DETECTION AND MAPPING OF SMALL-SCALE AND SLOW-MOVING LANDSLIDES FROM VERY HIGH RESOLUTION OPTICAL SATELLITE DATA

ETIM EFIONG EYO

A thesis submitted in fulfilmentof the
requirements for the award of the degree of
Doctor of Philosophy in (Geomatic Engineering)

Faculty of Built Environment and Surveying
Universiti Teknologi Malaysia

MARCH 2020

DEDICATION

This thesis is specially dedicated to my spiritual father Apostle Johnson Suleman, my beloved wife Rhoda and my treasured children Deborah, Daniel and Emmanuel – For your prayers, patience and labour of love.

ACKNOWLEDGEMENT

First and foremost, I give all the thanks and glory to Almighty God, for helping me through the difficult and tedious PhD journey. I have experienced Your favour and guidance day by day. I will continue to trust You for my remaining journey in life.

I would like to express my sincere appreciation to my main supervisor Prof. Mazlan Hashim for accepting me to work with him at a very critical stage of my research. I will forever appreciate his contributions, advice, encouragement and mentorship. I am grateful to my co-supervisor Dr. Nadzri Md. Reba for his support and contributions. I am particularly thankful to my former main supervisor Ass. Prof. Dr. Tajul Musa for the good foundation he laid for my research.

I am indebted to Prof. Dr. Temel Bayrak (and his family) for inviting me to Turkey and assisting me in the acquisition of RTK-GPS ground data in my study area, and giving me unrestricted access to the Geodesy Laboratory in Gümüşhane University. He was magnanimous to provide free accommodation and dinner for the period of my stay in Turkey. I am grateful to the Rector of Gümüşhane University for approving free lunch for me during my stay in Turkey. I will not forget the kindness by the Head of Department and academic staff members of Department of Geomatics Engineering, Gümüşhane University. I will always have very fond memories of my time in Turkey.

I would like to acknowledge the Vice Chancellor of UTM Prof. Dr. Wahid Omar, the Dean of Faculty of Built Environment and Surveying Prof. Dr. Mohd Hamdan Ahmad, Director of UTM Endowment Unit Assoc. Prof. Dr. Yusof Boon, Deputy Registrar of UTM Endowment Unit Mr. Baharudin Mastari, for the financial assistant given to me at a very crucial time. I remember the kindness by staff members of FABU, especially Norila Joyos and Sumi Binti Isman. My gratitude goes to members of Deeper Life Group in UTM, for their financial support and prayers.

I am grateful to staff members of INSTeG - Nurul Nadiah Yahya, Mohd Taufik Razali, Dr. Noordyana Hassan, Dr. Jaw Wei, and Dr. Rizaludin Mahmud. I will not forget the invaluable contributions made by Dr. Mohd Shawkat Hossain, Dr. Syarifuddin Misbari and Mr. Anuar Bin Arsyad. My special thanks to my colleagues in INSTeG Laboratory – Mr. Babangida Baiya, Mr. Dalhatu Sani, Mr. Hafiz Saman, Mr. Danboyi Amusuk, Mr. Mzumo Isa, Mr. Syed Najam, Maslina Natar, Linda Roziani, and Nooremi Fadzilah.

Finally, my profound gratitude goes to my spiritual father Apostle Johnson Suleman, my lovely wife Rhoda and my treasured children Deborah, Daniel and Emmanuel. They are the most important people in my world and I dedicate this thesis to them.

ABSTRACT

Small slope failures are often ignored because of their perceived less severe impact. Although they may have small velocity, small slope failures can cause damages to facilities such roads and pipelines. The main objective of this research is to utilise very high resolution Pleiades-1 data to extract surface features and identify surface deformations susceptible to small slope failures. An algorithm was developed using object-based image analysis (OBIA), Pleiades-1 imagery, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) and Real Time Kinematic-Global Positioning System (RTK-GPS) data. Using the OBIA algorithm four different object attribute parameters namely spectral, textural, spatial and topographic characteristics were applied in a rule-based classification, for semi-automated detection of small translational landslides. The developed OBIA algorithm was further modified by using Pleiades-1 imagery, Nearest Neighbors (k-NN) and Support Vector Machine (SVM) techniques in example-based classification for the detection of small landslides, with focus on the effects of the training samples size and type on the results of the classification. The horizontal displacement of the landslides was investigated based on sub-pixel image correlation method using Pleiades-1 images and Shuttle Radar Topographic Mission (SRTM). Kalman filtering method and RTK-GPS observations from TUSAGA-Aktif Global Navigation Satellite System (GNSS) Network in Turkey were utilised to formulate kinematic analysis model for the landslides. The developed algorithms were validated in Kutlugün test site in Northeastern Turkey. In the rule-based classification results, a total of 123 small landslides covering a total area of approximately 413.332 m^2 were detected. The size of landslides detected varied between 0.747 and 7.469 m^2. The detected landslides yielded user's accuracy of 81.8%, producer's accuracy of 80.6%, quality percentage of 82% and computed kappa index of 0.87. In the small landslides detection using the example-based classification, the SVM method had higher producer accuracy (85.9%), user accuracy (89.4%) and kappa index (0.82) compared to the k-NN algorithm that had producer accuracy (83.1%), user accuracy (86.0%) and kappa index (0.80). A total of 128 small landslides were detected using k-NN algorithm, while a total of 134 landslides were detected using SVM algorithm. The displacement results from RTK-GPS measurements varied from 2.77 mm to 24.87 mm in 6 months, while the velocities varied from 0.80 mm to 8.28 mm/6 month. The displacements from optical image correlation agreed well with RTK-GPS results and provided a more uniform movement pattern than could be derived solely using the RTK-GPS measurements. The landslide movements are dominantly toward the north direction. These trends agree with the results of previous study in the area. The main contributions of this research include – development of a comprehensive metrics to quantify the attribute parameters of small landslides, derivation of susceptibility and inventory maps for small landslides, and the design of an early warning system for small slope failures on highway infrastructures. The results of this research will add to the increasing applications of Pleiades-1 image in landslide investigations.

ABSTRAK

Kegagalan cerun kecil sering diabaikan kerana impaknya yang kurang ketara. Walaupun ia mungkin mempunyai nilai halaju yang kecil, kegagalan cerun kecil boleh menyebabkan kerosakan kepada kemudahan seperti jalan dan saluran paip. Objektif utama kajian ini adalah untuk menggunakan data Pleiades-1 resolusi tinggi untuk mengekstrak ciri-ciri permukaan dan mengenal pasti perubahan bentuk permukaan yang mudah terdedah kepada kegagalan cerun kecil. Satu algoritma telah dibangunkan menggunakan data imej berasaskan objek (OBIA), imej Pleiades-1, Pancaran Terma dan Radiometer Pantul Bawaan Angkasa Lanjutan (ASTER) Model Ketinggian Berdigit Global (GDEM) dan Kinematik Masa Hakiki-Sistem Penentududukan Global (RTK-GPS). Dengan menggunakan algoritma OBIA, empat parameter atribut objek yang berbeza iaitu ciri spektral, tekstural, spatial dan topografi digunakan dalam klasifikasi berasaskan peraturan untuk pengesanan separa automatik bagi tanah runtuh translasi kecil. Algoritma OBIA yang dibangunkan kemudian diubahsuai dengan menggunakan imejan Pleiades-1, teknik Jiran Terdekat (k-NN) dan Mesin Sokongan Vektor (SVM) dalam klasifikasi berasaskan contoh untuk mengesan tanah runtuh kecil, dengan memberi tumpuan kepada saiz kesan sampel latihan dan jenis pada hasil klasifikasi. Anjakan mendatar tanah runtuh dikaji berdasarkan kaedah korelasi imej sub-piksel menggunakan imej Pleiades-1 dan Misi Topografi Radar Ulang-Alik (SRTM). Kaedah penapisan Kalman dan pemerhatian RTK-GPS dari Rangkaian Sistem Satelit Navigasi Global TUSAGA-Aktif Global (GNSS) di Turki telah digunakan untuk merumus model analisis kinematik untuk tanah runtuh. Algoritma yang dibangunkan telah disahkan di tapak ujian Kutlugün di Timur Laut Turki. Berdasarkan keputusan klasifikasi berasaskan peraturan, sejumlah 123 tanah runtuh kecil yang meliputi kawasan seluas 413.332 m^2 telah dikesan. Saiz tanah runtuh dikesan bervariasi antara 0.747 dan 7.469 m^2. Tanah runtuh kecil yang dikesan menghasilkan ketepatan pengguna sebanyak 81.8%, ketepatan pengeluar 80.6%, peratusan kualiti 82% dan indeks kappa yang dikira sebanyak 0.87. Dalam pengesanan tanah runtuh kecil menggunakan klasifikasi berasaskan contoh, kaedah SVM mempunyai ketepatan pengeluar yang lebih tinggi (85.9%), ketepatan pengguna (89.4%) dan indeks kappa (0.82) berbanding dengan algoritma k-NN yang mempunyai ketepatan pengeluar (83.1%), ketepatan pengguna (86.0%) dan indeks kappa (0.80). Sejumlah 128 tanah runtuh kecil dikesan menggunakan algoritma k-NN, sementara sejumlah 134 tanah runtuh dikesan menggunakan algoritma SVM. Hasil anjakan daripada pengukuran RTK-GPS bervariasi dari 2.77 mm menjadi 24.87 mm dalam 6 bulan, manakala halaju bervariasi dari 0.80 mm menjadi 8.28 mm / 6 bulan. Anjakan dari korelasi imej optik telah dipersetujui dengan baik dengan hasil RTK-GPS dan menyediakan corak pergerakan yang lebih seragam daripada yang boleh diperoleh dengan menggunakan pengukuran RTK-GPS. Pergerakan tanah runtuh adalah dominan dalam arah utara. Tren ini sependapat dengan hasil kajian terdahulu di kawasan tersebut. Sumbangan utama kajian ini termasuk - pembangunan metrik komprehensif untuk mengukur parameter sifat tanah runtuh kecil, penerbitan kerentanan dan peta inventori untuk tanah runtuh kecil, dan reka bentuk sistem amaran awal untuk kegagalan cerun kecil di infrastruktur lebuh raya. Hasil kajian ini akan menambah kepada aplikasi imej Pleiades-1 dalam penyelidikan tanah runtuh.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

$\hat{Y}_k$	-	Status Vector
$T_{k,k+1}$	-	Prediction Matrix
I	-	Unit Matrix
$N_{k,k+1}$	-	System Noise Matrix
w_k	-	Random Noise Vector at Period *k*
$Q_{\bar{Y}\bar{Y},k}$	-	Cofactor Matrix of Status Vector
$Q_{ww,k}$	-	Cofactor Matrix of System Noises
V	-	Innovation Vector
L_k	-	Actual Observation
$A_k\hat{Y}_k$	-	Predicted Observation
~	-	Approximately
+, -	-	Plus, Minus
/	-	Division or Per
°, "	-	Degree, Minute
°C	-	Degree Celsius
$<, >$	-	Less Than, Greater Than
$\leq$	-	Less Than or Equal To
%	-	Percentage
$	-	United States of America Dollars
abs	-	Absolute Value
e.g.	-	For Example
etc.	-	And So On
i.e.	-	That Is
h	-	Hour
E	-	East
N	-	North
mm	-	Millimetre
µm	-	Micrometre
m	-	Metre or Mass
km	-	Kilometre
w	-	Weight
g	-	gravity
F	-	Friction
N	-	Normal Force

θ	-	Slope Angle
$\tan(\phi)$	-	Coefficient of Friction

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Landslide involves downward movement of earth (soil), debris or rock (Cruden and Varnes, 1996). Generally, landslide represents different geological processes that occur over time and space in many mountainous terrains (McKean and Roering, 2004), and causes damage to environment and infrastructure. The prediction of landslide occurrence is a challenging task due to: (i) difficult terrain and lack of access for direct observation, and; (ii) complex and uncertain relationship of many variables such as slope, soil properties, elevation, land cover, and lithology (Dai and Lee, 2002; Guzzetti, 2005).

There are increasing landslide events in many regions of the world (Petley, 2012). The causal factors of these include – anthropogenic and natural interventions on the environment, controlling factors, and the effect of climate change (Sidle et al., 2004; Gutiérrez et al., 2010). The consequences of landslide disasters are visible in many parts of the world, with damages on infrastructures, human lives and the economy. The continuous destruction caused by landslide occurrence requires the development of improved techniques for landslide detection and mapping.

Some of the world's landslide sites are located in the remote areas. These sites are typically characterised by: (1) high elevation differences, with increased precipitation; (2) steep and varied topography, with increased gravitational processes; and (3) high altitudinal change, with varying ecological zones (Lieb, 2006). The main consequence of these characteristics is that some of the landslide sites are not easily accessible using conventional terrestrial survey techniques. Thus, the difficult and inaccessible nature of landslide environment, and the various difficulties and limitations commonly associated with field studies, has made satellite remote sensing technology a highly viable tool for various landslide mapping studies.

One of the main problems faced in landslide studies is the challenge of detecting and assessing the conditions of small failures. Small failures, typically require more precise and accurate sensors to enhance the mapping of landslide surface features. The spatial resolution of the sensors needs to be relevant to the geomorphological features found in the landslides. Spatial resolution determines the smallest scale to which surface features may be detected. Therefore, a technology capable of mapping small failures precisely and consistently over large swaths of terrain is imperative. One of the main goals of this research is to explore the techniques that are able to detect and map small movements, slow deformations and displacements.

The main innovation in the use of remote sensing technology for operational purposes has been the latest generation of very high resolution (VHR) optical satellites (QuickBird, IKONOS-2, Pléiades-1, WorldView-1 and -2, and GeoEye-1 and -2) with sub-metre ground sampling distance and broad coverage. The main features of these VHR optical satellites images include - shorter repeatpass cycles, higher spatial resolutions and the ability to acquire image datasets of monoscopic, stereo, and multi-view characteristics. The improved spatial resolution can capture small changes with unimaginable level of precision, much better than the results previously achieved with high or medium resolution data (Landsat and ASTER). The spatial resolution improvement also provides mapping opportunities at large scales, suitable for mapping of the small spatial features for slow-moving landslide detection.

The availability of VHR optical satellites images has made it possible to obtain subtle information about features on the ground for many applications related to change detection, environmental monitoring and mapping. VHR optical satellites images can be useful as tools for hazard and risk mapping of infrastructures such as buildings, railway or pipelines. They are also closely related to aerial photographs. Compared to the conventional satellite data, VHR optical satellites images require little training for visual interpretation. All of these characteristics make VHR optical satellites images an ideal data source for detecting and mapping small slope failures. Although VHR optical satellite images suffer from the effect of cloud cover during data acquisition, they offer a fast and dynamic way of determining ground displacements. Moreover, there is a large repository of optical images from landslides and new images are continuously being added to the collection.

