4	Sketch of landslide distribution (1) advancing; (2) Progressing; (3) Enlarging; (4) Diminishing; (5) Confined. (Cruden & Varnes, 1996)	24
Figure 2.5	The stability states and destabilizing factors of landslide (after Crozier 1989; Glade and Crozier 2005)	25
Figure 2.6	Landslides Hazard Map in Peninsular Malaysia Source: National Slope Master Plan 2009-2023 (2009).	26
Figure 2.7	Debris flow of Gunung Pulai (right, 2001) and Keningau (left, 2011) (Rahman, (2015)	27
Figure 2.8	Examples of rockfall in Selangor (Photo courtesy to JMG Selangor)	28
Figure 2.9	Example of rotational landslide that occurred at Gunung Tempurung, Perak	28
Figure 2.10	Example of translational landslide that occurred at MRSM Bentong, Pahang (Kosmo, 2010)	28
Figure 2.11	Highland Tower (1993), Bukit Antarabangsa (2008), and Hulu Langat landslides (Rahmana and Mapjabilb, 2017)	29

Figure 2.12 Different techniques of landslide investigation (after Van Westen) 32

Figure 2.13 Chart showing Landslide Susceptibility/Hazard Assessment Methods 56

Figure 3.1 Conceptual Model of Landslide Hazard and Sensitivity Prediction 75

Figure 3.2 Schematic Representation of Landslide Inventory 78

Figure 3.3 Random Forest Classification Tree 79

Figure 3.4 Parameters and process adopted for the quantitative assessment of landslide hazard 81

Figure 3.5 Basic flow for designing CNN model. 85

Figure 3.6 Architecture of Multilayer Convolutional Neural Network (CNN) for the Prediction of Landslides 86

Figure 3.7 Architecture of multilayer convolutional network for the prediction of landslides 87

Figure 3.8 ROC (Receiver-Operating Characteristic) Curve 88

Figure 4.1 Location map of Sg Mesilau, Kundasang, Ranau, Saba state of Eastern Peninsular Malaysia 92

Figure 4.2 Average annual temperature of Mesilau, Kundasang 94

Figure 4.3 Average Monthly Precipitation of Mesilau, Kundasang 95

Figure 4.4 Map showing Location of Gombak Selangor Quartz Ridge (yellow bar) in Selangor state of Peninsular Malaysia 96

Figure 4.5 Average monthly precipitation of Gombak, Selangor 97

Figure 4.6 Average annual temperature of Gombak, Selangor 98

Figure 4.7 LiDAR derivatives: A) Slope, B) Hillshad, C) color composite, D) curvature, E) topographic openness, F) 3D anaglyph. 102

Figure 4.8 Diagnostic features of landslides in different morphological conditions 104

Figure 4.9 Simplified procedure for landslide interpretation (after Van Westen) 106

Figure 4.10 Landslide inventory maps presented based on visual interpretation and expert knowledge. A) Landslide inventory map of Mesilau River vally, Kundasang, B) landslide inventory map of Gombak Selangor Quartz Ridge, Selangor. 108
Figure 4.11 Geomorphological maps of Sg-Mesilau, Kundasang: A) Geomorphology, B) Aspect, C) Slope map D) Curvature, E) TRI, F) TSC 112
Figure 4.12 Geomorphological maps of Gombak Selangor Quartz Ridge, Selangor:A) Curvature, B) Slope, C) Aspect, 114
Figure 4.13 Geomorphological maps of Gombak Selangor Quartz Ridge, Selangor: D) TRI, E) TSC 115
Figure 4.14 Hydro-topographical maps of Sg-Mesilau, Kundasang: Distance to channel, B) Flow direction, C) TWI. 116
Figure 4.15 Hydro-topographical maps of Gombak Selangor Quartz Ridge, Selangor: Distance to channel, B) Flow direction, C) Stream order 117
Figure 4.16 Geological conditioning factor maps of Sg-Mesilau, Kundasang:A) Distance to Fault, B) Distance to Lineament, C) Lithology, 120
Figure 4.17 Geological conditioning factor maps of Gombak Selangor Quartz Ridge, Selangor: A) Distance to Fault, B) Distance to Lineament, C) Lithology 121
Figure 4.18 Variable importance of predisposing factors: (a) Mesilau River valley, Kundasang, (b) Gombak Selangor Quartz Ridge 125
Figure 5.1 Senario 1: Landslide Hazard Map Generated using 21 Parameters 133
Figure 5.2 ROC curve for landslide hazard map of Sg. Mesilau, Kundasang study area prepared from ALS-derived landslide inventory map, and historic landslide records. 134
Figure 5.3 Senario 3: Landslide Hazard map generated using top 10 priority parameters 136

Figure 5.4	ROC curve for landslide hazard map of Gombak Selangor Quartz Ridge area derived from ALS based landslide inventory and historical landslide inventory	136
Figure 5.5	Locations of the data points and the weight vectors.	138
Figure 5.6	Distances between neighboring neurons	138
Figure 5.7	Landslide Sensitivity Prediction map of Gombak Selangor Quartz Ridge area	140
Figure 5.8	ROC curve for landslide sensitivity prediction map of Gombak Selangor Quartz Ridge area based on spatio-temporal data of LHI, Rainfall And historical landslide inventory	140

LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
ALS	Airborne Laser Scanning
ANN	Artificial Neural Network
AUC	Area Under Curve
CNN	Convolutional Neural Network
CSV	Comma-separated Values
dSLAM	Dynamic Slope Stability Model
DSM	Digital Surface Model
DT	Decision Tree
DTM	Digital Terrain Model
DTs	Decision Trees
FC	Fully Connected
GIS	Geographic Information System
GPS	Global Positioning System
GQDM	Generalized Quasi Dynamic Model
GUI	Graphical User Interface
HI	Hazard Index
InSAR	Interferometric Synthetic Aperture Radar
JMG	Jabatan Mineral Dan Geosains Malaysia
JUPEM	Jabatan Ukur dan Pemetaan Malaysia
LAPSUS	Landscape Process Modelling at Multidimensions and Scales
LHI	Landslide Hazard Index
LiDAR	Light Detection and Ranging
LIM	Landslide Inventory Mapping
LR	Logistic Regression
LULC	Land Use Land Cover
ML	Machine Learning
MLR	Multiple Logistic Regression

NDMIDIR - Normalized Difference of Mid-InfraRed
NDVI - Normalized Difference Vegetation Index
OOB - Out of Bag
PCs - Principal Components
ReLU - Rectified Linear Unit
RF - Random Forest
ROC - Receiver Operating Characteristic
RS - Remote Sensing
SAM - Spectral Angel Mapper
SINMAP - Stability Index Map
SLIDE - Slope Infiltration Distributed Equilibrium
SLIP - Shallow Landslide Instability Prediction
SRC - Success Rate Curve
STI - Sediment Transport Index
SVM - Support Vector Machine
TIN - Triangular Irregular Networks
TRI - Terrain Ruggedness Index
TRIGRS - Transient Rainfall Infiltration and Grid-based Regional Slope Stability Model
TRMM - Tropical Rainfall Measuring Mission
TSC - Terrain Surface Classification
TST - Terrain Surface Texture
TWI - Topographic Wetness Index
UNESCO - United Nations Educational, Scientific and Cultural Organization
WOE - Weight of Evidence
WOECNN - Weight of Evidence Based Convolutional Neural Network

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Data Collection Letter	189
B	Data Checklist (JMG)	191
C	WOE Code to Calculate LHI	193
D	Predisposing/Conditioning Factors of Selangor	201
E	Predisposing/Conditioning Factors of Sg. Mesilau	203
F	Causal Factor Weights of Gombak Selangor Quartz Ridge, Selangor	205
G	Causal Factor Weights of Sg. Mesilau, Kundasang	209

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Geophysical hazard refers to the naturally occurred event, incidence or phenomenon which effect the human and environment negatively. It includes geological, geomorphological and metrological phenomenon’s, i.e. landslides, earthquakes, floods, tsunamis, volcanic eruptions, tornadoes, severe storms, droughts etc. (Strupler *et al.*, 2018). These are abrupt and unforeseen events which cause the disturbance in the balance of landscape and environment.

Currently, the world is threatened with a precipitously growing impact of geophysical hazards, which caused not only increase in the exposure but also increase in hazardous events. Every year several deaths have been recorded due to geophysical disasters all over the world especially in developing countries (Zorn, 2018). In developing countries, the probable impacts of hazardous incidents are huge as compare to developed countries. The impact of natural disasters on developing and developed countries can be judged by the fact that in the USA more or less 246 thousand deaths were recorded in the last ten years (2006-2015) while almost 113 million people were recorded as affective. In UK only around 800 deaths and some of 400 thousand of casualties were recorded for the same time period (EM-DATE, 2014). On the other hand, in Asia the highest loss of life and casualty rate is recorded, which is around 4 million deaths and more than one billion victims were recorded in the last ten years (2006-2015), (World Disaster Report, 2016).

Natural disasters and their consequences have considerable effects on human life, properties, infrastructure and environment. The important most natural hazard among these is landslide, which play vital role in these effects all over the world. Landslides is a regular hazard of mountainous terrain, particularly in active seismic regions of and high rainfall (tropics) areas. Among all the natural calamities landslides have substantial accountability for injury, life loss and property damage in mountainous regions around the world. Beside this it also has positive effects like form landforms and transport sediments and wood to streams.

The activation of landslide depends on both endogenic (igneous process and tectonic process) and exogenic (gradational process) forces. It is a rock or soil movement towards down along slope due to gravitational force when it loses its connectivity with the base. Although landslide is a natural hazard, but it can also accelerate due to human activities (e.g. construction, absence of vegetation cover, use of irrational farming technology, etc.). Usually it occurs at steep gradient but could also happen in areas having low relief based on its climatic, topographical, and geological conditions. Landslide is a regular event of tropical areas and is liable for critical fatalities and monetary losses. That’s why the assessment of landslide hazard on local scale as well as on regional scale is gaining much importance in recent years (Aydın and Eker, 2016).

Changes in the natural environment may affect environmental negatively. In the last century, the mountain landscapes have experienced significant transformations all over the world. Natural and anthropogenic changes, climate changes, tourism and industrial development, socio-economic interactions, and their consequences in terms of land use and land cover changes (LUCC) have directly influenced the spatial organization and vulnerability of mountain landscapes. Land use change (e.g. deforestation) can influence and disturb the vegetation cover and stability of water level which ultimately cause in an increase in erosion (Glade, 2003; Ghimire *et al.,* 2013). The ultimate result of this change is intense environmental risk, i.e. landslide incidence, which may leave a solid impact on the human wellbeing with greater scale (Tasser *et al.,* 2003; Ko¨rner *et al.,* 2005; Papathoma-Ko¨hle and Glade, 2013). Studying the change in nature due to human-environment interactions is thus crucial (Rounsevell *et al.,* 2006).

In the steep mountainous areas of tropics, the occurrence of landslides is more frequent due to high humidity, intensive rainfall, unstable soil and morphology. Moreover, being in tropical region, the hilly landscape in Malaysia, especially the eastern peninsula (Borneo) is extremely susceptible to landslide hazard due to active tectonic movement and intense rainfall. Rainfall-activated landslides is the common most type of landslide, occurring all over the mountains and foothills of western peninsula of Malaysia, while in eastern peninsula seismicity is contributing side by side with rainfall. Likely to assess the landslide hazard time data is obvious. It could be defined as the likelihood of landslide occurrence for a given region or area (X, Y) over time. Without including third dimension (time), it is not possible to assess the hazard but only susceptibility.

Carrying out a hazard evaluation of landslide needs both a spatial as well as temporal (3D) database. Nevertheless, most of the hazard maps for landslide presents only the susceptibility zoning (spatial likelihood) without utilizing the temporal information regarding that particular hazard. Among these one of the major problems while assessing temporal possibility of landslides lies in recognizing the frequency and magnitude relationship since historic landslide archives are not complete. Although, despite scarcity in data, there is immense need to address the recent incidences of landslides which might be connected to triggering events (e.g. earthquake, rainfall).

Numerous landslide hazard assessment models are mentioned in literature which can be grouped into direct methods (geomorphological and heuristic) and indirect (statistical and mechanistic approach) methods (Pardeshi, Autade and Pardeshi, 2013; Van Westen *et al.*, 2006). Usually the direct methods (knowledge driven/ qualitative) is dependent on the skills, experience and knowledge of the expert preparing the map. While the indirect methods or statistical modelling approach (data driven/ quantitative) are included multivariate and bivariate statistical models. The featured concept of statistical modelling is that, “the past is key to the future”, that’s why the historical landslide inventory and its causal associations can help to forecast future scenarios (Van Westen, Castellanos and Kuriakose, 2008). Conversely, data mining models (machine learning) such as decision tree (DT) random forest (RF), and support vector machine (SVM), gained the popularity among different geoscience applications for their great prediction ability (Wu *et al.,* 2013).

Scenario preparation for future along with probability model is a valuable tool for probing forthcoming consequences towards environmental change. Scenarios are impressions of likely futures (Abildtrup *et al.,* 2006). The visualization of these landslide scenarios can effectively contribute to the awareness of ultimate problems which may cause trouble in future (Promper *et al.,* 2014). Thus, the results of such analyses might support the enhancement of future adaption and management strategies. These results encourage the creativity and support to develop a vision and strategy for a safe future. While scenarios might provide assistance to prepare for expected inconvenient future expansions by disturbing the well-known planning pattern (Wollenberg *et al.,* 2000). They propose possibilities to assess the existing response options, while consulting decision makers as part of game (Shearer, 2005; Kriegler *et al.,* 2012).