In spite of the highlighted advantages, VHR optical images are still not being adequately utilised for operational application such as landslide detection and mapping. The main reason for this is the absence of standardised image processing technique that meets the requirements of landslide mapping, and can be adapted to suit different landslide types and environmental conditions (Stumpf, 2013). The standard analysis method for landslide mapping is the pixel-based classification. The geometric and contextual information inherent in the images are not being exploited in the per-pixel analysis method (Blaschke, 2010). The per-pixel approach produces intra-class variability and lower classification accuracies, especially when higher resolution images with higher spectral variance, are used (Woodcock and Strahler, 1987). In order to overcome this problem, the object-based image analysis (OBIA), which has the capability to extract geometric and contextual information from VHR images, has become a widely used tool for geoscientific research (Blaschke, 2010).

In order to tackle the menace of landslide hazards, particularly on critical infrastructures such as highways and pipelines, it is important to put in place mitigation measures. One of the main approaches to mitigate the hazards related to landslides is the design and implementation of an early warning system. The landslide early warning systems have been implemented in many regions of the world over the past years (Thiebes and Glade, 2016; Terranova et al., 2015; Segoni et al., 2015).

This study utilises very high resolution optical satellite images, Real Time Kinematic Global Positing System (RTK-GPS) observations, object-based image analysis (OBIA) techniques, and optical image correlation method for the detection and mapping of small and slow-moving landslides. The study area of this research is located in Kutlugün Village in Maçka County, Turkey. The North-eastern Black Sea Region of Turkey is a typical mountainous landscape, with complex geological setting and high rainfall pattern, which makes this region vulnerable to landslide events. The previous monitoring campaigns in this study area were based only on periodic and real-time GPS observations (Yalçinkaya et al., 2005; Yalçinkaya and Bayrak, 2005; Bayrak et al., 2015). For the first time, this study is using VHR optical satellite images for the detection and mapping of the Kutlugün landslides.

The thesis is broadly divided into four main sections, as follows: (1) the extraction of small and slow-moving landslide objects from remotely sensed data (Chapter 3, Objective 1). The extraction of small landslide objects from other surrounding features is vital for disaster management; (2) the detection and mapping of small and slow-moving landslides (Chapter 4, Objective 2); (3) the kinematic analysis of small and slow-moving landslides (Chapter 5, Objective 3). The determination of surface displacement rates is important to estimate the hazard related to slow-moving landslides; and (4) the mitigation of hazard and risk related to small and slow-moving landslides (Chapter 6, Objective 4). It is vital to implement an early warning system to reduce the hazard related to small and slow-moving landslides on road infrastructure.

1.1.1 Global Landslide Hazards

One of the basic peculiarities of landslide is that landslide-prone slopes are present in virtually every part of the globe (Gutiérrez et al., 2010). Landslides have, therefore, become one of the most destructive natural phenomena in the world today. The rising global trends in landslide risk can be ascribed to rapid human settlements and development in landslide-prone regions and the consequences of climate change (Petley, 2012). The global distribution of landslide-prone regions (Figure 1.1) shows that these regions are characterised by availability of high relief favourable for landslide occurrence, high precipitation to trigger landslides and high population density (Petley, 2012).

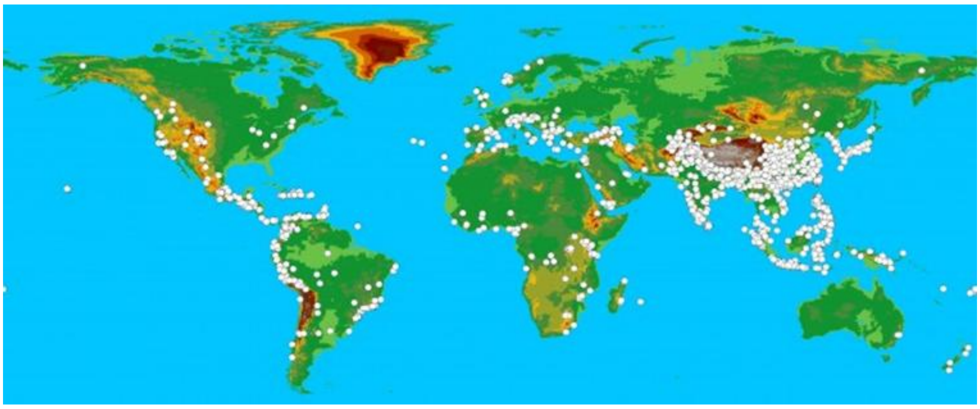

Figure 1.1 Global distribution of non-seismic fatal landslides. Each dot represents a single fatal landslide (Petley, 2012)

The world statistics for only rainfall-induced landslides per continent from April 1903 to June 2012 shows that in this period about 547 landslides have led to the death of 59,060 people, and displacement of over 13 million people, with the estimation of damage caused by landslides during this period being more than US$7 billion (Guhar-Sapir et al., 2012). Most statistics on impacts of landslides are often underestimated, as most landslides are secondary phenomena, and their statistics appear under the major disasters such as storms, floods or earthquakes. For instance, landslides triggered by earthquake shaking can impact heavily on the aggregate damage attributed to a particular earthquake event. This growing underestimation of the effects of landslide hazards has impacted negatively on the awareness of both the policy makers and general public towards the risk posed by landslides (Lacasse and Nadim, 2009).

1.1.2 Object- Based Image Analysis (OBIA) for Mapping of Small and Slow-Moving Landslides

Some of the approaches adopted for the analysis of optical satellite imagery for landslide mapping include: (i) interpretation of single and stereoscopic images using visual methods (Soeters and van Westen, 1996); (ii) semi-automated pixel-based methods for image classification (Marcelino et al., 2009); (iii) image classification using semi-automated OBIA methods (Stumpf and Kerle, 2011); (iv) change detection methods (Tsai et al., 2010); and (v) sub-pixel correlation of optical images (Debella-Gilo and Kääb, 2011). The conventional approach for analysing optical remote sensed imagery is the pixel-based methods. However, the pixel-based methods exploit only the spectral characteristics of the analysed image which greatly limits their use for classification of areas with spatially contiguous extent; often leading to errors in the classification results (Stumpf and Kerle, 2011).

The classifications using pixel-based techniques, which depend solely on spectral signatures, are not useful for detecting geomorphic processes such as landslides (Lahousse et al., 2011; Singleton et al., 2014); and it is difficult to validate the results of the pixel-based methods on the ground (Martha et al., 2010). The disadvantages of the pixel-based approaches became more pronounced, with the advent of very high resolution satellite sensors which provide a spatial resolution of $\leq$ 5m. Pixel-based methods also fail to realize the shape and the spatial relationship between neighbouring pixels, particularly for high resolution imagery, whose neighbouring pixels may have similar spectral behaviour (Blaschke, 2010). The OBIA approach, on the other hand, represents a more advanced method with several advantages. The grouping of image pixels in OBIA into homogeneous objects for the analyses of VHR data can reduce potential noises (Benz et al., 2004; Blaschke, 2010). OBIA integrates spectral statistics of neighbouring and surrounding pixels and the contextual analysis such as textural, spatial and shape measurements for improved image analysis.

OBIA has been widely utilised in the detection and mapping of landslides (Hölbling et al., 2016; Martha et al., 2012; Aksoy and Ercanoglu, 2011; Mondini et al., 2011; Lahousse et al., 2011). In the landslide application domain, the initial research efforts were focused on the development of automated OBIA using low resolution Landsat ETM+ images (Barlow et al., 2003; Martin and Franklin, 2005). The adopted approach was further enhanced in Barlow et al. (2006) by integrating higher resolution SPOT-5 data and geomorphic variables. Further contribution is reported in Moine et al. (2009), who applied sets of spectral, geometric and textural features from aerial and satellite images for automatic characterization of landslides.

An algorithm which integrates spectral, spatial and morphometric characteristics for identification and mapping of five different types of landslides in the Himalayas mountainous terrain, was also developed in Martha et al. (2010). These studies show the increasing potential and applicability of semi-automated and automated OBIA in detecting and mapping landslides. However, all of the studies are concentrated on large landslides.

In this study, OBIA was developed for mapping of small and slow-moving landslides. Cruden and Varnes' velocity classification considers slow-moving landslides as non-turbulent movement of hill-slope materials (soil, debris or rock) at velocities ranging from 1 m/year to 100 m/year, with the very slow-moving landslides moving at velocities of less than 1.6 m/year (Cruden and Varnes, 1996). Small and slow-moving landslides are common natural hazards in mountainous terrains, and they are mainly caused by precipitation, and the resultant increased in pore water pressure. While rapid landslides caused by rain storms and earthquakes result to major casualties (Petley, 2012), slow-moving landslides which are continuously active can still produce significant impacts by causing damages to infrastructure and facilities such as roads and pipelines (Mackey and Roering, 2011; Mansour et al., 2011). It is, therefore, important to embark on early warning to prevent potential landslide disasters by monitoring the slow movements. Remote sensing data constitute an efficient repository of geo-database which can be utilised in landslide susceptibility, hazard and risk mapping. Optical satellite images have the advantages of a higher spatial resolution, which can be exploited to detect small landslides, and a near-vertical acquisition that avoids masks prevalent in a typical landslide mountainous terrain (Lacroix et al., 2015).

1.2 Statement of the Problem

Existing landslide studies have paid less attention to investigation and mapping of small and slow-moving landslides that may not lead to loss of lives, but can cause damages to the environment and facilities such as pipeline and road infrastructure. These small slope failures often go undetected and unremediated because of their perceived less severe impact. Small and slow-moving landslides are predominant in mountainous terrain. The accurate detection of small landslides in the rugged and difficult mountainous environment, is hampered by a lack of field data and difficulties in deploying ground-based sensors. Remote sensing can fill this gap by providing data that are able to detect and map slow deformations of small landslides.

The extraction and mapping of small landslide objects from remotely sensed data is important for hazard assessment and disaster management. The conventional technique for ground objects extraction is based on the spectral signatures of the objects of interest. However, it is complicated to extract small landslide objects in VHR pixels as these subtle features are immersed in cluttered scene within the pixel spatial resolution. One innovative approach to extract small and subtle landslide objects from remotely sensed images is based on the integration of different parametric ground objects using object-based image analysis (Blaschke et al., 2014). The two main challenges in the integration are the complex issues with regards to image segmentation and the number (and values) of image object metrics that need to be determined for the detection of landslide features. While OBIA has been successfully utilised to quantify different image object metrics for the recognition of large landslide objects, no existing literature has determined the best diagnostic features that efficiently detect and map the small and slow-moving landslide objects.

The availability of a new generation of VHR optical satellite images has provided significant benefits for small landslide detection and mapping. One of these images is Pleiades-1 which has been utilised in a wide range of studies such as land cover mapping, preparation of digital terrain models, extraction of urban green space information, and estimation of height variations during earthquakes. But there is still paucity of studies related to their applications and more research is needed to evaluate their potentials, particularly in landslide detection and mapping. The Nearest Neighbors (k-NN) and Support Vector Machine (SVM) are two non-parametric algorithms widely acknowledged for producing accurate classification. However, no studies have compared the performances of these classifiers based on the criteria of different training sample sizes and Pleiades-1 imagery for detection and mapping of small and slow-moving landslides.

The detection of small and slow-moving landslides is problematic due to challenges in determining their mechanisms, the exact area affected by the landslides, their displacement rates and the prediction of their future behaviour. Small and slow-moving landslides are usually identified by cracks on ground surfaces or on the impacted facilities. Measuring the widths of the cracks caused by small landslides is quite challenging. These cracks may be hidden under debris or sand boils, and the measurement of their widths requires good skill and judgement, as the width may be overestimated if the sides of the crack have slumped. The conventional techniques to measure the widths of the cracks include extensometer, total station and Global Positioning System (GPS). However, these techniques have limitations in spatial coverage, and their deployment in the difficult mountainous terrain can be challenging. There is therefore the need to employ techniques with wide spatial coverage, accessibility in difficult and harsh terrain, and economical in terms of cost, time and labour.

Unlike fast landslide processes, emergency evacuation actions are not required for slow-moving landslides. But active and continuous movement by slow-moving landslides, for example on road infrastructure, requires timely maintenance and stabilisation works. One main approach to mitigate risk from landslides is implementing an early warning system (Schuster and Highland, 2007). In many regions of the world, landslide early warning systems have been designed, to mitigate the danger of sudden acceleration and catastrophic failure of large fast-moving landslides. These alert systems have been implemented by taking advantage of the availability of rainfall forecasts data, and the progress in information and communications technology (ICT). However, little or no attention has been invested on the design of early warning systems to provide information of small slope failures on vital infrastructure such as highway. The implementation of such a warning system on the highways will generate alerts to the relevant agencies for timely maintenance and remediation, and to manage risks associated with small and slow-moving landslides.

1.3 Research Questions

The research questions addressed in this thesis are:

(a) What are the best diagnostic features for the detection and mapping of small and slow-moving landslides?

(b) What are the efficient techniques for the detection and mapping of small and slow-moving landslides?

(c) What are the displacement rates and velocities of the small and slow-moving landslides?

(d) How can highway infrastructure be protected from the risk of small and slow-moving landslides?

1.4 Research Objectives

The main objective of this study is to utilise VHR optical satellite data to extract surface features and identify surface deformations susceptible to landslides, with emphasis on small and slow-moving landslides. The specific objectives are outlined as follows:

(a) To determine the best attribute parameters that distinctively distinguish the small and slow-moving landslides from other surrounding objects using semi-automated object-based image analysis (OBIA)

(b) To compare and evaluate the performance of k-Nearest Neighbors (k-NN) and Support Vector Machine (SVM) classifiers for the detection and mapping of small and slow-moving landslides using Pleiades-1 imagery

(c) To determine the kinematics of small and slow-moving landslides using sub-pixel image correlation method and Global Positioning System (GPS) monitoring data

(d) To design and implement an early warning system for highway infrastructure.

1.5 Scope of the Study

This research deals with small and slow-moving landslides with length less than 10 m and area smaller than 100 m^2. According to Cruden and Varnes' (1996) rate of movement classification, the displacement rates of extremely slow and very slow landslides are less than 1.6 m/year. The use of remote sensing images for the extraction and mapping of small and slow-moving landslide objects is important in studies related to environmental monitoring and disaster management.

The attribute parameters employed for the extraction of small and slow-moving landslides from other surrounding objects include spectral, textural, spatial (geometric) and topographic parameters. The spectral attributes used are mean reflectance in the blue, green, red and near-infrared (NIR) bands; normalized difference vegetation index (NDVI); and hue, intensity and saturation (HIS) colour space transformation. The textural attributes used are NDVI (mean), NDVI (variance), NDVI (entropy), and GLCM mean in the red, green, blue and NIR bands. The main spatial attributes employed are length, area, compactness, solidity, roundness, elongation and rectangular fit. Finally, the topographic parameters used are slope and elevation. All the attribute parameters were integrated by using very high resolution (VHR) Pléiades-1 optical satellite image and semi-automated object-based image analysis (OBIA), to extract small landslide objects in the Kutlugün study area. The rule-based approach was used in the classification.

Pléiades-1 is the latest generation of VHR optical satellite imagery designed for land and coastal applications. There is, therefore, the need to evaluate the potential and applicability of Pleiades-1 imagery, particularly for small landslides detection and mapping. K-NN and SVM are the two classifiers adapted in ENVI 5.1 image processing software for the evaluation and comparison of the performance of Pléiades-1 image in the detection and mapping of small and slow-moving landslides. K-NN is a classical technique, yet robust and simple for professional applications;

while SVM is a new generation algorithm widely used in scientific applications. It is therefore important to compare the performances of these two algorithms. The novel approaches applied in the performance evaluation of the two algorithms were based on the investigation of the effects of the training sample sizes and type on the accuracy of the classification results.

The kinematics and movement characteristics of slow-moving landslides over time were investigated using two approaches. The first approach was based on sub-pixel image correlation of two Pléiades-1 images using the software Co-Registration of Optically Sensed Images and Correlation (Cosi-Corr), to determine the horizontal displacements of the small landslides. In the second approach, RTK-GPS data and Kalman filtering procedures were used to determine the horizontal displacements and velocity fields of the landslide study area. A comparison of results of the two approaches was carried out to determine the displacement patterns of the landslide study area.

The design and implementation of an early warning system for highway infrastructure is important to provide relevant information for prompt maintenance and remediation, and to reduce risks related to slow-moving landslides. The case study is Trabzon-Gümüşhane Highway in Turkey. The framework of the early warning system is based on the server processing and two-way communication concepts, using the principles of Reverse Network Real-Time Kinematic positioning system (RNRTK). The main requirements for the early warning system include: low-cost GPS receivers for field data streaming, the software to implement the reverse RTK algorithms, Continuously Operating Reference Stations (CORS) infrastructure, and the transmission/internet infrastructures to enable data streaming and communication between reference and control processing centre. The three main components of the early warning system are - monitoring system, analysis system and alert system. The early warning system uses velocity to set the thresholds and alert levels. The field test of the early warning system was performed using ISKANDARnet CORS infrastructure, located in Universiti Teknologi Malaysia.

1.6 Significance of the Study

The mapping of surface deformation is an important aspect for understanding the mechanics of landslide processes, and is useful in monitoring activities for the purpose of ensuring safety of people and/or infrastructures. Mapping enhances the understanding of the magnitude and frequency of the landslide occurrence. Mapping also enables the causal factors prompting the landslides to be analysed. For instance, mapping landslides during rainy and non-rainy seasons can provide better correlations between displacements and hydrogeological forces. Long-term acquisition of monitoring data for landslide mapping are useful for planning of sustainable mitigation measures, which permits a better estimation and quantification of the future scenarios of the landslide.

The main products of this research are landslide inventory/displacement maps, and an early warning system for slow-moving landslides on highway infrastructure. These products are important tools for the scientific community, government agencies, planners and engineers, and the general public, for the mitigation of landslide hazards and risks. The mapping of slow-moving landslide phenomena is important for the scientific community, to improve the understanding of the mechanisms of landslide processes, their triggering forces, and sustainable measures to mitigate their effects and reduce the loss of infrastructures and assets. It is also important for understanding the kinematic of their movements and for their correct analysis and interpretation.

The acquisition of slow-moving landslide information is important for the planning and operations of governments at all levels to mitigate losses associated with these landslides. This will enhance the responsibility of governments to build and maintain vital infrastructures, promote public’s health and safety, and articulate efficient land-use management legislations for building and grading controls. This will also contribute to increased government funding towards landslide and hazard mapping. Without such pivotal role, losses to the nation and to individuals from landslides will continue to increase greatly.

The inventory of slow-moving landslides can be very useful to planners, developers and engineers for choosing suitable sites for future land use planning and developments, planning of urban settlement, road corridor planning and management. It is important to locate constructions in the stable zones, as roads constructed along unstable or partially unstable slopes will lead to problems during construction and the subsequent maintenance phase. Also, information on the surface evolution of an unstable slope provides tools for engineers to carry out correct design of effective stabilization measures. This information is important to design and implement mitigation measures, particularly for the setting up of an early warning system that can reduce harm to human lives and promote harmonious socio-economic activities.

Public safety is another significant aspect requiring the use of landslide inventory map and alert system. This is useful for emergency response teams, public safety teams, and the citizens living in the landslide-prone areas. In many areas residential and commercial buildings are located close to edge of the road. In most cases road construction leads to landslide occurrence, and constitute a high level of risk to the people living in close proximity to the road corridor. It is, therefore, important to make known to the public the areas which are susceptible to landslides and earthworks instability.

1.7 Study Area

Landslide is ranked second in frequent natural disasters in Turkey after the earthquake (Hasekiogullari and Ercanoglu, 2012). The study area is Kutlugün in Maçka district of Turkey (Figure 1.2) located approximately between 39° 43" E and 39° 46" E and 40° 56" N and 40° 58" N and covering the area of 25 km^2. The schematic diagram of Kutlugün landslides is shown in Figure 1.3, while the landslide susceptibility map produced for the study area is given in Figure 1.4. The topography of the study area consists of hillsides, mountains, valleys and stream channels. Human settlements are mostly concentrated in the mountain foothills, while grasslands, forested lands and plateaus are located at higher altitudes. The digital elevation model (DEM) shows that the terrain slope of this area is about 0° to 76° of which about 33% are slope around 0° to 20° and the rest are higher slopes (Kavzoglu et al., 2014). The DEM also indicates that the dominant area are mountainous terrain with the elevation of 0 to 3,500 m above mean sea level. Landslides are evident in the area at elevation from sea level to 1500 m but the largest are identified within 1000 to 1500 m due to the lithological character with pyroclastic compositions (Yalcin et al. 2011).

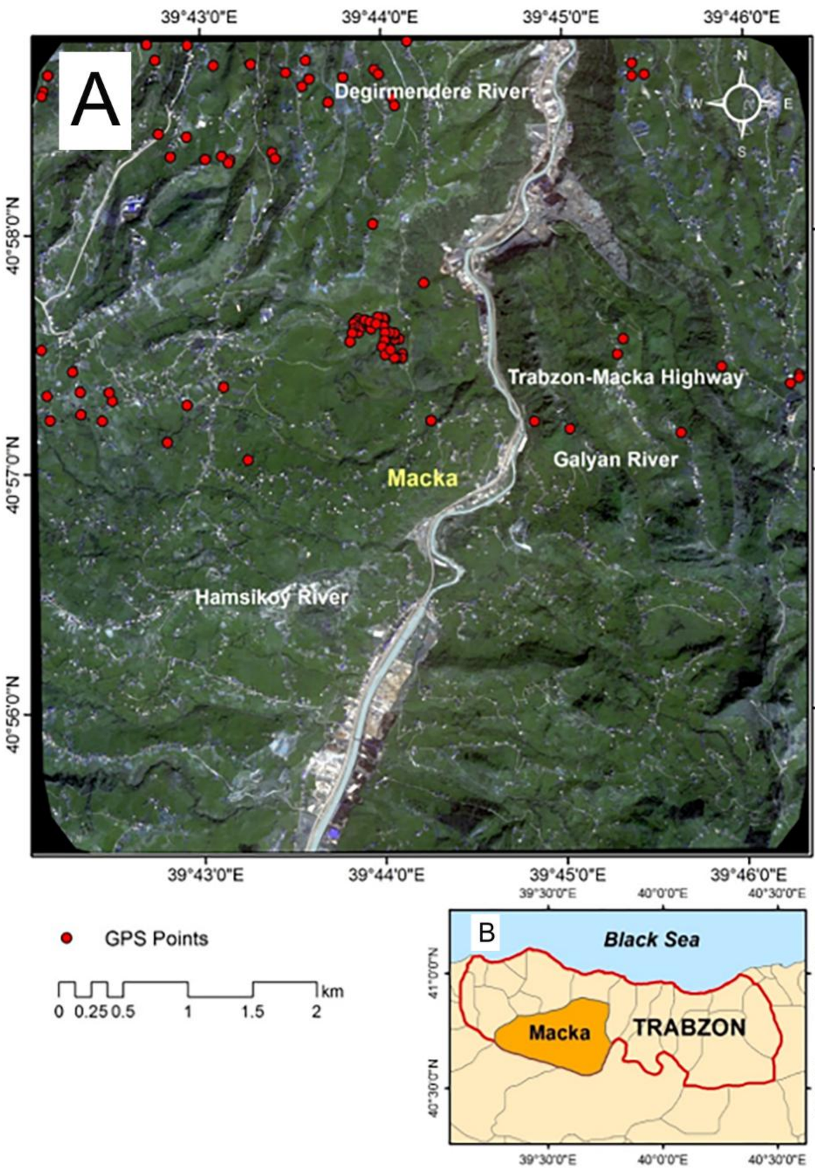

Figure 1.2 (A) Pleiades-1 image of study area showing GPS points; (B) Map of Turkey showing location of study area

The main land cover and land use are green tea, hazelnut, deciduous, coniferous, pasture, soil, rock, water, agriculture, and urban (Kavzoglu et al., 2015). Landslides are more prominent in deciduous and hazelnut areas. The composition of the deciduous vegetation includes thicket, brake and small wood. The surface flow of precipitations is obstructed by these tree types, leading to the increase in the pore water pressure of soil, and the increasing likelihood of landslide occurrence (Yalcin et al., 2011). The hydrology of this area is regulated by the activities of Değirmendere River Basin, which is surrounded by high mountains with maximum elevation of 3080 m. The size of the drainage area impacted by this river basin is about 1054 km^2 (Gürer and Uçar, 2010). Road construction, quarrying and tunnelling through the high mountainous terrain are the main anthropogenic activities in the study area. The Kutlugün landslides have contributed to the deformation of the highway, and destruction of a retaining wall and potable water pipeline in the study area (Yalçinkaya et al., 2005).

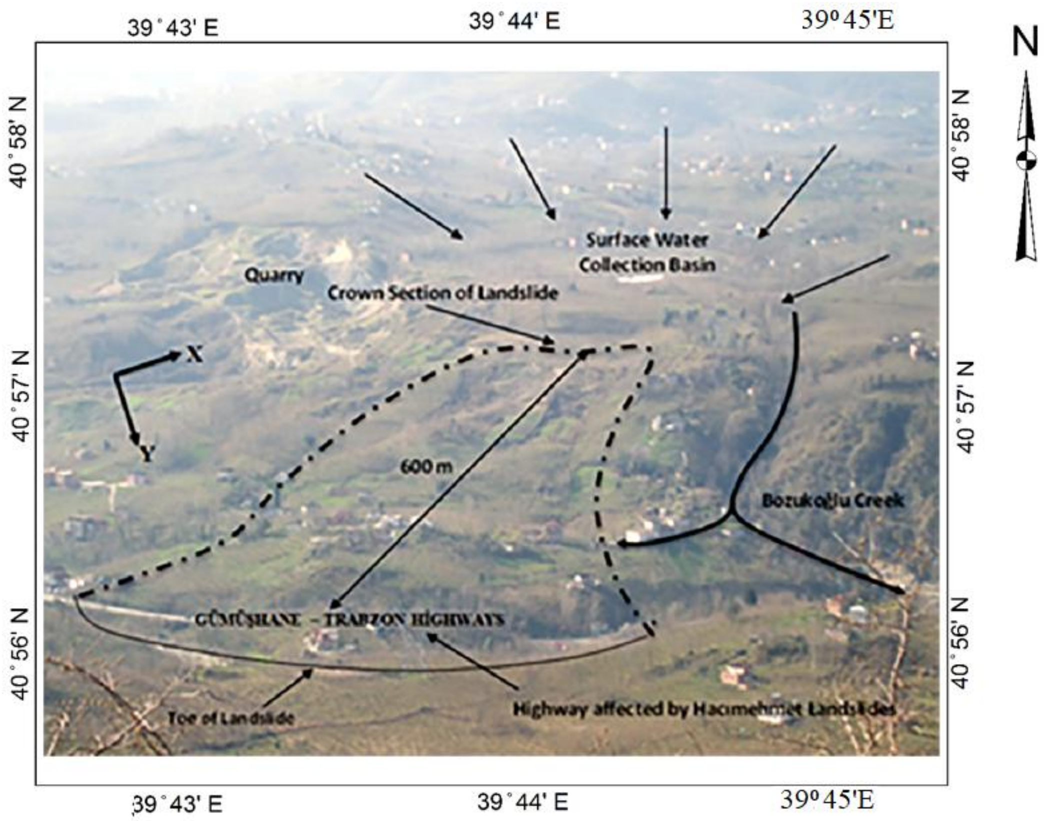

Figure 1.3 Schematic diagram of Kutlugün landslide

The area experiences temperate climate in summers and rainy season usually starting from September and ending around April. The average annual precipitation of the region is about 830 mm (Kavzoglu et al., 2014). However, the rainfall regime is not regular with some periods of unexpected and prolonged heavy rains, making the soil mantle to be mostly saturated. The coldest month is February with an average temperature of 6.7 °C, while August is the hottest month with an average temperature of 23.2 °C. (Yalcin et al., 2011). The geology of Kutlugün landslide area consists of weathered andesite-basalt and pyroclastic rocks, with clays developing due to the weathering of the rocks (Yalçinkaya and Bayrak, 2005).