Imageries are the ideal tool for inventory mapping and hazard assessment, since it offers information over large areas with short time intervals. Remote sensing (RS) techniques experienced speedy and important developments in last few epochs. The competence of advance and boosted remote sensing methods to obtain 2.5D spatial data (X, Y + elevation) along with high precision contours allows innovative and successful enquiries about landslide incidents. The data obtained from multi-sensors accompanied with airborne as well as ground-based allows to provide valuable knowledge for training the model, result validation and creating simulations of natural phenomena’s (Scaioni *et al.,* 2014). Amongst these technologies, the light detection and ranging (LiDAR) and laser interferometric synthetic aperture radar (InSAR) are widely used for landslide studies in last few decades. Unlike conventional approaches, these are fast and precise mapping techniques for hydrological, geomorphological and LULC etc. (Hervás *et al.,* 2003; Ardizzone *et al.,* 2007; Guzzetti *et al.,* 2012; Roering *et al.,* 2013; Daehne and Corsini, 2013).

The advent of remote sensing (RS) and geographical information systems (GISs) played vital role in the appliance and addition of numerous algorithms, methods and models in landslide research. Moreover, by determining and mitigating failures new visions into landslide studies have been exposed via these techniques. In spite RS and GIS, extended field knowledge, multiple expert's knowledge along with considerable budget, are mandatory to detect landslide prone sites (Van Westen *et al.,* 2006, 2008). Although the RS data may be used in several other stages of calamity management, for instance prevention, preparedness, relief, and reconstruction but in fact till todate it is generally utilized for monitoring and warning system. Therefore, hazard assessment can only be carried out effectively when it consist of widespread, multidisciplinary studies based on spatial information, derived from sensors and other sources. This study is concentrating on 3D (2D space + Time) hazard assessment for landslide using novel hybrid model (bivariate statistical model and machine learning techniques).

1.2 Research Problem

Landslide is a natural phenomenon but could turn into hazard and may cause either life losses or damage to structures including man-made as well as natural. The casualties and economic losses caused by landslides are greater than any other natural disaster in many countries. Landslide is a significant geo-hazard which causes impairment to social and natural environment (Pardeshi *et al.,* 2013). Brabb (1993) mentioned that around 90% of losses due to landslide could be avoided if the issue is identified before event. Landslide mapping, evaluation, assessment and prediction is a crucial step for disaster resilience especially in tropical regions, which are more prone to this disaster due to its climatic conditions. Hence, landslide hazard assessment at various spatial scales is important.

- Due to the wide range of uncertainties in data procurement, management, model selection and standardization, and to the complexity and exposure of modern societies, landslide mapping, hazard evaluation, and risk assessment seems to be out of the reach of traditional puzzle-solving scientific methods, based on controlled experiments and on a very generalized consensus amongst experts. These challenging problems may be solved by a new scientific practice which could be capable to handle large uncertainties, fluctuating expert views, and societal issues elevated by hazard assessment and risk evaluation researches (Guzzetti *et al.,* 1999). With this context, expended efforts are required to formulate new or combination (hybrid) of old methods and models for landslide mapping, susceptibility zoning and hazard assessment. It could be better documented and more efficient or “technical”. However additional efforts are required to transfer this scientific information regarding landslides and the related hazards and risk authorities involved with planning regulations, civil defense plans and building codes. In Malaysia landslides are the biggest threat to settlements, infrastructure and tourism industry in hilly areas (Pradhan *et al.,* 2010) because of its loose morphology, excessive rain and hot and moist climate. Seismic acceleration is also a major factor in eastern part (Borneo island) of Malaysia.

- To study the landslides, it is necessary to have understanding with its varied types, the causal factors and involving aspects, especially in more vulnerable locations. Landslide hazard investigation is the basic component of landslide risk management. Numerous techniques and models of landslide hazard assessment are in practice including heuristic (knowledge driven methods), semi-quantitative, quantitative (data driven methods), and machine learning (ML) etc. There is a long debate of researchers on Landslide hazard assessment methods however, there is no method universally accepted by a known team of researches for assessment of landslide hazards in terms of high accuracy (Pardeshi, 2013).

- The hazard assessment considers the triggering factor and temporal data. There is a variety of triggering factors which have strong connection with the activation of landslide but the most important ones according to literature are earthquake and rainfall. Anthropogenic triggering factors are also quite influential in this regard (e.g., water level change, fluvial erosion, change in vegetation cover (LULC) and human activities (Construction of roads, buildings etc.). Validating hazard map is a crucial step in landslide modelling, without it hazard maps are not reliable. There are several procedures for validation of susceptibility and hazard models are presented, so that the obtained results can be interpreted meaningfully with respect to future landslide occurrence and the significance of the predictions can be communicated to decision makers allowing them to perform sound planning for land use and landslide crisis management. In the case of landslide inventory mapping not only accuracy assessment and validation, but also the updating of the landslide inventory is important.

- Projection of hazard for future is an emerging concept in the field of geohazard all over the world. Hazard prediction fundamentally depends on the understanding of interplay of relevant determining factors (both predisposing and triggering) and their selective combinations for causing different slide types. Such understanding of landslide process forms on the basis of preparation of 3D spatio-temporal land slide inventory (Ghosh, 2014). In developing countries due to non-availability of temporal data of events, future projection is still at its infancy. In Malaysia, like other developing countries there is no database for historical landslide events except a few which gathered from different news reports of Mineral and Geoscience Department, Malaysia. Moreover, for future prediction temporal data of triggering factors e.g. rainfall and earthquake have equal importance as landslide events. The missing of any single database effects the accuracy of prediction because of which future prediction is very difficult to model. This research is incorporating ML technique for future modeling to fill the gap.

1.3 Research Questions

The research will address the following questions:

Which characteristics need to investigate to prepare a landslide inventory?

- What types of mass movement (topple, creep, debris flow, rock fall etc.) exists?
- What is the size, activity, type and dimension of each particular landslide?
- How to prepare multi temporal land slide inventories?

How to quantify the parameters, and which could be suitable models for computation of landslide hazard (type, magnitude and time) and validation on local scale?

- Which ground consequences (structural/ geological/ landuse) can play vital role in the emergence of landslide hazards (spatial query)?
- Which geomorphometric (relief, slope, aspect etc.) factors may play additional role to increase the intensity of damage many folds caused by a landslide (spatial query)?
- Which triggering factors (seismological/ hydrological/ Metrological) play important role in the activation of a landslide?
- Which model can efficiently assess the landslide hazard index using spatio-temporal data set?
- Which method could be used for validation of landslide hazard index (LHI) maps.
- Which predisposing parameters are important to assess the landslide hazard index (LHI) in that region.

What kind of data and technics could be used in future modelling of landslide hazard for future planning?

- Which dynamics (temporal data) could be considered for future scenario building?
- How time can affect the process and which technique/ models can efficiently project the landslide hazard index in future?

- What is the likelihood of occurrence of a particular landslide type with in a given time period?

1.4 Research Objectives

The key goal of this study is to design a hybrid model to assess the spatio-temporal probability and sensitivity prediction for landslide hazard in the densely vegetated tropical environment which might be helpful in decision making process about land use policies and disaster risk reduction.

Accordingly, the objectives of the study are:

- To investigate, identify and map the physical extent series of existing landslides, their type, intensity and frequency based on remotely sensed data, historical records and field verifications/ observation on local scale.
- To design the model to assess and validate the 3D landslide hazard and sensitivity prediction based on important predisposing parameters
- To evaluate different landslide hazard scenarios to find the future threats based on importance predisposing/ conditioning factor and validation through quantification of the model.
- To highlight the landslide, hazard sensitive areas by modelling spatio-temporal prediction for future.

1.5 Scope of the Study

This research is focused on modeling 3D landslide hazard sensitivity prediction. The scope of the study is limited to two different areas including S.g Mesilau valley, Kundasang in district Ranau, Sabah and Gombak Selangor Quartz Ridge in Selangor. The area of S.g Mesilau valley, Kundasang, is located in the state of Sabah. The area has a rural environment and the land is dominantly under agriculture as basic activity. The whole region lies under high rainfall intensity. The area is also cherecterized by active seismo-tectonic activity as it lays in the foothills of Mount Kinabalu. While the Gombak Selangor Quartz Ridge area lies in Selangor state. This study area has urban environment with rapid developments and high intensity of rainfall as well. Though the area has no history of seismic activity. The study utilized spatio-temporal data including past landslide location data with attribute together with date of incident and cumulative rainfall data. The seismic magnitude and rainfall intensity were used as triggering factor for hazard assessment. To assess the future sensitive areas for landslide hazard the previous spatio-temporal database was used side by side with forecast data of rainfall. In this study, the predisposing factors which may contribute to the landslide and other mass movements such as geological, geomorphological, hydro-topographical, and anthropogenic factors were utilized to calculate landslide hazard index (LHI) using data driven approach.

1.6 Significance of Study

Landslide is the movement of mass of rock, debris or earth (soil) down a slope under the influence of gravity. Although Malaysia is not a precipitous country (mountains and hills are less than 25% of the terrain), slope failures/landslides are a frequently happened. From 1993-2011, around 28 major landslides were reported in Malaysia with a total loss of more than 100 lives. Moreover, from 1973-2007, the total economic loss due to landslides in Malaysia was estimated about US $1 billion. The collapsed of the 14-storey block A of the Highland Tower in Ulu Klang, Selangor was the most tragic landslide in Malaysia with 48 deaths. The main factor that caused slopes failure/landslides at numbers site in hillside development in Malaysia are rainfall, storm water activities and poor slope management. Another cause of landslides can be due to the abuse prescriptive methods, inadequate study of past failures, design errors including insufficient site-specific ground investigation. Besides, the development of highland or hilly terrain has increased developed and many hills project are in the pipeline. All this factor together contributes to landslide disaster in this country. An impact of landslides in Malaysia has given rise to some environmental and socioeconomic issues such as loss of lives, damaged of properties and infrastructures, psychological pressures among the victims, disputes on land boundaries and also land degradation. Therefore, planning, design, construction and maintenance are very critical to achieve a safe and cost-effective hill-site development.

This study provides the understanding of relationship between rainfall amount and duration along with conditioning parameters that possesses the possibility to trigger a landslide. Since both areas have high landslide intensity thus, it is necessary to develop an empirical rainfall threshold to predict the landslide event.

1.7 Thesis Outline

This thesis is structured into five chapters as follows:

Chapter 1 includes the background of the study and the key challenges. The specific objectives of the study and Research questions are also the part of the chapter. The thesis outline structure is also elaborated.

Chapter 2 presents the literature review on landslides. This chapter describes definitions, classification of landslides, factors affecting landslides, tools to predict landslides such as remote sensing, Geographic Information Services (GIS), landslide inventory, susceptibility and hazard modelling.

Chapter 3 is about research methodology. It explains the study areas in different physical environments: i) Intermediate channel of River Mesilau, Kundasang, Saba, a rural area with active seismo-tectonic conditions ii) Gombak Selangor Quartz Ridge with grater urban expansion on critical slopes. The chapter also describes the methodology and models applied in this study.

Chapter 4 describes the data and initial outcomes in form of landslide inventories. This chapter also describes parameterization and factor importance ranking of predisposing factors.

Chapter 5 presents the results and discussion i.e.

- Landslide hazard Assessment results and its validation.
- Landslide hazard scenarios according to factor importance
- Landslide hazard future prediction which could be used efficiently in monitoring and early warning system.

Chapter 6 consists of conclusions and recommendations. This chapter discussed the very high and high landslide hazard occupies of the total study area based on the models and determining how to use this for monitoring and early warning system of landslide hazard caused by earthquake and rainfall based on community participation uses the danger level of rainfall. This chapter will also give some recommendation about areas having very high and high hazard and the prevention as well as mitigation efforts, especially related to land use directive must be continuously disseminated to the public.

REFERENCES

Abellán, A., Calvet, J., Vilaplana, J. M., & Blanchard, J. (2010). Detection and spatial prediction of rockfalls by means of terrestrial laser scanner monitoring. *Geomorphology*, *119*(3-4), 162-171.

Abildtrup, J., Audsley, E., Fekete-Farkas, M., Giupponi, C., Gylling, M., Rosato, P., & Rounsevell, M. (2006). Socio-economic scenario development for the assessment of climate change impacts on agricultural land use: a pairwise comparison approach. *Environmental Science & Policy*, *9*(2), 101-115.

Aghdam, I. N., Varzandeh, M. H. M., & Pradhan, B. (2016). Landslide susceptibility mapping using an ensemble statistical index (Wi) and adaptive neuro-fuzzy inference system (ANFIS) model at Alborz Mountains (Iran). *Environmental Earth Sciences*, *75*(7), 553.

Agliardi, F., Crosta, G. B., & Frattini, P. (2012). 18 Slow rock-slope deformation. *Landslides: Types, mechanisms and modeling*, 207.