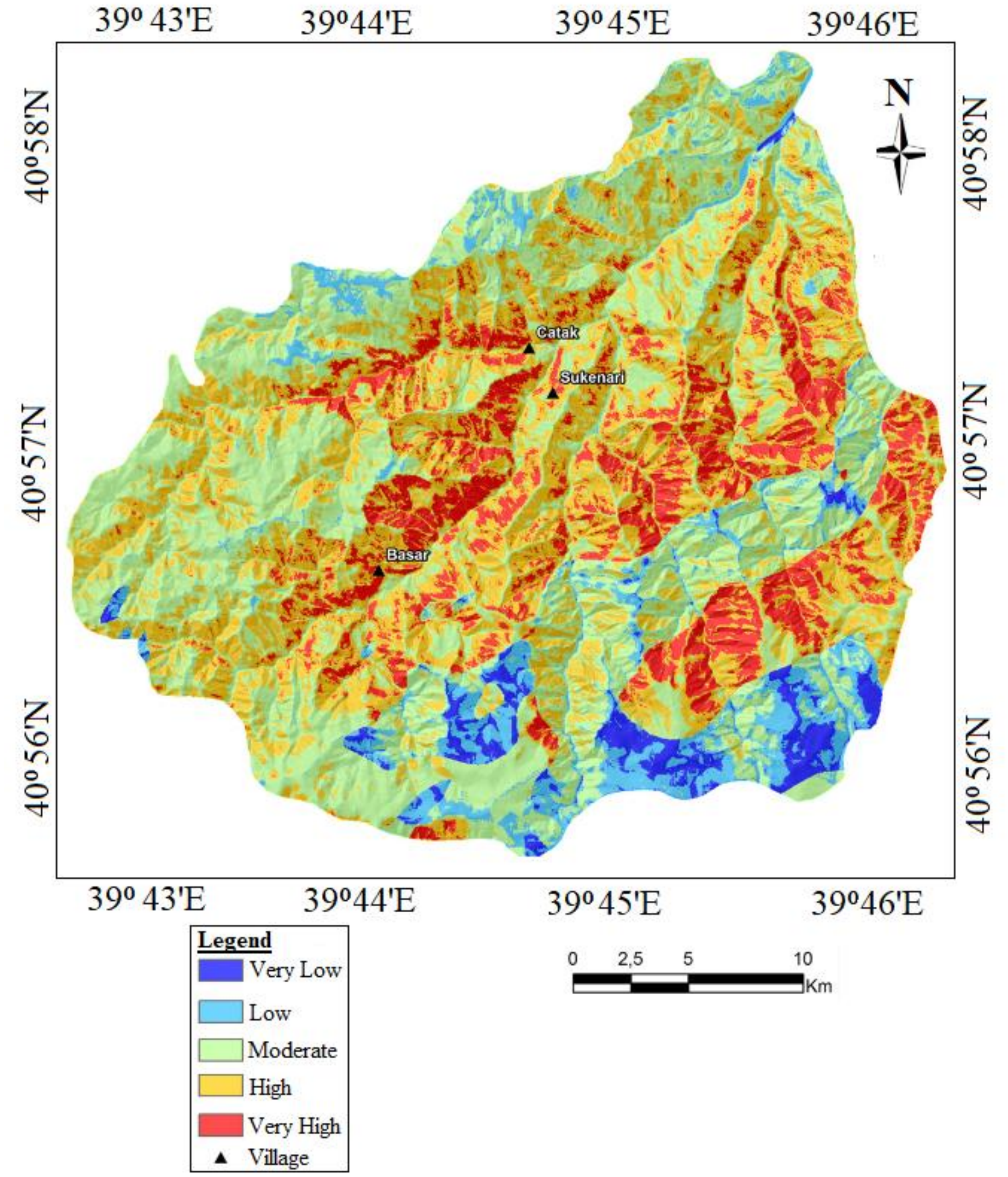

Figure 1.4 Landslide susceptibility map of the study area (Kavzoglu et al., 2015)

The topographical characteristics of Kutlugün, including geomorphology (slope and elevation), land use/cover types, anthropogenic activities, hydrologic conditions, meteorological patterns, and geological structure have led to increased shallow landslide occurrence in the area. The type of landslides movement in the study area, according to Varnes' (1978) classification of slope movements is slide, and soil is the dominant material involved in the landslides (Yalçinkaya and Bayrak

2005). The movement of shallow translational slides in the area amounts to several centimetres per month (Yalçinkaya and Bayrak 2005).

1.7.1 Data used for the Study

Table 1.1 presents the data used for this study, along with details of the acquisition parameters.

Table 1.1 Data used for the study

Data	Data/time of acquisition (dd/mm/yyyy)	Mean Across/ Mean along track viewing angle	Mean Across/ Mean along track incidence angle	Solar azimuth/ elevation	Spectral bands	Resolution
Pleiades-1 (Mono) Pleiades-1 (Mono)	21-10-2012 08:30:15.8 03-04-2013 08:18:20.9	15.66/ -12.24 -4.47/ 2.08	-19.79/ 9.97 5.26/ -1.20	168.92/ 37.70 152.73/ 51.66	PAN: 0.47-0.83 µm (black and white); MS bands: Blue = 0.43-0.55 µm; Green = 0.50-0.62 µm; Red = 0.59-0.71 µm; Near Infrared = 0.74-0.94 µm	PAN = 0.7 m MS = 2.8 m
GPS epoch1 GPS epoch2 GPS epoch3	24-10-2012 25-01-2013 25-03-2013					5 mm
ASTER GDEM	17-10-2011					30 m
SRTM	11-02-2000 17-04-2013	(Date acquired) (Date updated)				30 m

1.8 Structure of Thesis

In Chapter 1 the background of the study, statement of the problem, study objectives, scope of the study, significance of the study, study area, data used and the structure of thesis, are presented.

Chapter 2 presents a review of landslide processes and mapping methods, with particular emphasis on remote sensing approaches, namely - Very High Resolution (VHR) Optical Imagery, Synthetic Aperture Radar (SAR), Ground-Based Interferometric SAR, Airborne Laser Scanning, Terrestrial Laser Scanning, and Unmanned Aerial Vehicle (UAV).

Chapter 3 presents the extraction of small and slow-moving landslides using object-based approach and very high resolution Pleiades-1 imagery. The rule-based classification was performed using spectral, textural, spatial and topographic characteristics.

In Chapter 4 the supervised object-based techniques for the detection and mapping of small and slow-moving landslides is presented. The performance of two supervised algorithms - k-NN and SVM using Pleiades-1 imagery are analysed and evaluated.

Chapter 5 presents the kinematic analysis of the small and slow-moving landslides. The displacement pattern of the small and slow-moving landslides was analysed using sub-pixel image correlation techniques. A kinematic deformation model was formulated using Kalman filtering techniques, to evaluate the performance of the image correlation approach, and to estimate the velocity fields of the landslides study area.

In Chapter 6 the design and implementation of an early warning system for slow-moving landslides is presented. This chapter includes the concepts for the design of the early warning system, requirements and specifications for the early warning system, components of the early warning system, and field test for validation of the early warning system.

Finally, the summary, conclusions and recommendations for future work are discussed in Chapter 7.

REFERENCES

Abellan, A., Jaboyedoff, M., Oppikofer, T. and Vilaplana, J. M. (2009) 'Detection of millimetric deformation using a terrestrial laser scanner: experiment and application to a rockfall event', *Natural Hazards and Earth System Sciences*, 9, pp. 365-372.

Abellán, A., Vilaplana, J. M., Calvet, J., Garcıa-Selles, D. and Asensio, E. (2011) 'Rockfall monitoring by Terrestrial Laser Scanning - case study of the basaltic rock face at Castellfollit de la Roca (Catalonia, Spain)', *Natural Hazards and Earth System Sciences,* 11, pp. 829-841.

Acar, M., Ozludemir, M. T., Erol, S., Celik, R. N. and Ayan, T. (2008) 'Kinematic landslide monitoring with Kalman filtering', *Natural Hazards and Earth System Sciences*, 8, pp. 213-21.

Adam, E., Mutanga, O., Odindi, J. and Abdel-Rahman, E. M. (2014) 'Land-use/cover classification in a heterogeneous coastal land scape using RapidEye imagery: Evaluating the performance of random forest and support vector machines classifiers', *International Journal of Remote Sensing*, 35(10), pp. 3440-3458.

Akbulut, Y., Sengur, A., Guo, Y. and Smarandache, F. (2017) 'NS-k-NN: Neutrosophic set-based k-Nearest Neighbors classifier', *Symmetry*, 9(9), 179.

Aksoy, B. and Ercanoglu, M. (2012) 'Landslide identification and classification by object-based image analysis and fuzzy logic: An example from the Azdavay Region (Kastamonu, Turkey)', *Computers and Geosciences,* 38(1), pp. 87-98.

Alexander, D. (1993) Natural Disaster, London, University College Library Press.

Aljanabi, Q. A., Chik, Z. and Kasa, A. (2013) 'Construction of a new highway embankment on the soft clay soil treatment by stone columns in Malaysia', *Journal of Engineering Science and Technology,* 8(4), pp. 448 - 456.

Anderson, G. P., Felde, G. W., Hoke, M. L., Ratkowski, A. J, Cooley, T. W., Chetwynd, J. H. Jr., Gardner, J. A., Adler-Golden, S, M., Matthew, M. W. and Berk, A. et al. (2002) 'MODTRAN4-based atmospheric correction algorithm: FLAASH (fast line-of-sight atmospheric analysis of spectral hypercubes)', in *Algorithms and Technologies for Multispectral,* *Hyperspectral, and Ultraspectral Imagery VIII (Proceedings of SPIE 2002), Society of Photo Optics, Orlando, FL, USA,* pp. 65-71.

Archibald, R. and Fann, G. (2007) ‘Feature selection and classification of hyperspectral images with support vector machines’, *IEEE Geoscience and Remote Sensing Letters,* 4(4), pp. 674-677.

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

Ardizzone, F., Cardinali, M., Galli, M., Guzzetti, F. and 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), pp. 637-650.

Ayoub, F., Leprince, S. and Keene, L. (2009) ‘User’s guide to Cosi-Corr - Co-registration of Optically Sensed Images and Correlation’, *California Institute of Technology, Pasadena, CA, USA,* 38 pp.

Baatz, M. and Schäpe, A. (2000). ‘Multiresolution segmentation - an optimization approach for high quality multi-scale image segmentation’, in *Angewandte Geographische Informationsverarbeitung XII. Beiträge zum AGIT-Symposium Salzburg,* pp. 12-23.

Ballabio, C. and Sterlacchini, S. (2012) ‘Support vector machines for landslide susceptibility mapping: The Staffora River Basin case study, Italy’, *Mathematical Geoscience,* 44(1), pp. 47-70.

Baldo, M., Bicocchi, C., Chiocchini, U., Giordan, D. and Lollino, G. (2009) ‘LIDAR monitoring of mass wasting processes: The Radicofani landslide, Province of Siena, Central Italy’, *Geomorphology,* 105(3-4), pp. 193-201.

Barlow, J., Franklin, S. E. and Martin, Y. (2006) ‘High spatial resolution satellite imagery, DEM derivatives, and image segmentation for the detection of mass wasting processes’, *Photogrammetric Engineering and Remote Sensing,* 72(6), pp. 687-692.

Barlow, J., Martin, Y. and Franklin, S. E. (2003) ‘Detecting translational landslide scars using segmentation of Landsat ETM+ and DEM data in the northern Cascade Mountains, British Columbia’, *Canadian Journal of Remote Sensing,* 29(4), pp. 510-517.

Baum, R. L. and Godt, J. W. (2010) 'Early warning of rainfall-induced shallow landslides and debris flows in the USA', *Landslides*, 7(3), pp. 259-272.

Bayrak, T., Eyo, E., Başoğlu, N., Musa, T. and Akpee, D. (2015) 'Development of an alternative low-cost landslide monitoring method using data from TUSAGA-Aktif GNSS network', *Boletim de Ciências Geodésicas*, 21(3), pp. 610-623.

Behling, R., Roessner, S., Golovko, D. and Kleinschmit, B. (2016) 'Derivation of long-term spatiotemporal landslide activity - multi-sensor time series approach', *Remote Sensing of Environment*, 186, pp. 88-104.

Bell, R., Cepeda, J. and Devoli, G. (2014) 'Landslide susceptibility modelling at catchment level for improvement of the landslide early warning system in Norway', in *Proceedings of World Landslide Forum 3, June 2-6, Beijing*.

Benz, U. C., Hofmann, P., Willhauck, G., Lingenfelder, I. and Heynen, M. (2004) 'Multiresolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information', *ISPRS Journal of Photogrammetry and Remote Sensing*, 58(3-4), pp. 239-258.

Bertachini, E., Capitani, A., Capra, A., Castagnetti, C., Corsini, A., Dubbini, M. and Ronchetti, F. (2009) 'Integrated surveying system for landslide monitoring, Valoria landslide (Appennines of Modena, Italy)', in *FIG Working Week 2009. Eilat, Israel*.

Bethmann, F. and Luhmann, T. (2010) 'Least squares matching with advanced geometric transformation models', in Proceedings of ISPRS Commission V Mid-Term Symposium, Close Range Image Measurement Techniques, Newcastle upon Tyne, UK, 21-24 June 2010, International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, WG V/4, pp. 86-91.

Blaschke, T. (2010) 'Object based image analysis for remote sensing', *ISPRS Journal of Photogrammetry and Remote Sensing*, 65(1), pp. 2-16.

Blaschke, T., Feizizadeh, B. and Hölbling, D. (2014) 'Object-based image analysis and digital terrain analysis for locating landslides in the Urmia Lake Basin, Iran', *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 7(12), pp. 4806-4817.

Blikra, L. H. (2008) 'The Åknes rockslide: monitoring, threshold values and early-warning', in Landslides and Engineered Slopes - From the Past to the Future, Proceedings of the 10th International Symposium on Landslides and Engineered Slopes, 30 June - 4 July, Xi'an, China, pp. 1089-1094.

Bonnard, C. (2008) ‘Introduction to landslide: mechanisms of landslides and specificities of large landslides’, *Landslide Risk Assessment and Mitigation Summer School 2008 (LARAM), Ravello, Italy*.

Borghuis, A. M., Chang, K. and 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), pp. 1843-1856.

Brunner, F. K., Macheiner, K. and Woschitz, H. (2007) ‘Monitoring of deep-seated mass movements’, in Proceedings of the 3rd International Conference on Structural Health Monitoring of Intelligent Infrastructure, British Columbia, Canada.

Burghaus, S., Bell, R. and Kuhlmann, H. (2009) ‘Improvement of a terrestrial network for movement analysis of a complex landslide’, *FIG conference, Eilat, Israel*.

Calcaterra, D., Ramondini, M., Calò, F., Longobardi, V., Parise, M. and Galzerano, C. M. (2008) ‘DInSAR techniques for monitoring slow moving-landslides’, in *Landslides and Engineered Slopes - From the Past to the Future, Proceedings of the 10th International Symposium on Landslides and Engineered Slopes*, pp. 1089-1094.