Akgun, A. (2012). A comparison of landslide susceptibility maps produced by logistic regression, multi-criteria decision, and likelihood ratio methods: a case study at İzmir, Turkey. *Landslides*, *9*(1), 93-106

Aleotti, P., & Chowdhury, R. (1999). Landslide hazard assessment: summary review and new perspectives. *Bulletin of Engineering Geology and the environment*, *58*(1), 21-44.

Alkhasawneh, M.sh., Kalthum Ngah, U., Tien Tay, L., Ashidi Mat Isa, N., Subhi Al-Batah, M., 2014. Modeling and testing landslide hazard using a decision tree. Journal of Applied Mathematics. http://dx.doi.org/10.1155/2014/929768.

Althuwaynee, O. F., Pradhan, B., & Lee, S. (2016). A novel integrated model for assessing landslide susceptibility mapping using CHAID and AHP pair-wise comparison. *International Journal of Remote Sensing*, *37*(5), 1190-1209.

Althuwaynee, O. F., Pradhan, B., Park, H. J., & 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.

Anbalagan, R. (1992). Landslide hazard evaluation and zonation mapping in mountainous terrain. *Engineering geology*, *32*(4), 269-277.

Anderson, M. G., & Lloyd, D. M. (1991). Using a Combined Slope Hydrology/Stability Model to develop cut slope design charts. *ICE Proceedings*, *91*(4), 705–718. doi:10.1680/iicep.1991.17486.

Ardizzone, F., Cardinali, M., Carrara, A., Guzzetti, F., & Reichenbach, P. (2002). Impact of mapping errors on the reliability of landslide hazard maps. *Natural Hazards and Earth System Science*, *2*(1/2), 3-14.

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.

Atkinson, P. M., & Massari, R. (1998). Generalised linear modelling of susceptibility to landsliding in the central Apennines, Italy. *Computers & Geosciences*, *24*(4), 373-385.

Australian Geomechanics Society (2002) Landslide risk management concepts and guidelines. Australian Geomechanics Society sub-committee on landslide risk management, pp 51–70

Axelsson, P. (2000). DEM generation from laser scanner data using adaptive TIN models. *International archives of photogrammetry and remote sensing*, *33*(4), 110-117.

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*(1-2), 15-31.

Aydın, A., & Eker, R. (2016). Fuzzy rule-based landslide susceptibility mapping in Yığılca Forest District (Northwest of Turkey). *Journal of the Faculty of Forestry Istanbul University| İstanbul Üniversitesi Orman Fakültesi Dergisi*, *66*(2), 559-571.

Bachmair, S., & Weiler, M. (2012). Hillslope characteristics as controls of subsurface flow variability. *Hydrology and Earth System Sciences*, *16*(10), 3699-3715.

Bajracharya, B., & Bajracharya, S. R. (2008, January). Landslide mapping of the Everest region using high resolution satellite images and 3D visualization. In *Proceedings of the Mountain GIS e-Conference, Kathmandu, Nepal* (pp. 14-25).

Baum, R. L., & Reid, M. E. (1992). *Geology, Hydrology and Mechanics of the Alani-Paty Landslide, Manoa Valley, Oahu, Hawaii* (No. 92-501). US Geological Survey,.

Baum, R.L., Schuster, R.L., Godt, J.W., 1999. Map showing locations of damaging landslides in Santa Cruz County, California, resulting from 1997 to 98 El Nino rainstorms. U.S. Geological Survey Miscellaneous Field Studies Map, MF-2325-D, scale 1:125,000.

Behling, R., Roessner, S., Kaufmann, H., & Kleinschmit, B. (2014). Automated spatiotemporal landslide mapping over large areas using rapideye time series data. *Remote Sensing*, *6*(9), 8026-8055.

Berardi R, Mercurio G, Bartolini P, Cordano E (2005) Dynamics of saturation phenomena and landslide triggering by rain infiltration in a slope. In: Hungr O, Fell R, Couture R, Eberhardt E (eds) International conference on landslide risk management. Taylor & Francis Ltd., Vancouver, pp 212–219.

Berti, M., Martina, M. L. V., Franceschini, S., Pignone, S., Simoni, A., & Pizziolo, M. (2012). Probabilistic rainfall thresholds for landslide occurrence using a Bayesian approach. *Journal of Geophysical Research, 117*(F4). doi:10.1029/2012JF002367.

Bibi, T., Razak, K. A., Rahman, A. A., & Latif, A. (2017). Spatio temporal detection and virtual mapping of landslide using high-resolution airborne laser altimetry (lidar) in densely vegetated areas of tropics. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, *42*.

Booth, A. M., Roering, J. J., & Perron, J. T. (2009). Automated landslide mapping using spectral analysis and high-resolution topographic data: Puget Sound lowlands, Washington, and Portland Hills, Oregon. *Geomorphology*, *109*(3-4), 132-147.

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

Bouali, E. H., Oommen, T., & Escobar-Wolf, R. (2018). Mapping of slow landslides on the Palos Verdes Peninsula using the California landslide inventory and persistent scatterer interferometry. *Landslides*, *15*(3), 439-452.

Bovolo, C. I., & Bathurst, J. C. (2012). Modelling catchment-scale shallow landslide occurrence and sediment yield as a function of rainfall return period. *Hydrological Processes*, *26*(4), 579-596.

Brabb, E. E. (1993). Proposal for worldwide landslide hazard maps. In *Seventh International Conference and Field Workshop on Landslides in Czech and Slovak Republics* (pp. 15-27).

Brabb, E.E., Harrod, B.L. (Eds.), 1989. Landslides: Extent and Economic Significance. A.A. Balkema Publisher, Rotterdam. 385 pp.

Brardinoni, F., Slaymaker, O., & Hassan, M. A. (2003). Landslide inventory in a rugged forested watershed: a comparison between air-photo and field survey data. *Geomorphology*, *54*(3-4), 179-196.

Breiman, L. (2001). Random forests. *Machine learning*, *45*(1), 5-32.

Brenning, A. (2008). Statistical geocomputing combining R and SAGA: The example of landslide susceptibility analysis with generalized additive models. *SAGA–Seconds out*, *19*, 23-32.

Brocca, L., Tullo, T., Melone, F., Moramarco, T., & Morbidelli, R. (2012). Catchment scale soil moisture spatial–temporal variability. *Journal of hydrology*, *422*, 63-75.

Brunsden, D. (1985, April). Landslide types, mechanisms, recognition, identification. In *landslides in the South Wales coalfield, edited by: Morgan, CS, Proceedings Symposium, April* (pp. 1-3).

Brunsden, D. (1999). Some geomorphological considerations for the future development of landslide models. *Geomorphology*, *30*(1-2), 13-24.

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. In *Cartography from pole to pole* (pp. 303-317). Springer, Berlin, Heidelberg.

Bui, D. T., Pradhan, B., Revhaug, I., Nguyen, D. B., Pham, H. V., & Bui, Q. N. (2015). A novel hybrid evidential belief function-based fuzzy logic model in spatial prediction of rainfall-induced shallow landslides in the Lang Son city area (Vietnam). *Geomatics, Natural Hazards and Risk*, *6*(3), 243-271.

Bui, D. T., Tuan, T. A., Klempe, H., Pradhan, B., & Revhaug, I. (2016). Spatial prediction models for shallow landslide hazards: a comparative assessment of the efficacy of support vector machines, artificial neural networks, kernel logistic regression, and logistic model tree. *Landslides*, *13*(2), 361-378.

Bujang, B.K. Hua.T, Faisal Hj Ali, David, H. Baker., Harwant Singh and Husaini Omar. (2008). Landslides in Malaysia: Occurrences, assessment, analyses and remedition. Serdang: Universiti Putra Malaysia Publisher.

Buma, J. (2000). Finding the most suitable slope stability model for the assessment of the impact of climate change on a landslide in southeast France. *Earth Surface Processes and Landforms*, *25*(6), 565-582.

Caine, N. (1980). The Rainfall Intensity: Duration Control of Shallow Landslides and Debris Flows. *Physical Geography, 62*(1/2), 23–27. doi:10.2307/520449.

Calcaterra, D., De Riso, R., Evangelista, A., Nicotera, M. V., Santo, A., & Scotto di Santolo, A. (2003, May). Slope instabilities in the pyroclastic deposits of the Phlegraean district and the carbonate Apennine (Campania, Italy). In *Proceedings of an International Workshop on Occurrence and Mechanisms of Flows in Natural Slopes and Earthfills held in Sorrento, Italy* (pp. 61-75).

Cannon, S. H., Bigio, E. R., & Mine, E. (2001). A process for fire‐related debris flow initiation, Cerro Grande fire, New Mexico. *Hydrological Processes*, *15*(15), 3011-3023.

Capitani, M., Ribolini, A., & Bini, M. (2013). The slope aspect: A predisposing factor for landsliding?. *Comptes Rendus Geoscience*, *345*(11-12), 427-438.

Capparelli, G., & Versace, P. (2011). FLaIR and SUSHI: two mathematical models for early warning of landslides induced by rainfall. *Landslides*, *8*(1), 67-79.

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 n. 2116, scale 1:100,000.

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

Cardinali, M., Galli, M., Guzzetti, F., Ardizzone, F., Reichenbach, P., Bartoccini, P., 2006. Rainfall induced landslides in December 2004 in south-western Umbria, central Italy: types, extent, damage and risk assessment. Natural Hazards and Earth System Sciences 6, 237–260.

Carnec, C., Massonnet, D., & King, C. (1996). Two examples of the use of SAR interferometry on displacement fields of small spatial extent. *Geophysical research letters*, *23*(24), 3579-3582.

Carrara, A. (1988). Drainage and divide networks derived from high-fidelity digital terrain models. In *Quantitative analysis of mineral and energy resources* (pp. 581-597). Springer, Dordrecht.

Carrara, A., Cardinali, M., Guzzetti, F., & Reichenbach, P. (1995). GIS technology in mapping landslide hazard. In *Geographical information systems in assessing natural hazards* (pp. 135-175). Springer, Dordrecht.

Carrara, A., Crosta, G., & Frattini, P. (2003). Geomorphological and historical data in assessing landslide hazard. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, *28*(10), 1125-1142.

Carrara, A., Crosta, G., & Frattini, P. (2008). Comparing models of debris-flow susceptibility in the alpine environment. *Geomorphology*, *94*(3-4), 353-378.

Carrara, Alberto. "Uncertainty in evaluating landslide hazard and risk." In *Prediction and perception of Natural hazards*, pp. 101-109. Springer, Dordrecht, 1993.

Casagli, N., Catani, F., Puglisi, C., Delmonaco, G., Ermini, L., & Margottini, C. (2004). An inventory-based approach to landslide susceptibility assessment and its application to the Virginio River Basin, Italy. *Environmental and Engineering Geoscience*, *10*(3), 203-216.

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.

Catani, F., Casagli, N., Ermini, L., Righini, G., & Menduni, G. (2005). Landslide hazard and risk mapping at catchment scale in the Arno River basin. *Landslides*, *2*(4), 329-342.

Catani, M., Dell’Acqua, F., & De Schotten, M. T. (2013). A revised limbic system model for memory, emotion and behaviour. *Neuroscience & Biobehavioral Reviews*, *37*(8), 1724-1737.

Chang, K. T., & Liu, J. K. (2004, July). Landslide features interpreted by neural network method using a high-resolution satellite image and digital topographic data. In *Geo-Imagery Bridging Continents; Proc. of 20th ISPRS Congress, Istanbul, 12-23 July 2004*.

Chauhan, S., Sharma, M., Arora, M.K., Gupta, N.K., 2010. Landslide susceptibility zonation through ratings derived from artificial neural networks. International Journal of Applied Earth Observation and Geoinformation 12 (5), 340–350. doi:10.1016/j.jag.2010.04.006.

Chen, H., & Lee, C. F. (2003). A dynamic model for rainfall-induced landslides on natural slopes. *Geomorphology*, *51*(4), 269–288. doi:10.1016/S0169-555X(02)00224-6

Chen, W., Li, W., Hou, E., Bai, H., Chai, H., Wang, D., Cui, X., Wang, Q., 2015. Application of frequency ratio, statistical index, and index of entropy models and their comparison in landslide susceptibility mapping for the Baozhong Region of Baoji, China. Arabian Journal of Geosciences 8, 1829–1841. http://dx.doi.org/10.1007/s12517-014-1554-0.

Chen, W., Pourghasemi, H. R., Kornejady, A., & Zhang, N. (2017). Landslide spatial modeling: introducing new ensembles of ANN, MaxEnt, and SVM machine learning techniques. *Geoderma*, *305*, 314-327.

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

Chiang, S. H., Chang, K. T., Mondini, A. C., Tsai, B. W., & Chen, C. Y. (2012). Simulation of event-based landslides and debris flows at watershed level. *Geomorphology*, *138*(1), 306-318.

Chigira, M., Wu, X., Inokuchi, T., & Wang, G. (2010). Landslides induced by the 2008 Wenchuan earthquake, Sichuan, China. *Geomorphology*, *118*(3-4), 225-238.

Chow, M. F., Bakar, M. A., & Deck, R. (2016). A review on the development and challenges of green roof systems in Malaysia. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, *10*(1), 16-20.

Chow, W.S., Zakaria, M., 2003. Geological terrain mapping. JMG unpublished report. JMG.SWP.GS, vol. 16, 1-42 pp.