Calvello, M., Cascini, L. and Sorbino, G. (2008) ‘A numerical procedure for predicting rainfall-induced movements of active landslides along pre-existing slip surfaces’, *International Journal for Numerical and Analytical Methods in Geomechanics*, 32(4), pp. 327-351.

Canuti, P., Casagli, N., Catani, F., Falorni, G. and Farina, P. (2007) ‘Integration of remote sensing techniques in different stages of landslide response’, *Progress in Landslide Science*, 96, pp. 251-260.

Canuti, P., Casagli, N., Ermini, L., Fanti, R. and Farina, P. (2004) ‘Landslide activity as a geoindicator in Italy: significance and new perspectives from remote sensing’, *Environmental Geology*, 45(7), pp. 907-919.

Casagli, N., Frodella, W., Morelli, S., Tofani, V., Ciampalini, A., Intrieri, E., Raspini, F., Rossi, G., Tanteri, L. and Lu, P. (2017) ‘Spaceborne, UAV and ground-based remote sensing techniques for landslide mapping, monitoring and early warning’, *Geoenvironmental Disasters*, (2017)4, 9.

Chang, K.-T., Liu, J.-K. and Wang, C.-I. (2012) 'An object-oriented analysis for characterizing the rainfall-induced shallow landslide', *Journal of Marine Science and Technology*, 20(6), pp. 647-656.

Chang-Chun, L., Guang-Sheng, Z., Tian-jie, L. and A-du, G. (2011) 'Quick image processing method of UAV without control points data in earthquake disaster area', *Transactions of the Nonferrous Metals Society of China*, 21(3), pp. 523-528.

Chavez, P. S., Sides, S. C. and Anderson, J. A. (1991) 'Comparison of three different methods to merge multiresolution and multispectral data: TM and SPOT Panchromatic', *Photogrammetric Engineering and Remote Sensing*, 57(3), pp. 295-303.

Chen, W., Li, X., Wang, Y., Chen, G. and Liu, S. (2014) 'Forested landslide detection using LiDAR data and the random forest algorithm: a case study of the Three Gorges, China', *Remote Sensing of Environment*, 152, pp. 291-301.

Cheng, G., Guo, L., Zhao, T., Han, J., Li, H. and Fang, J. (2013) 'Automatic landslide detection from remote-sensing imagery using a scene classification method based on BoVW and pLSA', *International Journal of Remote Sensing*, 34(1), pp. 45-59.

Cheng, P. (2012) 'Geometric correction, Pan-sharpening and DTM extraction: Pleiades satellite', *GEO Informatics*, October/November 2012. http://www.pcigeomatics.com/pdf/Geomatica-Pleiades-Processing.pdf (Accessed on 6 April 2018).

Ching-Chuan, H., Yih-Jang, J., Lih-Kang, H. and Jin-Long, L. (2009) 'Internal soil moisture and piezometric responses to rainfall-induced shallow slope failures', *Journal of Hydrology*, 370(1-4), pp. 39-51.

Coe, J. A., Ellis, W. L., Godt, J. W., Savage, W. Z., Savage, J. E., Michael, J. A., Kibler, J. D., Powers, P. S., Lidke, D. J. and Debray, S. (2003) 'Seasonal movement of the Slumgullion landslide determined from Global Positioning System surveys and field instrumentation, July 1998-March 2002', *Engineering Geology*, 68(1-2), pp. 67-101.

Colditz, R. R. (2015) 'An evaluation of different training sample allocation schemes for discrete and continuous land cover classification using decision tree-based algorithms', *Remote Sensing*, 7(8), pp. 9655-9681.

Colomina I. and Molina P. (2014) ‘Unmanned aerial systems for photogrammetry and remote sensing: a review’, *ISPRS Journal of Photogrammetry and Remote Sensing*, 92, pp. 79-97.

Corsini, A., Berti, M., Monni, A., Pizziolo, M., Bonacini, F., Cervi, F., Ciccarese, G., Ronchetti, F., Bertacchini, E., Capra, A., Gallucci, A., Generali, M., Gozza, G., Pancioli, V., Pignone, S. and Truffelli, G. (2013) ‘Rapid assessment of landslide activity in Emilia Romagna using GB-InSAR short surveys’, *Landslide Science and Practice, Springer, Berlin Heidelberg*, pp. 391-399.

Corsini, A., Borgatti, L., Cervi, F., Dahne, A., Ronchetti, F. and Sterzai, P. (2009) ‘Estimating mass-wasting processes in active earth slides-earth flows with time-series of high-resolution DEMs from photogrammetry and airborne LiDAR’, *Natural Hazards and Earth System Sciences*, 9, pp. 433-439.

Crozier, M. J. (1999) ‘Prediction of rainfall-triggered landslides: a test of the antecedent water status model’, *Earth Surface Processes and Landforms*, 24(9), pp. 825-833.

Cruden, D. M. and Varnes, D. J. (1996) ‘Landslide types and processes’, Landslides, Investigation and Mitigation, Special Report 247, Transportation Research Board, Washington D.C., pp. 36-75.

Dai, F. C. and Lee, C. F. (2002) ‘Landslide Characteristics and Slope Instability Modelling using GIS, Lantau Island, Hong Kong’, *Geomorphology*, 42(3), pp. 213-28.

Debella-Gilo, M. (2011) Matching of repeat remote sensing images for precise analysis of mass movements, PhD dissertation, Department of Geosciences, University of Oslo, Norway.

Debella-Gilo, M. and Kääb, A. (2012) ‘Measurement of surface displacement and deformation of mass movements using least squares matching of repeat high resolution satellite and aerial images’, *Remote Sensing*, 4(1), pp. 43-67.

Debella-Gilo, M. and Kääb, A., (2011) ‘Sub-pixel precision image matching for measuring surface displacements on mass movements using normalized cross-correlation’, *Remote Sensing of Environment*, 115 (1), pp. 130-142.

Delacourt, C., Allemand, P., Berthier, E., Raucoules, D., Casson, B., Grandjean, P., Pambrun, C. and Varel, E. (2007) ‘Remote-sensing techniques for analysing landslide kinematics: a review’, *Bulletin de la Societe Geologique de France*, 178(2), pp. 89-100.

Delacourt, C., Allemmand, P., Casson, B. and Vadon, H. (2004) 'Velocity field of the La Clapière landslide measured by the correlation of aerial and QuickBird satellite images', *Geophysical Research Letters,* 31(15), pp. L15619.

Delvit, J.-M. and Michel, J. (2016) 'Digital terrain models from optical images', *Optical Remote Sensing of Land Surface: Techniques and Methods,* pp. 125-161.

Dikau, R., Brunsden, D. and Schrott, L. (1996) Landslide recognition: identification, movement and causes: identification, movement and courses, Wiley, New York.

Di Martire, D. (2013) 'Application of DInSAR data for slow-moving landslides monitoring', *PhD thesis, Università degli Studi di Napoli Federico II*, pp.128.

Drăguţ, L. and Eisank, C. (2012) 'Automated object-based classification of topography from SRTM data', *Geomorphology,* 141-142, pp. 21-33.

Dragut, L., Tiede, D. and Levick, S. R. (2010) 'ESP: A tool to estimate scale parameter for multiresolution image segmentation of remotely sensed data', *International Journal of Geographical Information Science*, 24(6), pp. 859-871.

Dvornychenko, V. N. (1983) 'Bounds on (deterministic) correlation-functions with application to registration', *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 5(2), pp. 206-213.

Eberhardt, E., Watson, A. D. and Loew, S. (2008) 'Improving the interpretation of slope monitoring and early warning data through better understanding of complex deep-seated landslide failure mechanisms', in *Landslides and Engineered Slopes: From the Past to the Future, Proceedings of the 10th International Symposium on Landslides and Engineered Slopes, Xi'an, China*, pp. 39-51.

Eyo, E. E., Musa, T. A., M.Idris, K. and Opaluwa, Y. D. (2014) Reverse RTK Data Streaming for Low-Cost Landslide Monitoring, Geoinformation for Informed Decisions, Springer International Publishing Switzerland, pp. 19-33.

Feng, Y., Rizos, C., Higgins, M., Lim, S. and Tang, M. (2009) 'Developing regional precise positioning services using the legacy and future GNSS receivers', *Journal of Global Positioning Systems*, 8(1), pp. 17-25.

Fiorio, C. and Gustedt, J. (1996) 'Two linear time union-find strategies for image processing', *Theoretical Computer Science*, 154(2), pp. 165-181.

Förstner, W. (1982) ‘On the geometric precision of digital image correlation’, in Proceedings of the ISPRS Symposium Mathematical Models, Accuracy Aspects and Quality Control, Finland, pp. 176-189.

Franco-Lopez, H., Ek, A. R. and Bauer, M. E. (2001) ‘Estimation and mapping of forest stand density, volume and cover type using the k-Nearest Neighbors method’, *Remote Sensing of Environment*, 77(3), pp. 251-274.

Froese, C. R., Van der Kooij, M. and Kosar, K. (2004) ‘Advances in the application of InSAR to complex, slowly moving landslides in dry and vegetated terrain’, in *Landslides: Evaluation and Stabilization, 9th International Symposium on Landslides*, pp. 1255-1264.

García, A., Hörd, A. and Fabian, M. (2010) ‘Landslide monitoring with high resolution tilt measurements at the Dollendorfer Hardt landslide, Germany’, *Geomorphology*, 120(1-2), pp. 16-25.

Gerçek, D., Toprak, V. and Strobl, J. (2011) ‘Object-based classification of landforms based on their local geometry and geomorphometric context’, *International Journal of Geographical Information Science*, 25(6), pp. 1011-1023.

Ghosh, A. and Joshi, P. K. (2014) ‘A comparison of selected classification algorithms for mapping bamboo patches in lower Gangetic plains using very high resolution WorldView-2 imagery’, *International Journal of Applied Earth Observation and Geoinformation*, 26, pp. 298-311.

Gigli, G., Frodella, W., Mugnai, F., Tapete, D., Cigna, F., Fanti, R., Intrieri, E. and Lombardi, L. (2012) ‘Instability mechanisms affecting cultural heritage sites in the Maltese Archipelago’, *Natural Hazards and Earth System Sciences*, 12, pp. 1883-1903.

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

Greco, R., Guida, A., Damiano, E. and Olivares, L. (2010) ‘Soil water content and suction monitoring in model slopes for shallow flowslides early warning applications’, *Physics and Chemistry of the Earth*, 35(3-5), pp. 127-136.

Guha-Sapir, D., Vos, F., Below, R, with Ponserre, S. (2012) ‘Annual disaster statistical review 2011: the numbers and trends’, *Brussels: CRED*.

Gündoğdu, B. (2011) Relations between pore water pressure, stability and movements in reactivated landslides, MSc Thesis, Middle East Technical University, 115 p.

Guo, X.-T., Huang, T., Zang, Q.-B. and Li, G.-H. (2015) ‘An approach for monitoring landslide deformation using least-square matching algorithm’, *Rock and Soil Mechanics*, 36(5), pp.1421-1427.

Gurer, I. and Ucar, I. (2010) ‘The importance of flood zoning using GIS - a case study from Maçka, Trabzon, Northeastern Turkey’, in *BALWOIS 2010 - Ohrid, Republic of Macedonia, 25-29 May.*

Gutiérrez, F., Soldati, M., Audemard, F. and Bălteanu, D. (2010) ‘Recent advances in landslide investigation: issues and perspectives’, *Geomorphology*, 124(3-4), pp. 95-101.

Guyon, D. and Bréda, N. (2016) Applications of multispectral optical satellite imaging in forestry, Land Surface Remote Sensing in Agriculture and Forest, pp. 249-329.

Guzzetti, F. (2005) Landslide hazard and risk assessment, PhD Dissertation, University of Bonn, Germany, 389 p.

Guzzetti, F., Cardinali, M. and Reichenbach, P. et al. (2000) ‘Comparing landslide maps: a case study in the Upper Tiber River Basin, Central Italy’, *Environmental Management*, 25 (3), pp. 247-263.

Guzzetti, F., Mondini, A. C., Cardinali, M., Fiorucci, F., Santangelo, M. and Chang, K.-T. (2012) ‘Landslide inventory maps: new tools for an old problem’, *Earth-Science Reviews*, 112(1-2), pp. 42-66.

Guzzetti, F., Peruccacci, S. and Rossi, M. (2005) ‘Definition of critical threshold for different scenarios (WP 1.16)’, *RISK-AWARE: Advance Weather forecast system to Advice on Risk Events and management, Action 1.16*, 38 p.

Hall-Beyer, M. (2017) ‘GLCM: A Tutorial, Version 3.0’, https://www.researchgate.net/publication/315776784_GLCM_Texture_A_Tutorial_v_30_March_2017. (Accessed on 5 April 2018).

Handwerger, A. L., Roering, J. J. and Schmidt, D. A. (2013) ‘Controls on the seasonal deformation of slow-moving landslides’, *Earth and Planetary Science Letters*, 377-378, pp. 239-247.

Hasekiogullari, G. D. and Ercanoglu, M. (2012) ‘A new approach to use AHP in landslide susceptibility mapping: a case study at Yenice (Karabuk, NW Turkey)’, *Natural Hazards*, 63(2), pp. 1157-1179.

Hastaoglu, K. and Sanli, D. (2011) ‘Monitoring Koyulhisar landslide using rapid static GPS: a strategy to remove biases from vertical velocities’, *Natural Hazards*, 58(3), pp. 1275-1294.

Haugerud, R. A., Harding, D. J., Johnson, S. Y., Harless, J. L. and Weaver, C. S. (2003) ‘High-resolution LiDAR topography of the Puget lowland, Washington’, *GSA Today*, 13(3), pp. 4-10.

Hay, G. J. and Castilla, G. (2008) ‘Geographic object-based image analysis (GEOBIA): a new name for a new discipline’, *Object-Based Image Analysis, Lecture Notes in Geoinformation and Cartography*, pp. 75-89.

He, H. and Garcia, E. A. (2009) ‘Learning from imbalanced data’, *IEEE Transactions on Knowledge and Data Engineering*, 21(9), pp. 1263-1284.

Heid, T. (2011) Deriving glacier surface velocities from repeat optical images. PhD Thesis, Department of Geosciences, University of Oslo, Norway.

Heid, T. and Kääb, A. (2012) ‘Repeat optical satellite images reveal widespread and long term decrease in land-terminating glacier speeds’, *The Cryosphere*, 6, pp. 467-478.

Heincke, B., Günther, T., Dalsegg, E., Ronning, J. S., Ganerod, G. V. and Elvebakk, H. (2010) ‘Combined three-dimensional electric and seismic tomography study on the Aknes rockslide in western Norway’, *Journal of Applied Geophysics*, 70(4), pp. 292-306.

Heleno, S., Matias, M., Pina, P. and Sousa, A. J. (2016) ‘Semi-automated object-based classification of rain-induced landslides with VHR multispectral images on Madeira Island’, *Natural Hazards and Earth System Sciences*, 16, pp. 1035-1048.

Heydari, S. S. and Mountrakis, G. (2018) ‘Effect of classifier selection, reference sample size, reference class distribution and scene heterogeneity in per-pixel classification accuracy using 26 Landsat sites’, *Remote Sensing of Environment*, 204, pp. 648-658.

Hild, F. and Roux, S. (2008) ‘CorreliQ4: a software for finite element displacement field measurements by digital image correlation’, *Internal Report No. 269, LMT-Cachan*, 55 p.

Hölbling, D., Eisank, C., Albrecht, F., Vecchiotti, F., Friedl, B., Weinke, E. and Kociu, A. (2017) ‘Comparing manual and semi-automated landslide mapping based on optical satellite images from different sensors’, *Geosciences*, 7(2), 37, pp. 1-20.

Hölbling, D., Eisank, C., Friedl, B., Chang, K-T., Tsai, T-T., Pedersen, G. B. M., Betts, H., Cigna, F., Chiang, S-H., Robson, B. A., Bianchini, S., Füreder, P., Albrecht, F., Spiekermann, R., Weinke, E., Blaschke, T. and Phillips, C. (2016) ‘Object-based landslide mapping: examples, challenges and opportunities’, *Geophysical Research Abstracts*, Vol. 18, EGU2016-520.

Holbling, D., Füreder, P., Antolini, F., Cigna, F., Casagli, N. and Lang, S. (2012) ‘A semi-automated object-based approach for landslide detection validated by persistent scatterer interferometry measures and landslide inventories’, *Remote Sensing*, 4, pp. 1310-1336.

Hollingsworth, J., Leprince, S., Ayoub, F. and Avouac, J.-P. (2012) ‘Deformation during the 1975-1984 Krafla rifting crisis, NE Iceland, measured from historical optical imagery’, *Journal of Geophysical Research*, 117 (B11407), pp. 1-24.

Hua, W. and Wu, L. (2016) ‘Ground deformation extraction using visible images and LiDAR data in mining area’, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XLI-B7, 2016 XXIII ISPRS Congress, 12-19 July 2016, Prague, Czech Republic.

Inglada, J. (2016) Land cover mapping from optical images, Land Surface Remote Sensing in Agriculture and Forest, pp. 81-111.

Intrieri, E., Gigli, G., Casagli, N. and Nadim, F. (2013) ‘Landslide Early Warning System: toolbox and general concepts’, *Natural Hazards and Earth System Sciences*, 13(1), pp. 85-90.

Intrieri, E., Gigli, G., Mugnai, F., Fanti, R. and Casagli, N. (2012) ‘Design and implementation of a landslide early warning system’, *Engineering Geology*, 147-148, pp. 124-136.

ITT Visual Information Solutions (2009) *Atmospheric Correction Module: QUAC and FLAASH User’s Guide, Version 4.7.* http://www.harrisgeospatial.com/portals/0/pdfs/envi/flaash_module.pdf (Accessed on 4 January 2018).

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

Jaboyedoff, M., Oppikofer, T., Abellán, A., Derron, M., Loye, A., Metzger, R. and Pedrazzini, A. (2012) 'Use of LIDAR in landslide investigations: a review', *Natural Hazards*, 61(1), pp. 5-28.

James, M. R. and Robson, S. (2012) 'Straightforward reconstruction of 3D surfaces and topography with a camera: accuracy and geoscience application', *Journal of Geophysical Research*, 117(F3), pp. 1-17.

Janssen, V. and Rizos, C. (2003) 'A mixed-mode GPS network processing approach for deformation monitoring applications', *Survey Review*, 37(287), pp. 2-19.

Jiang, S., Wen, B.-P., Zhao, C., Li, R.-D. and Li, Z.-H. (2016) 'Kinematics of a giant slow-moving landslide in Northwest China: constraints from high resolution remote sensing imagery and GPS monitoring', *Journal of Asian Earth Sciences*, 123, pp. 34-46.

Jongmans, D. and Garambois, S. (2007) 'Geophysical investigation of landslides: a review', *Bulletin de la Société Géologique de France*, 178(2), pp. 101-112.

Kääb, A. (2013) *Image correlation software CIAS*, http://www.mn.uio.no/icemass [Accessed on 9 September 2017].

Kääb, A. (2005) Remote sensing of mountain glaciers and permafrost creep, Geographisches Institut der Universität Zürich, Zürich.

Kandawasvika, A. M. (2009) On interoperable management of multi-sensors in landslide monitoring applications, PhD Thesis, Universität der Bundeswehr München, Germany, 172 p.

Kavzoglu, T., Sahin, E. K. and Colkesen, I, (2014) 'Landslide susceptibility mapping using GIS-based multi-criteria decision analysis, support vector machines, and logistic regression', *Landslides*, 11(3), pp. 425-439.

Kavzoglu, T., Sahin, E. K. and Colkesen, I. (2015) 'Selecting optimal conditioning factors in shallow translational landslide susceptibility mapping using genetic algorithm', *Engineering Geology*, 192, pp. 101-112.

Kerle, N. (2012) 'Satellite-based damage mapping following the 2006 Indonesia earthquake - How accurate was it?', *International Journal of Applied Earth Observation and Geoinformation*, 12(6), pp. 466-476.

Ketelaar, V. B. H. (2009) Satellite Radar Interferometry: subsidence Monitoring Techniques, Remote Sensing and Digital Image Processing, Springer, 270 p.

Khatami, R., Mountrakis, G. and Stehman, S. V. (2016) ‘A meta-analysis of remote sensing research on supervised pixel-based land cover image classification processes: general guidelines for practitioners and future research’, *Remote Sensing of Environment*, 177, pp. 89-100.

Kirschbaum, D. B., Adler, R., Hong, Y., Kumar, S., Peters-Lidard, C. and Lerner-Lam, A. (2012) ‘Advances in landslide nowcasting: evaluation of a global and regional modelling approach’, *Environmental Earth Sciences*, 66(6), pp. 1683-1696.

Koçan, N. (2007) ‘Research to landscape values of Gumushane-Trabzon Highway’, *Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi*, 8 (1), pp. 37-45.

Kuglin, C. D. and Hines, D. C. (1975) ‘The phase correlation image alignment method’, *Proceeding of IEEE International Conference on Cybernetics and Society*, pp. 163-165.

Kumar, D. M. (2014) ‘Density slicing, thresholding, intensity-hue-saturation (IHS) images, time composite images, synergetic images’, *Lecture Notes, IISc, Bangalore*. http://nptel.ac.in/courses/105108077/17 (Accessed on 17 April 2018).

Kurdoglu, O. and Kurdoglu, B. C. (2010) ‘Determining recreational, scenic, and historical-cultural potentials of landscape features along a segment of the ancient Silk Road using factor analysing’, *Environmental Monitoring and Assessment*, 170(1-4), pp. 99-116.

Kurtz, C., Stumpf, A., Malet, J.-P., Gançarski, P., Puissant, A. and Passat, N. (2014) ‘Hierarchical extraction of landslides from multiresolution remotely sensed optical images’, *ISPRS Journal of Photogrammetry and Remote Sensing*, 87, pp. 122-136.

Lacasse, S. and Nadim, F. (2009) Landslide risk assessment and mitigation strategy, Landslides - Disaster Risk Reduction, Springer-Verlag Berlin Heidelberg, pp. 31-61.

Lacroix, P., Berthier, E. and Maquerhua, E. T. (2015) ‘Earthquake-driven acceleration of slow-moving landslides in the Colca valley, Peru, detected from Pléiades images’, *Remote Sensing of Environment*, 165, pp. 148-158.

Lahousse, T., Chang, K. T. and Lin, Y. H. (2011) ‘Landslide mapping with multi-scale object-based image analysis - a case study in the Baichi Watershed, Taiwan’, *Natural Hazards and Earth System Sciences*, 11, pp. 2715-2726.

Lang, S., Albrecht, F., Kienberger, S. and Tiede, D. (2010) 'Object validity for operational tasks in a policy context', *Journal of Spatial Science,* 55(1), pp. 9-22.

Lee, C. H. (1986) 'Recursive region splitting at hierarchical scope views', *Computer Vision, Graphics, and Image Processing*, 33(2):237-258.

Lee, S., Hong, S.-M. and Jung, H.-S. (2017) 'A Support Vector Machine for landslide susceptibility mapping in Gangwon Province, Korea', *Sustainability*, 9(1), 48, pp. 1-15.

Leprince, S., Barbot, S., Ayoub, F. and Avouac, J. P. (2007) 'Automatic and precise orthorectification, coregistration, and subpixel correlation of satellite images - application to ground deformation measurements', *IEEE Transactions on Geoscience and Remote Sensing,* 45 (6), pp. 1529-58.

Leroueil, S. (2001) 'Natural slopes and cuts: movement and failure mechanisms', *Geotechnique*, 51(3), pp. 197-243.

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

Li, Z., Shi, W., Wang, Q. and Miao, Z. (2015a) 'Extracting man-made objects from remote sensing images via fast level set evolutions', *IEEE Transactions on Geoscience and Remote Sensing*, 53(2), pp. 883-899.

Li, X., Cheng, X, Chen, W., Chen, G. and Liu, S. (2015b) 'Identification of forested landslides using LIDAR data, object-based image analysis, and machine learning algorithms', *Remote Sensing*, 7(8), pp. 9705-9726.

Li, Y., Chen, G., Wang, B., Zheng, L., Zhang, Y. and Tang, C. (2013) 'A new approach of combining aerial photography with satellite imagery for landslide detection', *Natural Hazards*, 66(2), 649-669.

Li, Y., Huang, J., Jiang, S.-H., Huang, F. and Chang, Z. (2017) 'A web-based GPS system for displacement monitoring and failure mechanism analysis of reservoir landslide', *Scientific Reports*, 7(1), 17171 (2017), pp. 1-13.

Lieb, G. K. (2006) *Definition of high mountains*. http:\\www.uni-graz.at/geowww/hmrsc. [Accessed on 12 January 2018].

Lillesand, T., Kiefer, R. W. and Chipman, J. (2014) Remote sensing and image interpretation, Wiley, 736 p.

Lin, C. Y., Lo, H. M., Chou, W. C. and Lin, W. T. (2004) 'Vegetation recovery assessment on the Jou-Jou Mountain landslide area caused by the 921 earthquake in the Central Taiwan', *Ecological Modelling*, 176(1-2), pp. 75-81.

Liu, S. and Wang, Z. (2008) 'Choice of surveying methods for landslides monitoring', in Landslides and Engineered Slopes: From the Past to the Future, Proceedings of the 10th International Symposium on Landslides and Engineered Slopes, China, pp. 1-6.

Lombardi, L., Nocentini, M., Frodella, W., Nolesini, T., Bardi, F., Intrieri, E., Carlà, T., Solari, L., Dotta, G., Ferrigno, F. and Casagli, N. (2017) 'The Calatabiano landslide (southern Italy): preliminary GB-InSAR monitoring data and remote 3D mapping', *Landslides*, 14(2), pp. 685-696.

Lowry, B., Gomez, F., Zhou, W., Mooney, M. A., Held, B. and Grasmick, J. (2013) 'High resolution displacement monitoring of a slow velocity landslide using ground based radar interferometry', *Engineering Geology*, 166, pp. 160-169.

Lu, D. and Weng, Q. A. (2007) 'A Survey of image classification methods and techniques for improving classification performance', *International Journal of Remote Sensing*, 28(5), pp. 823-870.

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

Luo, X., Huang, G., Panga, L. and Zhaoa, Z. (2008) 'Study on airborne SAR image matching using epipolar geometry', *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVII, Part B1, pp. 399-402.

Lutes, J. (2002) 'DAIS: a digital airborne imaging system', in Proceedings Pecora 15/Land Satellite Information IV/ISPRS Commission I/FIEOS, pp. 1-6.

Ma, H. R., Cheng, X., Chen, L., Zhang, H. and Xiong, H. (2016) 'Automatic identification of shallow landslides based on Worldview-2 remote sensing images', *Journal of Applied Remote Sensing*, 10(1), 016008, pp. 1-12.

Mackey, B. H. and Roering, J. J. (2011) 'Sediment yield, spatial characteristics, and the long-term evolution of active earthflows determined from airborne LiDAR and historical aerial photographs, Eel River, California', *Geological Society of America Bulletin*, 123(7-8), pp. 1560-1576.

Maillard, P. and Clausi, A. D. (2006) ‘Pixel based sea ice classification using the MAGSIC system’, in *Proceedings of the 2006 ISPRS Commission VII Symposium, Enschede, The Netherlands, 8-11 May*, pp. 1-6.

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

Malet, J.-P., Maquaire, O. and Calais, E. (2002) ‘The use of Global Positioning System techniques for the continuous monitoring of landslides: application to the Super-Sauze earthflow (Alpes-deHaute-Province, France)’, *Geomorphology*, 43(1-2), pp. 33-54.

Mallinis, G., Koutsias, N., Tsakiri-Strati, M. and Karteris, M. (2008) ‘Object-based classification using QuickBird imagery for delineating forest vegetation polygons in a Mediterranean test site’, *ISPRS Journal of Photogrammetry and Remote Sensing*, 63(2), pp. 237-250.

Mansour, M. F., Morgenstern, N. R. and Martin, C. D. (2011) ‘Expected damage from displacement of slow-moving slides’, *Landslides*, 8(1), pp. 117-131.

Marcelino, E. V., Formaggio, A. R. and Maeda, E. E. (2009) ‘Landslide inventory using image fusion techniques in Brazil’, *International Journal of Applied Earth Observation and Geoinformation*, 11(3), pp. 181-191.

Marek, L., Miřijovský, J. and Tuček, P. (2015) ‘Monitoring of the shallow landslide using UAV photogrammetry and geodetic measurements’, *Engineering Geology for Society and Territory*, 2, pp. 113-116.

Martha, T. R. and Kerle, N. (2010) ‘Segment optimization for object-based landslide detection’, in GEOBIA 2010: Geographic Object-Based Image Analysis, Proceedings International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXVIII-4/C7, pp. 1-6.