Ciampalini, A., Raspini, F., Bianchini, S., Frodella, W., Bardi, F., Lagomarsino, D., ... & Onori, R. (2015). Remote sensing as tool for development of landslide databases: the case of the Messina Province (Italy) geodatabase. *Geomorphology*, *249*, 103-118.

Cigna, F., Bianchini, S., Righini, G., Proietti, C., & Casagli, N. (2010). Updating landslide inventory maps in mountain areas by means of Persistent Scatterer Interferometry (PSI) and photo-interpretation: Central Calabria (Italy) case study. *Mountain risks: bringing science to society. Florence: CERG Editions*, 3-9.

Claessens, L., Heuvelink, G. B. M., Schoorl, J. M., & Veldkamp, A. (2005). DEM resolution effects on shallow landslide hazard and soil redistribution modelling. *Earth Surface Processes and Landforms*, *30*(4), 461–477. doi:10.1002/esp.1155

Claessens, L., Schoorl, J. M., & Veldkamp, A. (2007). Modelling the location of shallow landslides and their effects on landscape dynamics in large watersheds: An application for Northern New Zealand. *Geomorphology*, *87*(1-2), 16–27. doi: 10.1016/j.geomorph.2006.06.039

Colesanti, C., & Wasowski, J. (2004, June). Satellite SAR interferometry for wide-area slope hazard detection and site-specific monitoring of slow landslides. In *Proceedings Ninth Internat. Symposium on Landslides* (pp. 795-802).

Corominas, J., & Moya, J. (2010). Contribution of dendrochronology to the determination of magnitude–frequency relationships for landslides. *Geomorphology*, *124*(3-4), 137-149.

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

Corominas, J., van Westen, C., Frattini, P., Cascini, L., Malet, J. P., Fotopoulou, S., ... & Pitilakis, K. (2014). Recommendations for the quantitative analysis of landslide risk. *Bulletin of engineering geology and the environment*, *73*(2), 209-263.

Corominas, L., Foley, J., Guest, J. S., Hospido, A., Larsen, H. F., Morera, S., & Shaw, A. (2013). Life cycle assessment applied to wastewater treatment: state of the art. *Water research*, *47*(15), 5480-5492.

Crosta, G. B., & Frattini, P. (2003). Distributed modelling of shallow landslides triggered by intense rainfall. *Natural Hazards and Earth System Science*, *3*(1/2), 81-93.

Crosta, G. B., & Frattini, P. (2008). Rainfall-induced landslides and debris flows. *Hydrological Processes: An International Journal*, *22*(4), 473-477.

Crozier MJ (1989) Landslides: causes, consequences and environment. Taylor & Francis, Routledge

Crozier MJ (2010) Deciphering the effect of climate change on landslide activity: a review. Geomorphology 124(3–4):260–267.

Crozier MJ, Glade T (2005) Landslide hazard and risk: issues, concepts, and approach. In: Glade T, Anderson M, Crozier MJ (eds) Landslide hazard and risk. Wiley, New York, pp 1–40

Crozier, M. J. (2005). Multiple-occurrence regional landslide events in New Zealand: hazard management issues. *Landslides*, *2*(4), 247-256.

Crozier, M., & Glade, T. (2010). 18 Hazard assessment for risk analysis and risk management. *Geomorphological hazards and disaster prevention*, 221.

Cruden, D. M. (1991). A simple definition of a landslide. *Bulletin of Engineering Geology and the Environment*, *43*(1), 27-29.

Cruden, D. M., & Varnes, D. J. (1996). Landslides investigation and mitigation, transportation research board. *Landslide types and process, National Research Council, National Academy Press, Special Report*, *247*, 36-75.

Cruden, D., & Lan, H. X. (2015). Using the Working Classification of Landslides to assess the danger from a natural slope. In *Engineering Geology for Society and Territory-Volume 2* (pp. 3-12). Springer, Cham.

Cruden, D., & VanDine, D. F. (2013). Classification, description, causes and indirect effects-Canadian technical guidelines and best practices related to landslides: a national initiative for loss reduction. *Geol Surv Can Open File*, *7359*, 2013.

Cutler, D. R., Edwards Jr, T. C., Beard, K. H., Cutler, A., Hess, K. T., Gibson, J., & Lawler, J. J. (2007). Random forests for classification in ecology. *Ecology*, *88*(11), 2783-2792.

Daehne, A., & Corsini, A. (2013). Kinematics of active earthflows revealed by digital image correlation and DEM subtraction techniques applied to multi-temporal LiDAR data. *Earth Surface Processes and Landforms*, *38*(6), 640-654.

Dahal, R. K., Hasegawa, S., Nonomura, A., Yamanaka, M., Dhakal, S., & Paudyal, P. (2008). Predictive modelling of rainfall-induced landslide hazard in the Lesser Himalaya of Nepal based on weights-of-evidence. *Geomorphology*, *102*(3-4), 496-510.

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

Das, I., Sahoo, S., van Westen, C., Stein, A., & Hack, R. (2010). Landslide susceptibility assessment using logistic regression and its comparison with a rock mass classification system, along a road section in the northern Himalayas (India). *Geomorphology*, *114*(4), 627-637.

Davies, T. C., & Nyambok, I. O. (1993). The Murang'a landslide, Kenya. *Environmental Geology*, *21*(1-2), 19-21.

Deb, S. K., & El-Kadi, A. I. (2009). Susceptibility assessment of shallow landslides on Oahu, Hawaii, under extreme-rainfall events. *Geomorphology*, *108*(3-4), 219-233.

Deb, S. K., & El-Kadi, A. I. (2009). Susceptibility assessment of shallow landslides on Oahu, Hawaii, under extreme-rainfall events. *Geomorphology*, *108*(3-4), 219-233.

DeGraff, J. V. (1994). The geomorphology of some debris flows in the southern Sierra Nevada, California. In *Geomorphology and Natural Hazards* (pp. 231-252).

Dehnavi, A., Aghdam, I. N., Pradhan, B., & Varzandeh, M. H. M. (2015). A new hybrid model using step-wise weight assessment ratio analysis (SWARA) technique and adaptive neuro-fuzzy inference system (ANFIS) for regional landslide hazard assessment in Iran. *Catena*, *135*, 122-148.

Dikau, R., & Schrott, L. (1999). The temporal stability and activity of landslides in Europe with respect to climatic change (TESLEC): main objectives and results. *Geomorphology*, *30*(1-2), 1-12.

Dikau, R., Cavallin, A., & Jäger, S. (1996). Databases and GIS for landslide research in Europe. *Geomorphology*, *15*(3-4), 227-239.

Dou J, Bui DT, Yunus AP, Jia K, Song X, Revhaug I, Xia H, Zhu Z. 2015. Optimization of causative factors for landslide susceptibility evaluation using remote sensing and GIS data in parts of Niigata, Japan. PLoS One. 10(7): e0133262.

Dou, J., Yamagishi, H., Pourghasemi, H. R., Yunus, A. P., Song, X., Xu, Y., & Zhu, Z. (2015). An integrated artificial neural network model for the landslide susceptibility assessment of Osado Island, Japan. Natural Hazards, 78(3), 1749-1776.

Douglas, I., 1999. Hydrological investigations of forest disturbance and land cover impacts in South-East Asia: a review. Philosophical Transactions of the Royal Society of London. Series B 354, 1725-1738.

Drăguț, L., & Blaschke, T. (2006). Automated classification of landform elements using object-based image analysis. *Geomorphology*, *81*(3-4), 330-344.

Ekanayake, J. C., Phillips, C. J., & Phillips, J. C. (1999). A model for determining thresholds for initiation of shallow landslides under near-saturated conditions in the East Coast region, New Zealand. *Journal of Hydrology (New Zealand),* 1-28.

EM-DAT, (2014). The OFDA/CRED International Disaster Database, Universite Catholique de Louvain, Brussela, Belgium.

Epting, J., Verbyla, D., & Sorbel, B. (2005). Evaluation of remotely sensed indices for assessing burn severity in interior Alaska using Landsat TM and ETM+. *Remote Sensing of Environment*, *96*(3-4), 328–339. doi: 10.1016/j.rse.2005.03.002

Erener, A., & Düzgün, H. S. B. (2008). Analysis of landslide hazard mapping methods: regression models versus weight rating; XXIst ISPRS Congress 2008; 3–11 July. *Beijing, China. Commission VIII papers, Part B, 8*, 1682-1750.

Fabre, S., Briottet, X., & Lesaignoux, A. (2015). Estimation of Soil Moisture Content from the Spectral Reflectance of Bare Soils in the 0.4–2.5 μm Domain. *Sensors*, *15*(2), 3262–3281. doi:10.3390/s150203262.

Fell, R. (1994). Landslide risk assessment and acceptable risk. *Canadian Geotechnical Journal*, *31*(2), 261-272.

Fell, R., Corominas, J., Bonnard, C., Cascini, L., Leroi, E., Savage, W.Z., 2008. Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. EngGeol 102:85–89. doi: 10.1016/j.enggeo.2008.03.022.

Fiorucci, F., Cardinali, M., Carlà, R., Rossi, M., Mondini, A. C., Santurri, L., ... & Guzzetti, F. (2011). Seasonal landslide mapping and estimation of landslide mobilization rates using aerial and satellite images. *Geomorphology, 129*(1-2), 59-70.

Fiorucci, F., Cardinali, M., Carlà, R., Rossi, M., Mondini, A.C., Santurri, L., Ardizzone, F., Guzzetti, F., 2011. Seasonal landslides mapping and estimation of landslide mobilization rates using aerial and satellite images. Geomorphology 129 (1–2), 59–70. doi:10.1016/j.geomorph.2011.01.013.

Fookes, P. G., Dale, S. G., & Land, J. M. (1991). Some observations on a comparative aerial photography interpretation of a landslipped area. *Quarterly Journal of Engineering Geology and Hydrogeology, 24*(3), 249-265.

Frattini P, Crosta G, Sosio R (2009) Approaches for defining thresholds and return periods for rainfall-triggered shallow landslides. Hydrol Process 23(10):1444–1460

Frattini, P., Crosta, G., & Carrara, A. (2010). Techniques for evaluating the performance of landslide susceptibility models. *Engineering Geology, 111*(1-4), 62–72. doi:10.1016/j.enggeo.2009.12.004.

Galeandro, A., Doglioni, A., Guerricchio, A., & Simeone, V. (2013). Hydraulic stream network conditioning by a tectonically induced, giant, deep-seated landslide along the front of the Apennine chain (south Italy). *Natural Hazards and Earth System Sciences*, *13*(5), 1269-1283.

Gerrard, J. (1994). The landslide hazard in the Himalayas: geological control and human action. In *Geomorphology and Natural Hazards* (pp. 221-230).

Ghestem, M., Sidle, R. C., & Stokes, A. (2011). The influence of plant root systems on subsurface flow: implications for slope stability. *BioScience*, *61*(11), 869-879.

Ghimire, C.P., Bonell, M., Bruijnzeel, L.A., Coles, N.A. and Lubczynski, M.W. (2013). Reforesting severely degraded grassland in the Lesser Himalaya of Nepal: Effects on soil hydraulic conductivity and overland flow production. Journal of Geophysical Research: Earth Surface 118: 2528–2545. doi:10.1002/2013JF002888

Ghosh, S., Bora, A., Nath, S., & Kumar, A. (2014). Analysing the spatio-temporal evolution of an active debris slide in Eastern Himalaya, India. *Journal of the Geological Society of India*, *84*(3), 292-302.

Giannecchini, M., Twine, W., & Vogel, C. (2007). Land-cover change and human–environment interactions in a rural cultural landscape in South Africa. *Geographical Journal*, *173*(1), 26-42.

Glade, T. (2001). Landslide hazard assessment and historical landslide data—An inseparable couple. In *The use of historical data in natural hazard assessments* (pp. 153-168). Springer, Dordrecht.

Glade, T. (2003). Landslide occurrence as a response to land use change: a review of evidence from New Zealand. *Catena*, *51*(3-4), 297-314.

Glade, T., & Crozier, M. J. (2005). Landslide hazard and risk—Concluding comment and perspectives. *Landslide hazard and risk*, 765-774.

Gobbett, D. J. (1964). The lower palaeozoic rocks of Kuala Lumpur, Malaysia. *Fed Mus J*, *9*, 67-79.

Gobbett, D. J., Hutchison, C. S., & Burton, C. K. (1973). Geology of the Malay Peninsula.

Godt, J. W., Baum, R. L., Savage, W. Z., Salciarini, D., Schulz, W. H., & Harp, E. L. (2008). Transient deterministic shallow landslide modeling: requirements for susceptibility and hazard assessments in a GIS framework. *Engineering Geology*, *102*(3-4), 214-226.

Goetz, J. N., Brenning, A., Petschko, H., & Leopold, P. (2015). Evaluating machine learning and statistical prediction techniques for landslide susceptibility modeling. *Computers & geosciences*, *81*, 1-11.

Gorsevski, P. V., Brown, M. K., Panter, K., Onasch, C. M., Simic, A., & Snyder, J. (2016). Landslide detection and susceptibility mapping using LiDAR and an artificial neural network approach: a case study in the Cuyahoga Valley National Park, Ohio. *Landslides*, *13*(3), 467-484.