Martha, T. R., Kerle, N., Jetten, V., van Westen, C. J. and Kumar, K. V. (2010) ‘Characterizing spectral, spatial and morphometric properties of landslides for semi-automatic detection using object-oriented methods’, *Geomorphology*, 116(1-2), pp. 24-36.

Martha, T. R., Kerle, N., van Westen, C. J., Jetten, V. and Kumar, K. V. (2012) ‘Object-oriented analysis of multi-temporal panchromatic images for creation of historical landslide inventories’, *ISPRS Journal of Photogrammetry and Remote Sensing*, 67, pp. 105-119.

Martha, T. R., van Westen, C. J., Kerle, N., Jetten, V. and Kumar, K. V. (2013) 'Landslide hazard and risk assessment using semi-automatically created landslide inventories', *Geomorphology*, 184, pp. 139-150.

Martha, T. R., Kerle, N., van Westen, C. J., Jetten, V. and Kumar, K. V. (2011) 'Segment optimization and data-driven thresholding for knowledge-based landslide detection by object-based image analysis', *IEEE Transactions on Geoscience and Remote Sensing*, 49(12), pp. 4928-4943.

Martin, J. G. (2014) Measuring liquefaction-induced deformation from optical satellite imagery, MSc Thesis, University of Texas at Austin, 152 p.

Martin, Y. E. and Franklin, S. E. (2005) 'Classification of soil-and bedrock-dominated landslides in British Columbia using segmentation of satellite imagery and DEM data', *International Journal of Remote Sensing*, 26(7), pp. 1505-1509.

Matsuura, T. and Aniya, M. (2012) 'Automated segmentation of hillslope profiles across ridges and valleys using a digital elevation model', *Geomorphology*, 177-178, pp. 167-177.

Mayr, A., Rutzinger, M., Bremer, M., Oude Elberink, S., Stumpf, F. and Geitner, C. (2017) 'Object-based classification of terrestrial laser scanning point clouds for landslide monitoring', *The Photogrammetric Record*, 32(160), pp. 377-397.

McClellan, J. H., Schafer, R. W. and Yoder, M. A. (2003) Signal Processing First, Pearson Education, Inc., Pearson Prentice Hall.

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

Medina-Cetina, Z. and Nadim, F. (2008) 'Stochastic design of an early warning system', *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, 2(4), pp. 223-236.

Meissen, U. and Voisard, A. (2010) 'Towards a reference architecture for early warning systems', *2nd International Conference on Intelligent Networking and Collaborative Systems (INCOS), Thessaloniki, Greece*, pp. 513-518.

Meric, O., Garambois, S., Jongmans, D., Wathelet, M., Chatelain, J. L. and Vengeon, J. M. (2005) 'Application of geophysical methods for the investigation of the large gravitational mass movement of Séchilienne, France', *Canadian Geotechnical Journal*, 42(4), pp. 1105-1115.

Micheletti, N. (2011) Landslide susceptibility mapping using adaptive support vector machines and feature selection, MSc Thesis, University of Lausanne, Switzerland, 99 p.

Miliaresis, G. C. (2001) 'Extraction of bajadas from digital elevation models and satellite imagery', *Computers and Geosciences*, 27(10), pp. 1157-1167.

Moine, M., Puissant, A. and Malet, J. P. (2009) 'Detection of landslides from aerial and satellite images with a semi-automatic method. Application to the Barcelonnette Basin (Alpes-de-Haute-Provence, France)', *Landslide Processes - from Geomorphological Mapping to Dynamic Modelling, Strasbourg, France*, pp. 63-68.

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

Monserrat, O., Crosetto, M. and Luzi, G. (2014) 'A review of ground-based SAR interferometry for deformation measurement', *ISPRS Journal of Photogrammetry and Remote Sensing*, 93, pp. 40-48.

Montrasio, L. and Valentino, R. (2007) 'Experimental analysis and modelling of shallow landslides', *Landslides*, 4(3), pp. 291-296.

Moore, J. R., Gischig, V., Button, E. and Loew, S. (2010) 'Rockslide deformation monitoring with fiber optic strain sensors', *Natural Hazards and Earth System Sciences*, 10(2), pp. 191-201.

Moosavi, V., Talebi, A. and Shirmohammadi, B. (2014) 'Producing a landslide inventory map using pixel-based and object- oriented approaches optimized by Taguchi method', *Geomorphology*, 204, pp. 646-656.

Morgenstern, N. R. and Martin, C. D. (2008) 'Landslides: seeing the ground', Landslides and engineered slopes: From the Past to the Future, Proceedings of the 10th international Symposium on Landslides and Engineered slopes, China, pp. 3-24.

Mountrakis, G., Im, J. and Ogole, C. (2011) 'Support vector machines in remote sensing: a review', *ISPRS Journal of Photogrammetry and Remote Sensing*, 66, pp. 247-259.

Myint, S. W., Gober, P., Brazel, A., Grossman-Clarke, S. and Weng, Q. (2011) 'Per-pixel vs. object-based classification of urban land cover extraction using high spatial resolution imagery', *Remote Sensing of Environment,* 115(5), pp. 1145-1161.

Nichol, J. and Wong, M. S. (2005) 'Satellite remote sensing for detailed landslide inventories using change detection and image fusion', *International Journal of Remote Sensing*, 26, pp. 1913-1926.

Noferini, L., Pieraccini, M., Mecatti, D., Macaluso, G., Atzeni, C., Mantovani, M., Marcato, G., Pasuto, A., Silvano, S. and Tagliavini, F. (2007) 'Using GB-SAR technique to monitor slow moving landslide', *Engineering Geology*, 95(3-4), pp. 88-98.

Noi, P. T. and Kappas, M. (2018) 'Comparison of Random Forest, k-Nearest Neighbors, and Support Vector Machine classifiers for land cover classification using Sentinel-2 imagery', *Sensors*, 18(1), pp. 1-20.

Ogaja, C., Li, X. and Rizos, C. (2007) 'Advances in structural monitoring with Global Positioning System technology: 1997-2006', *Journal of Applied Geodesy*. 1(3), pp. 171-179.

Oppikofer, T., Jaboyedoff, M., Blikra, L., Derron, M. H. and Metzger, R. (2009) 'Characterization and monitoring of the Aknes rockslide using terrestrial laser scanning', *Natural Hazards and Earth System Sciences*, 9, pp. 1003-1019.

Othman, Z., Wan Aziz, W. A. and Anuar, A. (2011a) 'Evaluating the performance of GPS survey methods for landslide monitoring at Hillside Residential Area: Static vs Rapid Static', *IEEE 7th International Colloquium on Signal Processing and its Applications*, pp. 453-459.

Othman, Z., Wan Aziz, W. A. and Anuar, A. (2011b) 'Landslide monitoring at Hillside Residential Area Using GPS technique: Static vs. RTK Network', *Joint International Symposium & Exhibition on Geoinformation (ISG) 2011 and ISPRS 2011.*

Özdoğan, F. and Günney, D. (2016) 'The importance of architecture education for disaster mitigation', *WIT Transactions on Ecology and the Environment*, 204, pp. 373-384.

Peer Review Turkey (2015) Report of 2015-2016 programme for peer reviews in the framework of EU cooperation on civil protection and disaster risk management.

http://ec.europa.eu/echo/sites/echo-site/files/turkey_peer_review_report_-_en.pdf [Accessed on 20 September 2018].

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

Peyret, M., Djamour, Y., Rizza, M., Ritz, J. F., Hurtrez, J. E., Goudarzi, M. A., Nankali, H., Chéry, J., Le Dortz, K. and Uri, F. (2008) 'Monitoring of the large slow Kahrod landslide in Alborz mountain range (Iran) by GPS and SAR interferometry', *Engineering Geology*, 100(3-4), pp. 131-141.

Pham, D. L., Xu, C. and Prince, J. L. (2000) 'A survey on current methods in medical image segmentation', *Annual Review of Biomedical Engineering*, 2, pp. 315-337.

Pierrot-Deseilligny, M. (2014) MicMac. Apero, Pastis and Other Beverages in a Nutshell. http://logiciels.ign.fr/?Micmac.

Pietikainen, M., Rosenfeld, A. and Walter, I. (1982) 'Split and link algorithms for image segmentation', *Pattern Recognition*, 15(4), pp. 287-298.

Pradhan, B. and Alsaleh, A. (2017) A supervised object-based detection of landslides and man-made slopes using airborne laser scanning data, Laser Scanning Applications in Landslide Assessment, Springer International Publishing, pp. 23-50.

Qian, Y., Zhou, W., Yan, J., Li, W. and Han, L. (2015) 'Comparing machine learning classifiers for object-based land cover classification using very high resolution imagery', *Remote Sensing*, 7(1), pp. 153-168.

Qin, S. Q., Jiao, J. J. and Wang, S. J. (2001) 'The predictable time scale of landslides', *Bulletin of Engineering Geology and the Environment*, 59(4), pp. 307-312.

Quincey, D. J. and Glasser, N. F. (2009) 'Morphological and ice-dynamical changes on the Tasman Glacier, New Zealand, 1990-2007', *Global and Planetary Change*, 68(3), pp. 185-197.

Rau, J. Y., Jhan, J. P. and Rau, R. J. (2014) 'Semiautomatic object-oriented landslide recognition scheme from multisensory optical imagery and DEM', *IEEE Transactions on Geoscience and Remote Sensing*, 52(2), pp. 1336-1349.

Rawat, M. S., Joshi, V., Rawat, B. S. and Kumar, K. (2011) 'Landslide movement monitoring using GPS technology: a case study of Bakthang landslide, Gangtok, East Sikkim, India’, *Journal of Development and Agricultural Economics*, 3(5), pp. 194-200.

Razak, K. A., Straatsma, M. W., van Westen, C. J., Malet, J. P. and de Jong, S. M. (2011) ‘Airborne laser scanning of forested landslides characterization: terrain model quality and visualization’, *Geomorphology*, 126(1-2), pp. 186-200.

Rizzo, V. (2002) ‘GPS monitoring and new data on slope movements in the Maratea Valley (Potenza, Basilicata)’, *Physics and Chemistry of the Earth. Parts A/B/C*, 27(36), pp. 1535-1544.

Romstad, B. and Etzelmüller, B. (2012) ‘Mean-curvature watersheds: a simple method for segmentation of a digital elevation model into terrain segments’, *Geomorphology*, 139, pp. 293-302.

Rossi, G., Nocentini, M., Lomabrdi, L., Vannocci, P., Tanteri, L., Dotta, G., Bicocchi, G., Scaduto, G., Salvatici, T., Tofani, V., Moretti, S. and Casagli, N. (2016) *Integration of multicopter drone measurements and ground-based data for landslide monitoring, Landslides and Engineered Slopes. Experience, Theory and Practice*, pp. 1745-1750.

Rotaru, A., Oajdea, D. and Răileanu, P. (2007) ‘Analysis of the landslide movements’, *International Journal of Geology*, 1(3), pp. 70-79.

Rott, H. and Nagler, T. (2006) ‘The contribution of radar interferometry to the assessment of landslide hazards’, *Advances in Space Research*, 37(4), pp. 710-719.

Sass, O., Bell, R. and Glade, T. (2008) ‘Comparison of GPR, 2D-resistivity and traditional techniques for the subsurface exploration of the Öschingen landslide, Swabian Alb (Germany)’, *Geomorphology*, 93(1-2), pp. 89-103.

Sassa, K., Tsuchiya, S., Fukuoka, H., Mikos, M. and Doan, L. (2015) ‘Landslides: review of achievements in the second 5-year period (2009–2013)’, *Landslides*, 12(2), 213-223.

Scheidl, C., Rickenmann, D. and Chiari, M. (2008) ‘The use of airborne LiDAR data for the analysis of debris flow events in Switzerland’, *Natural Hazards and Earth System Sciences*, 8, pp. 1113-1127.

Schmidt, L. J. (2001) *When land slides*. https://www.earthobservatory.nasa.gov/Features/Landslide. [Accessed on 12th March 2018].

Schrott, L. and Sass, O. (2008) ‘Application of field geophysics in geomorphology: advances and limitations exemplified by case studies’, *Geomorphology*, 93(1-2), pp. 55-73.

Schulz,, W. H., Coe, J. A., Ricci, P. P., Smoczyk, G. M., Shurtleff, B. L. and Panosky, J. (2017) ‘Landslide kinematics and their potential controls from hourly to decadaltimescales: Insights from integrating ground-based InSAR measurements with structural maps and long-term monitoring data’, *Geomorphology*, 285, pp. 121-136.

Schulz, W. H., Coe, J. A., Shurtleff, B. L., Panosky, J., Farina, P., Ricci, P. P. and Barsacchi, G. (2012) ‘Kinematics of the Slumgullion landslide revealed by ground-based InSAR surveys’, in *Proceedings of Landslides and Engineered Slopes: Protecting Society through Improved Understanding, the 11th International and 2nd North American Symposium on Landslides and Engineered Slopes, Banff, Canada*, pp. 3-8.

Schuster, R. L. and Highland, L. M. (2007) ‘The Third Hans Cloos Lecture - Urban landslides: socioeconomic impacts and overview of mitigative strategies’, *Bulletin of Engineering Geology and the Environment*, 66 (1), pp. 1-27.

Segoni, S., Lagomarsino, D., Fanti, R., Moretti, S. and Casagli, N. (2015) ‘Integration of rainfall thresholds and susceptibility maps in the Emilia Romagna (Italy) regional-scale landslide warning system’, *Landslides*, 12 (4), pp. 773-785.

Shan, J. and Toth, C. (2008) Topographic Laser Ranging and Scanning: Principles and Processing, CRC Press, Taylor and Francis Group.

Shao, Y. and Lunetta, R. S. (2012) ‘Comparison of support vector machine, neural network, and CART algorithms for the land-cover classification using limited training data points’, *ISPRS Journal of Photogrammetry and Remote Sensing*, 70, pp. 78-87.

Shi, B., Liu, C., Wu, H. and Lu, P. (2016) ‘Elementary analysis of the mechanism of Xishan Landslide based on pixel tracking on VHR Images’, *International Journal of Geohazards and Environment*, 2(2), pp. 53-71.

Shi, D. and Yang, X. (2015). Support vector machines for land cover mapping from remote sensor imagery, Monitoring and Modelling of Global Changes: A Geomatics Perspective, Springer: Dordrecht, The Netherlands, pp. 265-279.

Sidle, R. C., Taylor, D., Lu, X. X., Adger, W. N., Lowe, D. J., de Lang, W. P., Newnham, R. M. and Dodson, J. R. (2004) 'Interactions of natural hazards and society in Australia-Asia: evidence in past and recent records', *Quaternary International*, 118-119, pp. 181-203.