Gupta, R. P., & Joshi, B. C. (1990). Landslide hazard zoning using the GIS approach—A case study from the Ramganga catchment, Himalayas. *Engineering Geology*, *28*(1-2), 119–131. doi:10.1016/0013-7952(90)90037-2

Guzzetti F, Reichenbach P, Cardinali M, Galli M, Ardizzone F (2005) Probabilistic landslide hazard assessment at the basin scale. Geomorphology 72(1–4):272–299. Accessed 25 Oct 2010.

Guzzetti, F. (2000). Landslide fatalities and the evaluation of landslide risk in Italy. *Engineering Geology, 58*(2), 89-107.

Guzzetti, F., & Cardinali, M. (1990). Landslide inventory map of the Umbria region, Central Italy. *Proceedings ALPS, 90,* 273-284.

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., Mondini, A. C., Cardinali, M., Fiorucci, F., Santangelo, M., & Chang, K. T. (2012). Landslide inventory maps: New tools for an old problem. *Earth-Science Reviews, 112*(1-2), 42-66.

Guzzetti, F., Peruccacci, S., Rossi, M., & Stark, C. P. (2007a). The rainfall intensity–duration control of shallow landslides and debris flows: an update. *Landslides, 5*(1), 3–17. doi:10.1007/s10346-007-0112-1.

Guzzetti, F., Peruccacci, S., Rossi, M., & Stark, C. P. (2007b). Rainfall thresholds for the initiation of landslides in central and southern Europe. *Meteorology and Atmospheric Physics, 98*(3-4), 239–267. doi:10.1007/s00703-007-0262-7.

Guzzetti, F., Reichenbach, P., Ardizzone, F., Cardinali, M., & Galli, M. (2006). Estimating the quality of landslide susceptibility models. *Geomorphology, 81*(1-2), 166-184.

Haeberlin, Y., Turberg, P., Retiere, A., Senegas, O., & Parriaux, A. (2004). Validation of Spot-5 satellite imagery for geological hazard identification and risk assessment for landslides, mud and debris flows in Matagalpa, Nicaragua. *Nat. Resour. Canada, 35*(1), 273-278.

Haeberlin, Y., Turberg, P., Retière, A., Senegas, O., Parriaux, A., 2004. Validation of SPOT 5 Satellite Imagery for Geological Hazard Identification and Risk Assessment for landslides, mud and debris flows in Matagalpa, Nicaragua: ISPRS XX, Istanbul, Turkey, IAPRS, Vol. 35, pp. 273–278. ISSN 1682–1750 Part. B1.

Hamdhan, I. N., & Schweiger, H. (2011). Slope stability analysis of unsaturated soil with fully coupled-deformation analysis. In *Annual Conference of the International Association for Mathematical Geosciences*. IAMG.

Havlin, A., Magulova, B., & Bednarik, M. (2013). Vyuziti map sesuvneho hazardu k planovani trasy liniovych staveb v prostredi nachylnem ke vzniku svahovych deformaci. *Zpravy o geologickych vyzkumech, 2012,* 323-327.

Hervás, J., Barredo, J. I., Rosin, P. L., Pasuto, A., Mantovani, F., & Silvano, S. (2003). Monitoring landslides from optical remotely sensed imagery: the case history of Tessina landslide, Italy. *Geomorphology*, *54*(1-2), 63-75.

Highland, L., & Bobrowsky, P. T. (2008). *The landslide handbook: a guide to understanding landslides* (p. 129). Reston: US Geological Survey.

Hinkelmann, R., Zehe, E., Ehlers, W., & Joswig, M. (2011). Special section on landslides: Setting the scene and outline of contributing studies. *Vadose Zone Journal*, *10*(2), 473-476.

Höfle, B., & Rutzinger, M. (2011). Topographic airborne LiDAR in geomorphology: A technological perspective. *Zeitschrift für Geomorphologie, Supplementary Issues*, *55*(2), 1-29.

Hong, Y., Adler, R. F., Negri, A., & Huffman, G. J. (2007). Flood and landslide applications of near real-time satellite rainfall products. *Natural Hazards, 43*(2), 285-294.

Huang, J. C., & Kao, S. J. (2006). Optimal estimator for assessing landslide model performance. *Hydrology and Earth System Sciences Discussions*, *10*(6), 957-965.

Hung, L. Q., Batelaan, O., & De Smedt, F. (2005). Lineament extraction and analysis, comparison of LANDSAT ETM and ASTER imagery. Case study: Suoimuoi tropical karst catchment, Vietnam. In M. Ehlers & U. Michel (Eds.), *Proceedings of SPIE Remote sensing for Environmental monitoring, GIS applications and Geology* (Vol. 5983, p. 59830T–59830T–12). International Society for Optics and Photonics. doi:10.1117/12.627699.

Hung, L. Q., Batelaan, O., & De Smedt, F. (2005). Lineament extraction and analysis, comparison of LANDSAT ETM and ASTER imagery. Case study: Suoimuoi tropical karst catchment, Vietnam. In M. Ehlers & U. Michel (Eds.), *Proceedings of SPIE Remote sensing for Environmental monitoring, GIS applications and Geology* (Vol. 5983, p. 59830T–59830T–12). International Society for Optics and Photonics. doi:10.1117/12.627699.

Hunger, O., Evans, S.G., Bovis, M., and Hutchinson, J.N. (2001). "Review of the Classification of Landslides of the Flow Type". Environmental and Engineering Geoscience, 8, 221-238.

Hungr, O., Leroueil, S., & Picarelli, L. (2014). The Varnes classification of landslide types, an update. *Landslides, 11*(2), 167-194.

IAEG Commission on Landslides, 1990. Suggested nomenclature for landslides. Bulletin International Association of Engineering Geology, 41: 13-16.

Ibsen, M. L., & 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*(3-4), 241-258.

Imaizumi, F., Sidle, R. C., & Kamei, R. (2008). Effects of forest harvesting on the occurrence of landslides and debris flows in steep terrain of central Japan. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group, 33*(6), 827-840.

IUGS—Working group on landslide, 1995. A suggested method for describing the rate of movement of a landslide. Bulletin of the International Association of Engineering Geology 52, 75–78.

IUGS-Working group on landslide, 2001. A suggested method for reporting landslide remedial measures. Bulletin of Engineering Geology and Environment 60, 69–74.

Iwahashi, J., & Pike, R. J. (2007). Automated classifications of topography from DEMs by an unsupervised nested-means algorithm and a three-part geometric signature. *Geomorphology*, *86*(3-4), 409-440.

Jaboyedoff, M., Oppikofer, T., Abellán, A., Derron, M. H., Loye, A., Metzger, R., & Pedrazzini, A. (2012). Use of LIDAR in landslide investigations: a review. *Natural hazards*, *61*(1), 5-28.

Jaboyedoff, M., Oppikofer, T., Abellán, A., Derron, M. H., Loye, A., Metzger, R., & Pedrazzini, A. (2012). Use of LIDAR in landslide investigations: a review. *Natural hazards*, *61*(1), 5-28.

Jade, S., & Sarkar, S. (1993). Statistical models for slope instability classification. *Engineering Geology*, *36*(1-2), 91–98. doi:10.1016/0013-7952(93)90021-4

Jaiswal, P., van Westen, C. J., & Jetten, V. (2010). Quantitative landslide hazard assessment along a transportation corridor in southern India. *Engineering geology*, *116*(3-4), 236-250.

Jakob, M., Holm, K., Lange, O., & Schwab, J. W. (2006). Hydrometeorological thresholds for landslide initiation and forest operation shutdowns on the north coast of British Columbia. *Landslides*, *3*(3), 228-238.

Jing, W., Yang, Y., Yue, X., and Zhao, X., 2016. A Comparison of Different Regression Algorithms for Downscaling Monthly Satellite-Based Precipitation over North China. Remote Sens. 2016, 8(10), 835; doi:10.3390/rs8100835.

JMG. Geological Terrain Mapping of the Kundasang Area, Sabah. 2003

Jordan, M. I., & Mitchell, T. M. (2015). Machine learning: Trends, perspectives, and prospects. *Science*, *349*(6245), 255-260.

Joyce, K. E., Wright, K. C., Samsonov, S. V., & Ambrosia, V. G. (2009). Remote sensing and the disaster management cycle. In *Advances in geoscience and remote sensing*. InTech.

Kanungo, D. P., Arora, M. K., Sarkar, S., & Gupta, R. P. (2006). 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*(3-4), 347-366.

Kanungo, D. P., Arora, M. K., Sarkar, S., & Gupta, R. P. (2006). 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*(3-4), 347–366. doi:10.1016/j.enggeo.2006.03.004

Kanungo, D. P., Arora, M. K., Sarkar, S., & Gupta, R. P. (2009). Landslide Susceptibility Zonation (LSZ) Mapping - A Review. *Journal of South Asia Disaster Studies*, *2*(1), 81–10

Kanungo, D. P., Arora, M. K., Sarkar, S., & Gupta, R. P. (2012). Landslide Susceptibility Zonation (LSZ) Mapping–A Review.

Karim, S., Jalileddin, S., & Ali, M. T. (2011). Zoning Landslide by Use of Frequency Ratio Method (Case Study: Deylaman Region). *Middle East Journal of Scientific Research*, *9*(5), 578–583.

Karsli, F., Atasoy, M., Yalcin, A., Reis, S., Demir, O., & Gokceoglu, C. (2009). Effects of land-use changes on landslides in a landslide-prone area (Ardesen, Rize, NE Turkey). *Environmental monitoring and assessment*, *156*(1-4), 241.

Kasai, M., Ikeda, M., Asahina, T., Fujisawa, K., 2009. LiDAR-derived DEM evaluation of deepseated landslides in a steep and rocky region of Japan. Geomorphology 113, 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.

Khazai, B., & Sitar, N. (2004). Evaluation of factors controlling earthquake-induced landslides caused by Chi-Chi earthquake and comparison with the Northridge and Loma Prieta events. *Engineering geology*, *71*(1-2), 79-95.

Kazmi, D., Qasim, S., Harahap, I., Baharom, S., Imran, M., & Moin, S. (2016). A study on the contributing factors of major landslides in Malaysia. *Civil Eng J, 2*(12), 669-678.

Klimeš, J., Baroň, I., Pánek, T., Kosačík, T., Burda, J., Kresta, F., & Hradecký, J. (2009). Investigation of recent catastrophic landslides in the flysch belt of Outer Western Carpathians (Czech Republic): progress towards better hazard assessment. *Natural Hazards and Earth System Sciences*, *9*(1), 119-128.

Ko¨rner C, Ohsawa M, Spehn E et al (2005) Mountain systems. In: Hassan R, Scholes R, Ash N (eds) Ecosystem and human wellbeing: current state and trends: findings of the Conditions and Trends working group. Millennium Ecosystem Assessment, pp 681–716.

Komoo, I. (2000). Conservation geology: a multidisciplinary approach in utilization of earth resources without destruction. *Geological Heritage of Malaysia–Resource Development for Conservation and Nature Tourism. Bangi: LESTARI UKM*.

Korup, O., & Stolle, A. (2014). Landslide prediction from machine learning. *Geology Today, 30*(1), 26-33.

Korup, O., 2005. Geomorphic imprint of landslides on alpine river systems, southwest New Zealand. Earth Surface Processes and Landforms 30, 783–800.

Kraus, K., 2007. Photogrammetry, 2nd ed. Walter de Gruyter, Berlin

Kriegler, E., O'Neill, B. C., Hallegatte, S., Kram, T., Lempert, R. J., Moss, R. H., & Wilbanks, T. (2012). The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways. *Global Environmental Change*, *22*(4), 807-822.

Kuriakose, S. L., Van Beek, L. P. H., & Van Westen, C. J. (2009). Parameterizing a physically based shallow landslide model in a data poor region. *Earth surface processes and landforms, 34*(6), 867-881.

Kuriakose, S.L., 2010. Physically based dynamic modelling of the effect of land use changes on shallow landslide initiation in the Western Ghats of Kerala. PhD Thesis. University of Twente Faculty of Geo-Information and Earth Observation ITC, 2010. ITC Dissertation 178, ISBN: 978-90-6164-298-5.

Ladd, G. E. (1935). *Landslides, subsidences and rock-falls*. American Railway Engineering Association.

Lang, C. C., Anantharamaiah, K. R., Kassim, N. E., & Lazio, T. J. W. (1999). Discovery of a nonthermal galactic center filament (g358. 85+ 0.47) parallel to the galactic plane. *The Astrophysical Journal Letters*, *521*(1), L41.

Larsen, I. J., Almond, P. C., Eger, A., Stone, J. O., Montgomery, D. R., & Malcolm, B. (2014). Rapid soil production and weathering in the Western Alps, New Zealand. *Science*, 1244908.

Lee, S., & Talib, J. A. (2005). Probabilistic landslide susceptibility and factor effect analysis. *Environmental Geology*, *47*(7), 982-990.

Leroi, E. (1996). Landslide hazard-risk maps at different scales: objectives, tools and developments. *Landslides, 1*, 35-51.

Liao, Z., Hong, Y., Kirschbaum, D., & Liu, C. (2011). Assessment of shallow landslides from Hurricane Mitch in central America using a physically based model. *Environmental Earth Sciences*, *66*(6), 1697–1705. doi:10.1007/s12665-011-0997-9.

Liao, Z., Hong, Y., Wang, J., Fukuoka, H., Sassa, K., Karnawati, D., & Fathani, F. (2010). Prototyping an experimental early warning system for rainfall-induced landslides in Indonesia using satellite remote sensing and geospatial datasets. *Landslides*, *7*(3), 317–324. doi:10.1007/s10346-010-0219-7.

Liaw, A., & Wiener, M. (2002). Classification and regression by randomForest. *R news*, *2*(3), 18-22.

Listo, F. de L. R., & Carvalho, V. B. (2012). Mapping of risk and susceptibility of shallow-landslide in the city of São Paulo, Brazil. *Geomorphology*, *169-170*, 30–44. doi:10.1016/j.geomorph.2012.01.010.

Liu, J. G., Mason, P. J., Clerici, N., Chen, S., Davis, A., Miao, F., ... & Liang, L. (2004). Landslide hazard assessment in the Three Gorges area of the Yangtze river using ASTER imagery: Zigui–Badong. *Geomorphology*, *61*(1-2), 171-187.

Lombardo, L., Cama, M., Conoscenti, C., Märker, M., & Rotigliano, E. (2015). Binary logistic regression versus stochastic gradient boosted decision trees in assessing landslide susceptibility for multiple-occurring landslide events: application to the 2009 storm event in Messina (Sicily, southern Italy). *Natural Hazards*, *79*(3), 1621-1648.

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

Mahalingam, R., Olsen, M. J., & O'Banion, M. S. (2016). Evaluation of landslide susceptibility mapping techniques using lidar-derived conditioning factors (Oregon case study). *Geomatics, Natural Hazards and Risk*, *7*(6), 1884-1907.

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.

Mancarella, D., Doglioni, A., & Simeone, V. (2012). On capillary barrier effects and debris slide triggering in unsaturated layered covers. *Engineering geology*, *147*, 14-27.

Mann, U., Pradhan, B., Prechtel, N., & Buchroithner, M. F. (2012). An automated Approach for detection of shallow landslides from LiDAR derived DEM using geomophological indicators in a tropical Forest. In B. Pradhan & M. F. Buchroithner (Eds.), Terrigenous Mass Movements: Detection, Modelling, Early Warning and Mitigation using Geoinformation Technology (pp. 1–22). Berlin: Springer. doi:10.1007/978-3-642-25495-6_1.

Marcelino, E. V., Formaggio, A. R., & Maeda, E. E. (2009). Landslide inventory using image fusion techniques in Brazil. *International Journal of applied Earth observation and geoinformation*, *11*(3), 181-191.

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

Martha, T. R., Kerle, N., Jetten, V., van Westen, C. J., & Kumar, K. V. (2010). Characterising spectral, spatial and morphometric properties of landslides for semi-automatic detection using object-oriented methods. *Geomorphology*, *116*(1-2), 24-36.

Mashari, S., Solaimani, K., & Omidvar, E. (2012). Landslide susceptibility mapping using multiple regression and GIS tools in Tajan Basin, North of Iran. *Environment and Natural Resources Research, 2*(3), 43.

Matsushi, Y., & Matsukura, Y. (2007). Rainfall thresholds for shallow landsliding derived from pressure-head monitoring: cases with permeable and impermeable bedrocks in Boso Peninsula, Japan. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, *32*(9), 1308-1322.

McIntosh, P.D., Price, D.M., Eberhardt, R., Slee, A.J., 2009. Late Quaternary erosion events in lowland and mid-altitude Tasmania in relation to climate change and first human arrival. Quaternary Science Reviews 28, 850–872.

McKean, J., & Roering, J. (2003, December). Operational accuracy of LiDAR in mountainous terrain. In *AGU Fall Meeting Abstracts*.

McKean, J., & Roering, J. (2004). Objective landslide detection and surface morphology mapping using high-resolution airborne laser altimetry. *Geomorphology*, *57*(3-4), 331-351.

Meisina, C., Zucca, F., Fossati, D., Ceriani, M., & Allievi, J. (2006). Ground deformation monitoring by using the permanent scatterers technique: the example of the Oltrepo Pavese (Lombardia, Italy). *Engineering Geology, 88*(3-4), 240-259.

Metelka, V., & Kycl, P. (2007). Mapping of slope landslides susceptibility in GIS environment, Miramar, Kostarika. *Svahové deformace a pseudokras*, 29-31.

Metternicht, G., Hurni, L., & Gogu, R. (2005). Remote sensing of landslides: An analysis of the potential contribution to geo-spatial systems for hazard assessment in mountainous environments. *Remote sensing of Environment, 98*(2-3), 284-303.

Meusburger, K., & Alewell, C. (2008). Impacts of anthropogenic and environmental factors on the occurrence of shallow landslides in an alpine catchment (Urseren Valley, Switzerland). *Natural Hazards and Earth System Sciences*, *8*, 509-520.

Middleton, M., Schnur, T., Sorjonen-Ward, P., & Hyvönen, E. (2015). Geological lineament interpretation using the object-based image analysis approach: results of semi-automated analyses versus visual interpretation. *Geological Survey of Finland, Special Paper*, *57*, 135-154.

Miller, A. J. (2013). Assessing landslide susceptibility by incorporating the surface cover index as a measurement of vegetative cover. *Land Degradation & Development*, *24*(3), 205-227.

Mitasova, H., Harmon, R. S., Weaver, K. J., Lyons, N. J., & Overton, M. F. (2012). Scientific visualization of landscapes and landforms. *Geomorphology, 137*(1), 122–137. doi:10.1016/j.geomorph.2010.09.033.

MOGHADDAS, N. H., & GHAFOORI, M. (2006). The role of weathering in the occurrence of landslides in centeral Alborz, Iran.

Moine, M., Puissant, A., & Malet, J. P. (2009, February). Detection of landslides from aerial and satellite images with a semi-automatic method. Application to the Barcelonnette basin (Alpes-de-Hautes-Provence, France). In *Landslide processes-from geomorphologic mapping to dynamic modelling* (pp. 63-68).

Mondini, A. C., 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.

Mondini, A.C., Chang, K.T., Yin, H.Y., 2011a. Combining multiple change detection indices for mapping landslides triggered by typhoons. Geomorphology 134 (3–4), 440–451. doi:10.1016/j.geomorph.2011.07.021.

Moore, I. D., & Wilson, J. P. (1992). Length-slope factors for the Revised Universal Soil Loss Equation: Simplified method of estimation. *Journal of soil and water conservation*, *47*(5), 423-428.

Moosavi, V., & Niazi, Y. (2016). Development of hybrid wavelet packet-statistical models (WP-SM) for landslide susceptibility mapping. *Landslides*, *13*(1), 97-114.

Morgenstern, N. R., Martin, C. D., Chen, Z., Zhang, J. M., Li, Z. K., Wu, F. Q., & Ho, K. (2008, June). Landslides: seeing the ground. In *Proceedings of the Tenth International Symposium on Landslides and Engineered Slopes. Balkema, Christchurch* (pp. 3-24).

Mwaniki, M. W. (2016). Modelling the Impacts of Predicted Environmental Change on the Frequency and Magnitude of Rainfall Induced Landslides in Central Kenya.

Mwaniki, M. W., Kuria, D. N., Boitt, M. K., & Ngigi, T. G. (2016). Image enhancements of Landsat 8 (OLI) and SAR data for Preliminary Landslide identification and mapping applied to the central region of Kenya. *Geomorphology*.

National Slope Master Plan 2009-2023. (2009). Public Works Department: Kuala Lumpur.

Neaupane, K. M., & Piantanakulchai, M. (2006). Analytic network process model for landslide hazard zonation. *Engineering Geology*, *85*(3-4), 281-294.

Nefeslioglu, H. A., 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*(3-4), 171-191.

Neuhäuser, B., Damm, B., & Terhorst, B. (2012). GIS-based assessment of landslide susceptibility on the base of the Weights-of-Evidence model. *Landslides*, *9*(4), 511–528. doi:10.1007/s10346-011-0305-5.

Ngecu, W. M., & Ichang'i, D. W. (1999). The environmental impact of landslides on the population living on the eastern footslopes of the Aberdare ranges in Kenya: a case study of Maringa Village landslide. *Environmental Geology*, *38*(3), 259-264.

Oguchi, T., Aoki, T., & Matsuta, N. (2003). Identification of an active fault in the Japanese Alps from DEM-based hill shading. *Computers & Geosciences*, *29*(7), 885-891.

Oh, H. J., & 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. (2007). Plan curvature and landslide probability in regions dominated by earth flows and earth slides. *Engineering Geology*, *91*(2-4), 117-134.

Ortenberg, F. (2016). Hyperspectral Sensor Characteristics: Airborne, Hand-Held, and Truck-Mounted; Integration of Hyperspectral Data with LIDAR. In P. S. Thenkabail, J. G. Lyon, & A. Huete (Eds.), *Hyperspectral remote sensing of vegetation* (pp. 39–68). Boca Raton, Fla.: CRC Press. doi:10.1201/b11222.

Pack, R. T., Tarboton, D. G., & Goodwin, C. N. (1998). The SINMAP approach to terrain stability mapping. In *Proceedings of the Eighth Congress of the International Association of Engineering Geology*. Vancouver, British Columbia, Canada.

Pack, R. T., Tarboton, D. G., & Goodwin, C. N. (1999). GIS-based landslide susceptibility mapping with SINMAP. In *Proceedings of the 34th symposium on engineering geology and geotechnical engineering* (pp. 219–231). Utah State University, Logan, UT, United States.

Pagano, L., Zingariello, M. C., & Vinale, F. (2008, June). A large physical model to simulate flowslides in pyroclastic soils. In *Proceedings of the 1st European Conference on Unsaturated Soils, E-UNSAT* (pp. 111-115).

Papathoma-Köhle, M., & Glade, T. (2013). The role of vegetation cover changes for landslide hazard and risk. *The role of ecosystems in disaster risk reduction. UNU-Press, Tokyo*, 293-320.

Pardeshi, S. D., Autade, S. E., & Pardeshi, S. S. (2013). Landslide hazard assessment: recent trends and techniques. *SpringerPlus*, *2*(1), 523.

Pascale, S., Parisi, S., Mancini, A., Schiattarella, M., Conforti, M., Sole, A., ... & Sdao, F. (2013, June). Landslide susceptibility mapping using artificial neural network in the urban area of Senise and San Costantino Albanese (Basilicata, Southern Italy). In *International Conference on Computational Science and Its Applications* (pp. 473-488). Springer, Berlin, Heidelberg.

Passalacqua, P., Belmont, P., Staley, D. M., Simley, J. D., Arrowsmith, J. R., Bode, C. A., ... & Lague, D. (2015). Analyzing high resolution topography for advancing the understanding of mass and energy transfer through landscapes: A review. *Earth-Science Reviews*, *148*, 174-193.

Passalacqua, P., Tarolli, P., Foufoula-Georgiou, E., 2010. Testing space-scale methodologies for automatic geomorphic feature extraction from LiDAR in a complex mountainous landscape. Water Resources Research 46, W11535. doi:10.1029/ 2009WR008812.

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.

Peres, D. J., & Cancelliere, A. (2014). Derivation and evaluation of landslide-triggering thresholds by a Monte Carlo approach. *Hydrology and Earth System Sciences*, *18*(12), 4913–4931. doi:10.5194/hess-18-4913-2014.

Perotto-Baldiviezo, H. L., Thurow, T. L., Smith, C. T., Fisher, R. F., & Wu, X. B. (2004). GIS-based spatial analysis and modeling for landslide hazard assessment in steeplands, southern Honduras. *Agriculture, Ecosystems & Environment*, *103*(1), 165-176.

Petley, D. (2012). Global patterns of loss of life from landslides. *Geology*, *40*(10), 927-930.

Petley, D. N., Mantovani, F., Bulmer, M. H., & Zannoni, A. (2005). The use of surface monitoring data for the interpretation of landslide movement patterns. *Geomorphology*, *66*(1-4), 133-147.

Petley, D.N., Hearn, G.J., Hart, A., Rosser, N.J., Dunning, S.A., Oven, K., Mitcell, W.A., 2007. Trends in landslide occurrence in Nepal. Natural Hazards 43, 23-44.

Petrie, G., & Toth, C. K. (2008). I. Introduction to laser ranging, profiling and scanning, II. Airbone and spaceborne laser profiles and scanners, III. Terrestrial laser scanners (chapters 1 to 3). *Topographic laser ranging and scanning: principles and processing, CRC Press, Taylor & Francis*.

Pham, B. T., Jaafari, A., Prakash, I., & Bui, D. T. (2018). A novel hybrid intelligent model of support vector machines and the MultiBoost ensemble for landslide susceptibility modeling. *Bulletin of Engineering Geology and the Environment*, 1-22.

Pham, B.T., D.T. Bui, I. Prakash, and M.B. Dholakia. 2017. Hybrid integration of Multilayer Perceptron Neural Networks and machine learning ensembles for landslide susceptibilityassessment at Himalayan area (India) using GIS. CATENA 149: 52–63.

Pike, R. J. (1988). The geometric signature: quantifying landslide-terrain types from digital elevation models. *Mathematical geology*, *20*(5), 491-511.