Singleton, A., Li, Z., Hoey, T. and Muller, J. P. (2014) 'Evaluating sub-pixel offset techniques as an alternative to D-InSAR for monitoring episodic landslide movements in vegetated terrain', *Remote Sensing of Environment*, 147, pp. 133-144.

Slob, S., Hack, H. R. G. K., Feng, Q., Röshoff, K. and Turner, A. K. (2007) 'Fracture mapping using 3D laser scanning techniques', in *Proceedings of the 11th Congress of the International Society for Rock Mechanics, Lisbon, Portugal,* Volume 1, pp. 299-302.

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

Soeters, R. and Van Westen, C. J. (1996). Slope instability recognition, analysis and zonation, Landslides, Investigation and Mitigation. Transportation Research Board, National Research Council, Special Report 247, National Academy Press, Washington D.C., U.S.A., pp. 129-177.

Squarzoni, C., Delacourt, C. and Allemand, P. (2005) 'Differential single frequency GPS monitoring of the La Valette landslide (French Alps)', *Engineering Geology*, 79(3-4), pp. 215-229.

Statnikov, A., Wang, L. and Aliferis, C. F. (2008) 'A comprehensive comparison of random forests and support vector machine for microarray-based cancer classification', *BMC Bioinformatics*, 9, 319, pp. 1-10.

Stumpf, A. (2013) Landslide recognition and monitoring with remotely sensed data from passive optical sensors, PhD Thesis, University of Strasbourg, 281 pp.

Stumpf, A., Delacourt, C. and Malet, J-P. (2015) 'Towards time-series processing of VHR satellite images for surface deformation detection and measurements', *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XL-3/W3, pp. 1-5.

Stumpf, A. and Kerle, N. (2011) 'Object-oriented mapping of landslides using random forests', *Remote Sensing of Environment*, 115, pp. 2564-2577.

Stumpf, A., Malet, J. P., Allemand, P. and Ulrich, P. (2014) 'Surface reconstruction and landslide displacement measurements with Pléiades satellite images', *ISPRS Journal of Photogrammetry and Remote Sensing*, 95, pp. 1-12.

Stumpf, A., Malet, J. P. and Delacourt, C. (2017) 'Correlation of satellite image time-series for the detection and monitoring of slow-moving landslides', *Remote Sensing of Environment*, 189, pp. 40-55.

Sun, Q., Hu, J., Zhang, L. and Ding, X. (2016) 'Towards slow-moving landslide monitoring by integrating multi-Sensor InSAR time series datasets: the Zhouqu case study, China', *Remote Sensing*, 8(11), p. 908.

Sun, W., Tian, Y., Mu, X., Zhai, J., Gao, P. and Zhao, G. (2017) 'Loess landslide inventory map based on GF-1 satellite imagery', *Remote Sensing*, 9(4), pp. 1-17.

Tagliavini, F., Mantovani, M., Marcato, G., Pasuto, A. and Silvano, S. (2007) 'Validation of landslide hazard assessment by means of GPS monitoring technique - a case study in the Dolomites (Eastern Alps, Italy)', *Natural Hazards and Earth System Sciences*, 7(1): 185-193.

Takasu, T. and Yasuda, A. (2009) 'Development of the low-cost RTK GPS receiver with the open source program package RTKLIB', *International Symposium on GPS/GNSS, International Convention Centre Jeju, Korea*, pp. 1-6.

Terranova, O. G., Gariano, S.L., Iaquinta, P. and Iovine, G. G. R. (2015) 'GASAKe: forecasting landslide activations by a genetic-algorithms-based hydrological model', *Geoscientific Model Development*, 8 (7), pp. 1955-1978.

Teshebaeva, K., Roessner, S., Echtler, H. and Motagh, M. (2015) 'ALOS/PALSAR InSAR time-series analysis for detecting very slow-moving landslides in Southern Kyrgyzstan', *Remote Sensing*, 7, pp. 8973-8994.

Thiebes, B. (2012) Landslide analysis and early warning Local and regional case study in the Swabian Alb, Germany Verfasser, PhD Thesis, University of Vienna, 295 p.

Thiebes, B. and Glade, T. (2016) 'Landslide early warning systems - fundamental concepts and innovative application', Landslides and Engineered slopes: Experience, Theory and Practice, Proceedings of the 12th International Symposium on Landslides, pp. 12-19.

Todoroff, P. and Kemp, J. (2016) Contribution of remote sensing to crop monitoring in tropical zones, Land Surface Remote Sensing in Agriculture and Forest, pp. 179-220.

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

Travelletti, J., Delacourt, C., Allemand, P., Malet, J. P., Schmittbuhl, J., Toussaint, R. and Bastard, M. (2012) 'Correlation of multi-temporal ground-based optical images for landslide monitoring: application, potential and limitations', *ISPRS Journal of Photogrammetry and Remote Sensing*, 70, pp. 39-55.

Tsai, F., Hwang, J.-H., Chen, L.-C. and Lin, T.-H. (2010) 'Post-disaster assessment of landslides in southern Taiwan after 2009 Typhoon Morakot using remote sensing and spatial analysis', *Natural Hazards and Earth System Sciences*, 10, pp. 2179-2190.

Turkish Ministry of Transport and Communications (2011) 'Transportation in Turkey - Country Report, Republic of Turkey', *Ministry of Transport and Communications*, October 2011. http://www.comcec.org/wp-content/uploads/2015/02/Turkey.pdf [Accessed on 24 September 2018].

Twigg, J. (2004) 'Disaster Risk Reduction: Mitigation and Preparedness in Development and Emergency Programming', *Humanitarian Practice Network (HPN)*.

Tzotsos, A. (2006) 'A support vector machine approach for object based image analysis', in Bridging Remote Sensing and GIS, Proceedings of the 2006 International Conference on Object-based Image Analysis, Salzburg, Austria, 4-5 July 2006.

United Nations (2006) 'Global survey in early warning systems', *International Strategy for Disaster Reduction (ISDR)*, Available online at: http://www.unisdr.org/ppew/info-resources/ewc3/Global-Survey-of-Early-Warning-Systems.pdf (Accessed 29 September 2013).

Urciuoli, G., Picarelli, L. and Leroueil, S. (2007) 'Local failure before general slope failure', *Geotechnical and Geological Engineering*, 25(1), pp. 103-122.

van Asch, Th. W. J., Malet, J.-P., van Beek, L. P. H. and Amitrano, D. (2007) 'Techniques, advances, problems and issues in numerical modelling of landslide hazard', *Bulletin de la Société Géologique de France*, 178(2), pp. 65-88.

van Beek, L. P. H. (2002) Assessment of the influence of changes in climate and land use on landslide activity in a Mediterranean environment, Netherlands Geographical Studies, 294, Utrecht, 366 p.

van Den Eeckhaut, M., Poesen, J., Verstraeten, G., Vanacker, V., Nyssen, J., Moeyersons, J., van Beek, L. P. H. and Vandekerckhove, L. (2007) 'Use of LIDAR-derived images for mapping old landslides under forest', *Earth Surface Processes and Landforms*, 32(5), pp. 754-769.

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

Vapnik, V. (1999) The nature of statistical learning theory, Springer-Verlag, 344 p.

Varnes, D. J. (1984) Landslide hazard zonation: a review of principles and practice, UNESCP Press, Paris.

Varnes, D. J. (1978) 'Slope movement types and processes', Landslides - Analysis and Control, Special Report 176, Transportation Research Board, Washington, pp. 12-33.

Vaunat, J., Leroueil, S. and Faure, R. (1994) 'Slope movements: a geotechnical perspective', in *Proceeding of 7th Congress International Association of Engineering Geology, Lisbon, Portugal. Balkema, Rotterdam*, pp. 1637-1646.

Voigt, S., Kemper, T., Riedlinger, T., Kiefl, R., Scholte, K. and Mehl, H. (2007). 'Satellite image analysis for disaster and crisis-management support', *IEEE Transactions on Geoscience and Remote Sensing*, 45(6), pp. 1520-1528.

Wang, G. (2011) 'GPS landslide monitoring: single base vs. network solutions - a case study based on the Puerto Rico and Virgin Islands permanent GPS network', *Journal of Geodetic Science*, 1(3), pp. 191-203.

Wang, G., Philips, D., Joyce, J. and Rivera, F. (2011) 'The integration of TLS and continuous GPS to study landslide deformation: a case study in Puerto Rico', *Journal of Geodetic Science,* 1(1), pp. 25-34.

Wang, G.-Q. (2012) 'Kinematics of the Cerca del Cielo, Puerto Rico landslide derived from GPS observations', *Landslides*, 9(1), pp. 117-130.

Wang, G. and Soler, T. (2012) 'OPUS for horizontal sub-centimeter accuracy landslide monitoring: Case study in Puerto Rico and Virgin Islands region', *Journal of Surveying Engineering*, 138(3), pp. 143-153.

Waske, B. and Braun, M. (2009) 'Classifier ensembles for land cover mapping using multi temporal SAR imagery', *ISPRS Journal of Photogrammetry and Remote Sensing*, 64(5), pp. 450-457.

Wasowski, J. and Bovenga, F. (2014) 'Investigating landslides and unstable slopes with satellite multi temporal interferometry: current issues and future perspectives', *Engineering Geology*, 174, pp. 103-138.

Weber, G. and Dettmering, D. (2005) 'Networked Transport of RTCM via Internet Protocol (Ntrip): IP-Streaming for Real-Time GNSS Applications', *18th International Technical Meeting of the Satellite Division of the U.S. Institute of Navigation, 13-16 September, Long Beach, CA*, pp. 2243-2247.

Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J. and Reynolds, J. M. (2012) 'Structure-from motion photogrammetry: a low-cost, effective tool for geoscience applications', *Geomorphology*, 179, pp. 300-314.

Whiteside, T. and Ahmad, W. (2005) 'A comparison of object-oriented and pixel-based classification methods for mapping land cover in Northern Australia', *Proceedings of SSC2005 Spatial Intelligence, Innovation and Praxis, The National Biennial Conference of the Spatial Sciences Institute, Melbourne*, pp. 1225-1231.

Whitworth, M., Giles, D. and Murphy, W. (2001) 'Identification of landslides in clay terrains using Airborne Thematic Mapper (ATM) multispectral imagery', *Proceedings of the 8th International Symposium on Remote Sensing, Toulouse France, Remote Sensing for Environmental Monitoring, GIS Applications and Geology*, SPIE Volume 4545.

Wieczorek, G. F. and Snyder, J. B. (2009) 'Monitoring slope movements', in *Geological Monitoring: Boulder, Colorado, Geological Society of America*, pp. 245-271.

Woodcock, C. E. and Strahler, A. H. (1987) 'The factor of scale in remote sensing', *Remote Sensing of Environment*, 21(3), pp. 311-332.

Xiao, R., He, X. and Li, L. (2012) 'Continuous monitoring of landslide and atmospheric water vapour using GPS: applications in Pubugou Hydropower

Resettlement Zone', *Proceedings of the 2012 China Satellite Navigation Conference (CSNC), Lecture Notes in Electrical Engineering*, pp. 305-313.

Xu, C., Dai, F., Xu, X. and Lee, Y. H. (2012) 'GIS-based support vector machine modelling of earthquake-triggered landslide susceptibility in the Jianjiang River watershed, China', *Geomorphology,* 145-146, pp. 70-80.

Yalcin, A., Reis, S., Aydinoglu, A. C. and 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), pp. 274-287.

Yalçinkaya, M. and Bayrak, T. (2005) 'Comparison of static, kinematic and dynamic geodetic deformation models for Kutlugün landslide in North-eastern Turkey', *Natural Hazards,* 34, pp. 91-110.

Yalçinkaya, M., Bayrak, T. and Yalçin, A. (2005) 'Modelling landslide surfaces by kinematic and dynamic surface models: a case study in North Eastern Turkey', *Survey Review*, 38(297), pp. 229-242.

Yildirim, O., Salgin, O. and Bakici, S. (2011) 'The Turkish CORS Network (TUSAGA-Aktif)', *FIG Working Week, Bridging the Gap between Cultures, Marrakech, Morocco*, pp. 1-17.

Yilmaz, S. (2011) 'A case study of the application of electrical resistivity imaging for investigation of a landslide along highway', *International Journal of the Physical Sciences*, 6(24), pp. 5843-5849.

Yin, J. H., Zhu, H. H. and Jin, W. (2008) 'Monitoring of soil nailed slopes and dams using innovative technologies', in Landslides and Engineered Slopes: From the Past to the Future, Proceedings of the 10th International Symposium on Landslides and Engineered Slopes, China, pp. 1361-1366.

Yin, Y., Zheng, W., Liu, Y., Zhang, J. and Li, X. (2010) 'Integration of GPS with InSAR to monitoring of the Jiaju landslide in Sichuan, China', *Landslides*, 7(3), pp. 359-365.

Yourdon, E. (1993) Object-oriented systems design: An integrated approach, Prentice Hall, Upper Saddle River, NJ, USA.

Zakharov, I. and Toutin, T. (2012) 'Sub-pixel image matching based on Fourier phase correlation for Radarsat-2 stereo-radargrammetry', *Canadian Journal of Remote Sensing*, 38(4), pp. 487-495.

Zhou, W., Troy, A. and Grove, M. (2008) ‘Modelling residential lawn fertilization practices: integrating high resolution remote sensing with socioeconomic data’, *Environmental Management*, 41(5), pp. 742-752.

Zhou, Y., Parsons, B., Elliott, J. R., Barisin, I. and Walker, R. T. (2015) ‘Assessing the ability of Pleiades stereo imagery to determine height changes in earthquakes: a case study for the El Mayor- Cucapah epicentral area’, *Journal of Geophysical Research: Solid Earth*, 120, pp. 8793-8808.

Zitova, B. and Flusser, J. (2003) ‘Image registration methods: a survey’, *Image and Vision Computing*, 21(11), pp. 977-1000.

Zizioli, D., Meisina, C., Bordoni, M. and Zucca, F. (2014) Rainfall-triggered shallow landslides mapping through Pleiades images, Landslide Science for a Safer Geoenvironment, Springer: Berlin, Germany, Volume 2, pp. 325-329.

Zylshal, Sulma, S., Yulianto, F., Nugroho, J. T. and Sofan, P. (2016) ‘A support vector machine object based image analysis approach on urban green space extraction using Pleiades-1A imagery’, *Modelling Earth Systems and Environment*, 2(54), pp. 1-12.