Plaza, A., Benediktsson, J. A., Boardman, J. W., Brazile, J., Bruzzone, L., Camps-Valls, G., ... & Marconcini, M. (2009). Recent advances in techniques for hyperspectral image processing. *Remote sensing of environment*, *113*, S110-S122.

Polemio, M., & Petrucci, O. (2000). Rainfall as a landslide triggering factor an overview of recent international research. In *Landslides in research, theory and practice*. Thomas Telford Ltd..

Pourghasemi, H. R., & Rahmati, O. (2018). Prediction of the landslide susceptibility: which algorithm, which precision?. *Catena, 162*, 177-192.

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

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., & Sameen, M. I. (2017). Laser scanning systems in landslide studies. In *Laser Scanning Applications in Landslide Assessment* (pp. 3-19). Springer, Cham.

Pradhan, B., Singh, R. P., & Buchroithner, M. F. (2006). Estimation of stress and its use in evaluation of landslide prone regions using remote sensing data. *Advances in Space Research*, *37*(4), 698–709. doi:10.1016/j.asr.2005.03.137

Promper, C., Puissant, A., Malet, J. P., & Glade, T. (2014). Analysis of land cover changes in the past and the future as contribution to landslide risk scenarios. *Applied Geography*, *53*, 11-19.

Rahman, A. U., Khan, A. N., & Collins, A. E. (2014). Analysis of landslide causes and associated damages in the Kashmir Himalayas of Pakistan. *Natural hazards*, *71*(1), 803-821.

Rahman, H. A. (2015). An Overview of Environmental Disaster in Malaysia and Prepa-redness Strategies. *Iranian Journal of Public Health*, *43*(3), 17-24.

Rahmana, H. A., & Mapjabilb, J. (2017). Landslides Disaster in Malaysia: an Overview. *Health*, *8*(1), 58-71.

Razak, K. A. (2014). Airborne laser scanning for forested landslides investigation in temperate and tropical environments. *Enschede, The Netherlands*.

Razak, K. A., Santangelo, M., Van Westen, C. J., Straatsma, M. W., & de Jong, S. M. (2013). Generating an optimal DTM from airborne laser scanning data for landslide mapping in a tropical forest environment. *Geomorphology, 190*, 112-125.

Razak, K. A., Straatsma, M. W., Van Westen, C. J., Malet, J. P., & De Jong, S. M. (2011). Airborne laser scanning of forested landslides characterization: Terrain model quality and visualization. Geomorphology, 126(1-2), 186-200.

Razak, K.A., Straatsma, M.W., Van Westen, C.J., Malet, J.P., de Jong, S.M., 2011. Airborne laser scanning of forested landslides characterization: terrain model quality and visualization. Geomorphology 126, 186–200.

Regmi, A. D., Yoshida, K., Dhital, M. R., & Devkota, K. (2013). Effect of rock weathering, clay mineralogy, and geological structures in the formation of large landslide, a case study from Dumre Besei landslide, Lesser Himalaya Nepal. *Landslides*, *10*(1), 1-13.

Rigon, R., Bertoldi, G., & Over, T. M. (2006). GEOtop: A Distributed Hydrological Model with Coupled Water and Energy Budgets. *Journal of Hydrometeorology, 7*(3), 371–388. doi:10.1175/JHM497.1.

Riley, S. J., DeGloria, S. D., & Elliot, R. (1999). Index that quantifies topographic heterogeneity. *intermountain Journal of sciences*, *5*(1-4), 23-27.

Roback, K., Clark, M. K., West, A. J., Zekkos, D., Li, G., Gallen, S. F., Chamlagain, D., Godt, J. W., 2017. The size, distribution, and mobility of landslides caused by the 2015 Mw7.8 Gorkha earthquake, Nepal, Geomorphology (2017), http://dx.doi.org/10.1016/j.geomorph.2017.01.030

Roering, J. J., Mackey, B. H., Marshall, J. A., Sweeney, K. E., Deligne, N. I., Booth, A. M., ... & Cerovski-Darriau, C. (2013). ‘You are HERE’: Connecting the dots with airborne lidar for geomorphic fieldwork. *Geomorphology*, *200*, 172-183.

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

Roslee, R., Jamaluddin, T. A., & Talip, M. A. (2012). Intergration of GIS Using GEOSTAtistical INterpolation Techniques (Kriging)(GEOSTAINT-K) in Deterministic Models for Landslide Susceptibility Analysis (LSA) at Kota Kinabalu, Sabah, Malaysia. *Journal of Geography and Geology*, *4*(1), 18.

Roslee, R., Jamaluddin, T. A., & Talip, M. A. (2012). Landslide susceptibility mapping (LSM) at Kota Kinabalu, Sabah, Malaysia using factor analysis model (FAM). *Journal of Advanced Science and Engineering Research*, *2*(1), 80-103.

Rounsevell, M. D. A., Reginster, I., Araújo, M. B., Carter, T. R., Dendoncker, N., Ewert, F., ... & Schmit, C. (2006). A coherent set of future land use change scenarios for Europe. *Agriculture, Ecosystems & Environment, 114*(1), 57-68.

Rudd, L. P. (2005). *Using AVIRIS hyperspectral imagery to study the role of clay mineralogy in Colorado Plateau debris flow initiation* (PhD Thesis). University of Arizona.

Ruiz-Villanueva, V., Bodoque, J. M., Díez-Herrero, A., & Calvo, C. (2011). Triggering threshold precipitation and soil hydrological characteristics of shallow landslides in granitic landscapes. *Geomorphology*, *133*(3-4), 178-189.

Saito, H., Nakayama, D., & Matsuyama, H. (2010). Relationship between the initiation of a shallow landslide and rainfall intensity—duration thresholds in Japan. *Geomorphology, 118*(1-2), 167-175.

Samodra, G., Chen, G., Sartohadi, J., & Kasama, K. (2018). Generating landslide inventory by participatory mapping: an example in Purwosari Area, Yogyakarta, Java. *Geomorphology, 306,* 306-313.

San, H. P., Singh, K. S, A., Ismail, A.Z., Singh, K. K. A and Kum, P. S, 2015. Initiatives and Efforts Toward Greening Malaysian Furniture Industry. *Asian Journal of Scientific Research, 8: 122-133*

Sangchini, E. K., Emami, S. N., Tahmasebipour, N., Pourghasemi, H. R., Naghibi, S. A., Arami, S. A., & Pradhan, B. (2016). Assessment and comparison of combined bivariate and AHP models with logistic regression for landslide susceptibility mapping in the Chaharmahal-e-Bakhtiari Province, Iran. *Arabian Journal of Geosciences*, *9*(3), 201.

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

Santurri, L., Carlà, R., Fiorucci, F., Aiazzi, B., Baronti, S., Mondini, A., & Cardinali, M. (2010). *Assessment of very high resolution satellite data fusion techniques for landslide recognition*. na.

Sato, H. P., & Harp, E. L. (2009). Interpretation of earthquake-induced landslides triggered by the 12 May 2008, M7. 9 Wenchuan earthquake in the Beichuan area, Sichuan Province, China using satellite imagery and Google Earth. *Landslides*, *6*(2), 153-159.

Scaioni, M., Longoni, L., Melillo, V., & Papini, M. (2014). Remote sensing for landslide investigations: An overview of recent achievements and perspectives. *Remote Sensing*, *6*(10), 9600-9652.

Scaioni, M., Roncella, R., & Alba, M. I. (2013). Change detection and deformation analysis in point clouds. *Photogrammetric Engineering & Remote Sensing*, *79*(5), 441-455.

Schlögel, R., Torgoev, I., De Marneffe, C., & Havenith, H. B. (2011). Evidence of a changing size–frequency distribution of landslides in the Kyrgyz Tien Shan, Central Asia. *Earth Surface Processes and Landforms*, *36*(12), 1658-1669.

Schulz WH., 2007. Landslide susceptibility revealed by LIDAR imagery and historical records, Seattle, Washington. Eng Geol. 89:67–87. DOI: 10.1016/j.enggeo.2006.09.019.

Sengupta, A., Gupta, S., & Anbarasu, K. (2010). Rainfall thresholds for the initiation of landslide at Lanta Khola in north Sikkim, India. *Natural hazards*, *52*(1), 31-42.

Shearer, P., Hauksson, E., & Lin, G. (2005). Southern California hypocenter relocation with waveform cross-correlation, Part 2: Results using source-specific station terms and cluster analysis. *Bulletin of the Seismological Society of America*, *95*(3), 904-915.

Shi, J., Du, Y., Du, J., Jiang, L., Chai, L., Mao, K., … Wang, Y. (2012). Progresses on microwave remote sensing of land surface parameters. *Science China Earth Sciences*, *55*(7), 1052–1078. doi:10.1007/s11430-012-4444-x.

Shirzadi, A., Shahabi, H., Chapi, K., Bui, D. T., Pham, B. T., Shahedi, K., & Ahmad, B. B. (2017). A comparative study between popular statistical and machine learning methods for simulating volume of landslides. *Catena*, *157*, 213-226.

Sidle, R. C., & Ochiai, H. (2006). Landslides: processes, prediction, and land use. *Water resources monograph series*.

Simoni, S., Zanotti, F., Bertoldi, G., & Rigon, R. (2008). Modelling the probability of occurrence of shallow landslides and channelized debris flows using GEOtop-FS. *Hydrological Processes*, *22*(4), 532–545. doi:10.1002/hyp.6886

Sims, D. A., & Gamon, J. A. (2002). Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. *Remote Sensing of Environment*, *81*(2-3), 337–354. doi:10.1016/S0034-4257(02)00010-X

Singh, P., Gupta, A., & Singh, M. (2014). Hydrological inferences from watershed analysis for water resource management using remote sensing and GIS techniques. *The Egyptian Journal of Remote Sensing and Space Science, 17*(2), 111–121.

Singhal, B. B. S., & Gupta, R. P. (2010). Fractures and Discontinuities. In *Applied Hydrogeology of Fractured Rocks* (pp. 13–33). Dordrecht: Springer Netherlands. doi:10.1007/978-90-481-8799-7.

Singhroy, V. (2009). Satellite remote sensing applications for landslide detection and monitoring. In *Landslides–Disaster Risk Reduction* (pp. 143-158). Springer, Berlin, Heidelberg.

Sithole, G., & Vosselman, G. (2001). Filtering of laser altimetry data using a slope adaptive filter. *International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences*, *34*(3/W4), 203-210.

Smailbegovic, A., Mendenhall, M., Clark, J., Gray, K., & Wooten, R. (2011, June). Landslide imaging and detection with horizontal-scanning active and passive remote sensing methods: A study of data integration in assessing complex target environment. In *Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS), 2011 3rd Workshop on* (pp. 1-4). IEEE.

Smith, M. J., Chandler, J., & Rose, J. (2009). High spatial resolution data acquisition for the geosciences: kite aerial photography. *Earth Surface Processes and Landforms*, *34*(1), 155-161.

Soeters, R., & van Westen, C. J. (1996). Landslides: Investigation and mitigation. Chapter 8-Slope instability recognition, analysis, and zonation. *Transportation research board special report*, (247).

Sterzai, P., Vellico, M., Berti, M., Coren, F., Corsini, A., Rosi, A., ... & Ronchetti, F. (2010). LiDAR and hyperspectral data integration for landslide monitoring: The test case of Valoria landslide. *Italian Journal of Remote Sensing*, *42*(3), 89-99.

Stow, D., Hope, A., Nguyen, A. T., Phinn, S., & Benkelman, C. A. (1996). Monitoring detailed land surface changes using an airborne multispectral digital camera system. *IEEE Transactions on Geoscience and Remote Sensing*, *34*(5), 1191-1203.

Strupler, M., Danciu, L., Hilbe, M., Kremer, K., Anselmetti, F. S., Strasser, M., & Wiemer, S. (2018). A subaqueous hazard map for earthquake-triggered landslides in Lake Zurich, Switzerland. *Natural Hazards*, *90* (1), 51-78.

Stumpf, A., & Kerle, N. (2011). Object-oriented mapping of landslides using Random Forests. *Remote sensing of environment*, *115*(10), 2564-2577.

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

Syafrina, A. H., Zalina, M. D., & Juneng, L. (2015). Historical trend of hourly extreme rainfall in Peninsular Malaysia. *Theoretical and Applied Climatology*, *120*(1-2), 259-285.Tasser, E., Mader, M., & Tappeiner, U. (2003). Effects of land use in alpine grasslands on the probability of landslides. *Basic and Applied Ecology*, *4*(3), 271-280.

Takara, K., Yamashiki, Y., Sassa, K., Ibrahim, A. B., & Fukuoka, H. (2010). A distributed hydrological–geotechnical model using satellite-derived rainfall estimates for shallow landslide prediction system at a catchment scale. *Landslides*, *7*(3), 237–258. doi:10.1007/s10346-010-0214-z

Tarolli, P. (2014). High-resolution topography for understanding Earth surface processes: Opportunities and challenges. *Geomorphology*, *216*, 295-312.

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.

Tarolli, P., Sofia, G., Dalla Fontana, G., 2010. Geomorphic features extraction from high resolution topography: landslide crowns and bank erosion. Natural Hazards. doi:10.1007/s11069-010-9695-2.

Tating, F. F. (2006). *Geological factors contributing to the landslide hazard area at the Tamparuli-Ranau Highway, Sabah, Malaysia*.

Terlien, M. T. (1998). The determination of statistical and deterministic hydrological landslide-triggering thresholds. *Environmental geology*, *35*(2-3), 124-130.

Terlien, M. T. J., van Asch, T. W. J., & Van Westen, C. J. (1995). Deterministic modelling in GIS-based landslide hazard assessment. In *Geographical Information systems in Assessing Natural Hazards* (A. Carrara and F. Guzzetti, pp. 57–77). Kluwer Academic Publishers.

Terranova, O., Antronico, L., & Gullà, G. (2007). Landslide triggering scenarios in homogeneous geological contexts: The area surrounding Acri (Calabria, Italy). *Geomorphology, 87*(4), 250-267.

Terzaghi K (1950) Mechanisms of landslides. In: Paige S (ed) Application of geology to engineering practice. Geological Society of America, Berkley, pp 83–123.

Terzaghi K (1961) Die Bodenmechanik in der Baupraxis. Springer, Berlin.

Terzaghi, K., Peck, R. B., & Mesri, G. (1996). *Soil mechanics in engineering practice*. John Wiley & Sons.

Tien Bui, D., Pham, B. T., Nguyen, Q. P., & Hoang, N. D. (2016). Spatial prediction of rainfall-induced shallow landslides using hybrid integration approach of Least-Squares Support Vector Machines and differential evolution optimization: a case study in Central Vietnam. *International Journal of Digital Earth*, *9*(11), 1077-1097.

Tien Bui, D., Pradhan, B., Lofman, O., & Revhaug, I. (2012). Landslide susceptibility assessment in vietnam using support vector machines, decision tree, and Naive Bayes Models. *Mathematical problems in Engineering*, *2012*.

Tjia, H. D. (2007). Kundasang (Sabah) at the intersection of regional fault zones of Quaternary age.

Tjia, H. D. (2007). Kundasang (Sabah) at the intersection of regional fault zones of Quaternary age.

Tofani, V., Segoni, S., Agostini, A., Catani, F., & Casagli, N. (2013). Use of remote sensing for landslide studies in Europe. *Natural Hazards and Earth System Sciences*, *13*(2), 299-309.

Tomás, R., Romero, R., Mulas, J., Marturià, J. J., Mallorquí, J. J., Lopez-Sanchez, J. M., ... & Duque, S. (2014). Radar interferometry techniques for the study of ground subsidence phenomena: a review of practical issues through cases in Spain. *Environmental earth sciences*, *71*(1), 163-181.

Tropeano, D., & Turconi, L. (2004). Using historical documents for landslide, debris flow and stream flood prevention. Applications in Northern Italy. *Natural Hazards*, *31*(3), 663-679.

Tsai, T. L., & Chen, H. F. (2010). Effects of degree of saturation on shallow landslides triggered by rainfall. *Environmental Earth Sciences*, *59*(6), 1285-1295.

Tsai, T.-L. (2007). The influence of rainstorm pattern on shallow landslide. *Environmental Geology*, *53*(7), 1563–1569. doi:10.1007/s00254-007-0767-x.

Tsangaratos, P., & Ilia, I. (2016). Comparison of a logistic regression and Naïve Bayes classifier in landslide susceptibility assessments: The influence of models complexity and training dataset size. *Catena*, *145*, 164-179.

Umar, Z., Pradhan, B., Ahmad, A., Jebur, M. N., & Tehrany, M. S. (2014). Earthquake induced landslide susceptibility mapping using an integrated ensemble frequency ratio and logistic regression models in West Sumatera Province, Indonesia. *Catena*, *118*, 124-135.

UNESCO-WP/WLI, 1993a. A suggested method for describing the activity of a landslide. Bulletin of the International Association of Engineering Geology (47): 53-57.

UNESCO-WP/WLI, 1993b. Multilingual Landslide Glossary, Bitech Publishers, Richmond, British Columbia, 59 p.

UNESCO-WP/WLI, 1994. A suggested method for reporting landslide causes. Bulletin of the International Association of Engineering Geology 50, 71–74. WP/WLI (International Geotechnical Societies'

Van Den Eeckhaut, M., & Hervás, J. (2012). State of the art of national landslide databases in Europe and their potential for assessing landslide susceptibility, hazard and risk. *Geomorphology*, *139*, 545-558.

Van Den Eeckhaut, M., Muys, B., Verstraeten, G., Vanacker, V., Nyssen, J, Moeyersons, J., Van Beek, L.P.H., & Vandekerckhove, L., 2007. Use of LIDAR-derived images for mapping old landslides under forest. Earth Surf. Proc. Land., 32: 754-769.

Van Den Eeckhaut, M., Reichenbach, P., Guzzetti, F., Rossi, M., & Poesen, J. (2009). Combined landslide inventory and susceptibility assessment based on different mapping units: an example from the Flemish Ardennes, Belgium. *Natural Hazards and Earth System Sciences*, *9*(2), 507-521.

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*(3-4), 392-410.

Van der Meer, F. D., Van der Werff, H. M., Van Ruitenbeek, F. J., Hecker, C. A., Bakker, W. H., Noomen, M. F., ... & Woldai, T. (2012). Multi-and hyperspectral geologic remote sensing: A review. *International Journal of Applied Earth Observation and Geoinformation*, *14*(1), 112-128.

Van Westen, C. J., Castellanos, E., & Kuriakose, S. L. (2008). Spatial data for landslide susceptibility, hazard, and vulnerability assessment: an overview. *Engineering geology*, *102*(3-4), 112-131.

Van Westen, C. J., 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.

Van Westen, C.J., Lulie Getahun, F., 2003. Analyzing the evolution of the Tessina landslide using aerial photographs and digital elevation models. Geomorphology 54, 77-89.

Varnes DJ (1954) Landslide types and processes. In: Eckel EB (ed) Landslides and engineering practice, special report 28. Highway research board. National Academy of Sciences, Washington, DC, pp. 20–47

Varnes DJ (1978) Slope movement types and processes. In: Schuster RL, Krizek RJ (eds) Landslides, analysis and control, special report 176: Transportation research board, National Academy of Sciences, Washington, DC., pp. 11–33

Varnes, D. J. (1984). IAEG Commission on Landslides (1984) Landslide hazard zonation—a review of principles and practice.

Varnes, D. J. (1984). IAEG Commission on Landslides (1984) Landslide hazard zonation—a review of principles and practice.

Vohora, V. K., & Donoghue, S. L. (2004). Application of remote sensing data to landslide mapping in Hong Kong. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*.

Vohora, V. K., & Donoghue, S. L. (2004). Application of remote Sensing data to Landslide mapping in Hong Kong. *International Archives of Photogrammetry, Remote Sensing & GIS*, *V*(XXXV-B4), 489–494.

Vorovencii, I. (2007). Use of the 'Tasseled Cap' Transformation for the Interpretation of Satellite Images. *Cadastre Journal RevCAD*, 75–82.

Vorpahl, P., Elsenbeer, H., Märker, M., & Schröder, B. (2012). How can statistical models help to determine driving factors of landslides?. *Ecological Modelling*, *239*, 27-39.

Vosselman, G., & Maas, H. G. (2001, March). Adjustment and filtering of raw laser altimetry data. In *Proceedings of OEEPE Workshop on Airborne Laserscanning and Interferometric SAR for Detailed Digital Terrain Models, Stockholm, Sweden*.

Walker, L. R.& Shiels, A. B., (2013). Landslides cause spatial and temporal gradients at multiple scales in the Luquillo Mountains of Puerto Rico.

Weirich, F., & Blesius, L. (2007). Comparison of satellite and air photo based landslide susceptibility maps. *Geomorphology*, *87*(4), 352-364.

Whitworth, M. C. Z., Giles, D. P., & Murphy, W. (2005). Airborne remote sensing for landslide hazard assessment: a case study on the Jurassic escarpment slopes of Worcestershire, UK. *Quarterly Journal of Engineering Geology and Hydrogeology*, *38*(3), 285-300.

Wieczorek, G. F. (1996). Landslides: investigation and mitigation. Chapter 4-Landslide triggering mechanisms. *Transportation Research Board Special Report*, (247).

Wieczorek, G. F., & Guzzetti, F. (1999, October). A review of rainfall thresholds for triggering landslides. In *Proc. of the EGS Plinius Conference, Maratea, Italy* (pp. 407-414).

Wieczorek, G.F., 1984. Preparing a detailed landslide-inventory map for hazard evaluation and reduction. Bulletin of the Association of Engineering Geologists 21 (3), 337–342.

Wilkinson, P. L., Anderson, M. G., & Lloyd, D. M. (2002). An integrated hydrological model for rain‐induced landslide prediction. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, *27*(12), 1285-1297.

Wills, C.J., 2002. Acquisition of a LIDAR survey of the highway 299 corridor, Humboldt County, California and preliminary analysis of its utility for landslide mapping, summary report. California Geological Survey 16.

Wilson, R. C. (2005). The Rise and Fall of a Debris‐Flow Warning System for the San Francisco Bay Region, California. *Landslide hazard and risk*, 493-516.

Witten, I. H., Frank, E., Hall, M. A., & Pal, C. J. (2016). *Data Mining: Practical machine learning tools and techniques*. Morgan Kaufmann.

Wollenberg, E., Edmunds, D., & Buck, L. (2000). *Anticipating change: scenarios as a tool for adaptive forest management: a guide*. CIFOR.

World Disaster Report. (2016). Resilience: saving lives today, investing for tomorrow. International Federation of Red Cross and Red Crescent Societies.

WP/WLI *(International Geotechnical Societies=UNESCO Working Party on World Landslide Inventory), 1993. Multilingual Landslide Glossary. BiTech Publishers Ltd.*

Wu, D., & Sun, D. W. (2013). Advanced applications of hyperspectral imaging technology for food quality and safety analysis and assessment: A review—Part II: Applications. *Innovative Food Science & Emerging Technologies*, *19*, 15-28.

Yalcin, A. (2008). GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): comparisons of results and confirmations. *Catena*, *72*(1), 1-12.

Yalcin, A., Reis, S., Aydinoglu, A. C., & Yomralioglu, T. (2011). A GIS-based comparative study of frequency ratio, analytical hierarchy process, bivariate statistics and logistics regression methods for landslide susceptibility mapping in Trabzon, NE Turkey. *Catena*, *85*(3), 274-287.

Yang, X., & Chen, L. (2010). Using multi-temporal remote sensor imagery to detect earthquake-triggered landslides. *International Journal of Applied Earth Observation and Geoinformation*, *12*(6), 487-495.

Yang, Y., Zhao, X., Dong, T., Yang, Z., Zhang, Q., & Zhang, Y. (2017). Risk factors for postoperative delirium following hip fracture repair in elderly patients: a systematic review and meta-analysis. *Aging clinical and experimental research*, *29*(2), 115-126.

Yesilnacar, E., & Topal, T. (2005). Landslide susceptibility mapping: a comparison of logistic regression and neural networks methods in a medium scale study, Hendek region (Turkey). *Engineering Geology*, *79*(3-4), 251-266.

Yilmaz, I. (2010). The effect of the sampling strategies on the landslide susceptibility mapping by conditional probability and artificial neural networks. *Environmental Earth Sciences*, *60*(3), 505–519. doi:10.1007/s12665-009-0191-5.

Yin, Y., Wang, H., Gao, Y., & Li, X. (2010). Real-time monitoring and early warning of landslides at relocated Wushan Town, the Three Gorges Reservoir, China. *Landslides*, *7*(3), 339-349.

Yokoyama, R., Shirasawa, M., & Pike, R. J. (2002). Visualizing topography by openness: a new application of image processing to digital elevation models. Photogrammetric engineering and remote sensing, 68(3): 257-266.

Younis, S. M. Z., & Iqbal, J. (2015). Estimation of soil moisture using multispectral and FTIR techniques. *The Egyptian Journal of Remote Sensing and Space Science*, *18*(2), 151-161.

Yuan, H., Van Der Wiele, C. F., & Khorram, S. (2009). An automated artificial neural network system for land use/land cover classification from Landsat TM imagery. *Remote Sensing*, *1*(3), 243-265.

Zêzere, J. L. (2002). Landslide susceptibility assessment considering landslide typology. A case study in the area north of Lisbon (Portugal). *Natural Hazards and Earth System Science*, *2*(1/2), 73-82.

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*(1-2), 133-146.

Zhan, Z., & Lai, B. (2015). A novel DSM filtering algorithm for landslide monitoring based on multiconstraints. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *8*(1), 324-331.

Zhang, K., Chen, S. C., Whitman, D., Shyu, M. L., Yan, J., & Zhang, C. (2003). A progressive morphological filter for removing nonground measurements from airborne LIDAR data. *IEEE transactions on geoscience and remote sensing*, *41*(4), 872-882.

Zhang, S., Zhang, L., Lacasse, S., Nadim, F., 2016. Evolution of mass movements near epicentre of Wenchuan earthquake, the first eight years. Sci. Rep. 6, 36154.

Zhao, G., & Cawood, P. A. (2012). Precambrian geology of China. *Precambrian Research*, *222*, 13-54.

Zorn M. (2018). Natural Disasters and Less Developed Countries. In: Pelc S., Koderman M. (eds) Nature, Tourism and Ethnicity as Drivers of (De)Marginalization. Perspectives on Geographical Marginality, vol 3. Springer, Cham.