THREE-DIMENSIONAL MOVEMENT OF LANDSLIDE USING MOBILE LASER SCANNING TECHNIQUE

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DEDICATION

First of all,

Alhamdulillah and thank you ALLAH S.W.T.

To my beloved parents,

AHMAD FUAD MD IDRIS & HINDUN SALLEH

Thank you so much, Abah & Mak for the infinite moral and financial support.

To my lovely brother and sister,

MUHAMMAD RIDHWAN & NURFAZLINA

Let us be good daughters & son that our parents will be proud of.

To my little niece and nephews,

ALYA, AIMAN, IRFAN & IMRAN

Thank you for always blessing my life with your laughter and cuteness.

To my lovely husband,

ANUAR ARSYAD

Thank you for always being by my side through all the ups and downs.

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ABSTRACT

Landslide is one of the natural disasters which occurs after a flood when the land, rocks and earth debris could no longer be held together. As such, landslides should be monitored periodically to prevent damage and loss of human life. Various technologies can be used to monitor the occurrence of landslides. Recently, geoinformation technology provides a surface-based approach using the Mobile Laser Scanning (MLS) methods. MLS is able to provide fast and accurate data acquisition of the landslide surface. Steep slope conditions at the area of study has caused a limitation for the vehicle-based MLS to cover flat areas. Nevertheless, with a combination of human-based approach MLS have helped in completing the point cloud data of the study area. Besides, using Geographic Information System (GIS) spatial analysis methods has also provided better visualization on the movement at landslide area. Thus, the aim of this study is to investigate landslide surface movement area using MLS and GIS spatial analysis methods. The methodology of this study began with the research planning and later the MLS survey was conducted which involved the use of vehicle and human-based data acquisition approach and the total station survey for the three-dimensional (3D) target measurement. Then, the MLS data went through the point cloud registration methods involving four types of cloud-to-cloud (C2C) distance computation methods. Finally, it was determined that the Iterative Closest Point (ICP) was the best registration method and the least square plane as the best C2C distance computation methods for calculating the difference between the clouds. The results from total station survey showed that the area nearest to the target labelled BW110 had greater movement that affected the fractures at the top of the slope area. Surface deviation analysis carried out using CloudCompare software showed that the movement had happened at the same area which was similar to results obtained from the visualization analysis using GIS software. The comparison analysis of MLS output with Unmanned Aerial Vehicle (UAV) photogrammetric data also showed similar movement at the same area. The MLS data was then evaluated using 3D coordinate of measurement targets obtained from total station survey and it achieved a Root Mean Square Error (RMSE) value of about ± 0.639 meter. Through the generation of several landslide movement maps using MLS data, showed there were movements which occurred at the area of study within a period of one month. This proved that the surface deviation analysis and visualization analysis was able to detect the movement of landslides. More significantly, the combination of MLS technology with GIS spatial analysis method were capable in providing useful landslide information and monitoring.

ABSTRAK

Tanah runtuh merupakan salah satu bencana alam yang terjadi setelah banjir apabila tanah, batu dan serpihan bumi tidak dapat lagi menampung antara satu sama lain. Oleh itu, tanah runtuh perlu dipantau secara berkala untuk mengelakkan kerosakan dan korban jiwa. Pelbagai teknologi dapat digunakan untuk memantau tanah runtuh. Baru-baru ini, teknologi geoinformasi memberikan pendekatan berasaskan permukaan menggunakan kaedah imbasan laser mudah alih (MLS). MLS mampu memberikan pemerolehan data yang cepat dan tepat bagi permukaan tanah runtuh. Keadaan cerun yang curam di kawasan kajian menyebabkan batasan bagi MLS berasaskan kenderaan untuk peroleh data di kawasan tanah rata. Namun begitu, dengan gabungan pendekatan MLS berasaskan teknik manusia telah membantu melengkapkan data titik awan di kawasan kajian. Selain itu, penggunaan kaedah analisis Sistem Maklumat Geografi (GIS) juga memberikan visualisasi yang lebih baik mengenai pergerakan di kawasan tanah runtuh. Oleh itu, tujuan kajian ini dijalankan adalah untuk mengkaji kawasan pergerakan permukaan tanah runtuh menggunakan kaedah MLS dan kaedah analisis spasial GIS. Metodologi kajian ini dimulakan dengan perancangan penyelidikan dan seterusnya tinjauan MLS dilakukan dengan menggunakan pendekatan pemerolehan data berdasarkan kenderaan dan manusia serta kerja lapangan untuk pengukuran keseluruhan sasaran tiga dimensi (3D). Kemudian, data MLS diperoleh melalui kaedah pendaftaran titik awan yang melibatkan empat jenis kaedah pengiraan jarak antara titik awan. Akhirnya, terbukti bahawa Titik Lelaran Terdekat (ICP) adalah kaedah pendafttaran titik awan terbaik dan satah kuasa dua terkecil adalah kaedah pengiraan jarak antara titik awan yang terbaik untuk mengira perbezaan antara awan. Hasil daripada ukur stesen penuh menunjukkan bahawa kawasan yang berdekatan dengan BW110 mempunyai pergerakan yang lebih besar yang mempengaruhi keretakan di bahagian cerun. Analisis sisihan permukaan tanah runtuh dilakukan dengan menggunakan perisian CloudCompare dan analisis visualisasi menggunakan GIS juga menunjukkan pergerakan berlaku di tempat yang sama. Analisis perbandingan bagi data MLS dengan data fotogrametri pesawat udara tanpa pemandu (UAV) juga menunjukkan hasil pergerakan di tempat yang sama. Data MLS kemudiannya dinilai menggunakan koordinat sasaran 3D yang diperolehi daripada ukur stesen penuh dan mencapai nilai ralat punca min kuasa dua (RMSE) sebanyak ± 0.639 meter. Melalui penghasilan beberapa peta pergerakan tanah runtuh menggunakan data MLS menunjukkan bahawa terdapat pergerakan yang berlaku di tempat kajian dalam tempoh sebulan. Ini membuktikan bahawa analisis sisihan permukaan dan analisis visualisasi dapat mengesan pergerakan tanah runtuh. Secara signifikan, gabungan teknologi MLS dengan kaedah analisis spasial GIS mampu memberi maklumat yang berguna dan pemantauan tanah runtuh.

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LIST OF ABBREVIATIONS

GPS	-	Global Positioning System
MLS	-	Mobile Laser Scanning
GIS	-	Geographic Information System
2D	-	2-Dimensional
3D	-	3-Dimensional
4D	-	4-Dimensional
JMG	-	Mineral and Geoscience Department
ARSM	-	Malaysia Remote Sensing Agency
JKR	-	Public Works Department
JPS	-	Department of Irrigation and Drainage
DoE	-	Department of Environment
EDM	-	Electronic Distance Measurement
LPIS	-	Land Parcel Information Systems
LiDAR	-	Light, Detection and Ranging
TLS	-	Terrestrial Laser Scanning
ALS	-	Airborne Laser Scanning
DTM	-	Digital Terrain Model
TS	-	Total Station
ASCII	-	American Standard Code for Information Interchange
USGS	-	United State Geological Survey
DGPS	-	Differential Global Positioning System
RTK	-	Real Time Kinematic
LS	-	Laser Scanning
GNSS	-	Global Navigation Satellite System
TOF	-	Time of Flight
DEM	-	Digital Elevation Model
MMS	-	Mobile Mapping System
LSZ	-	Landslide Susceptibility Zonation
ROC	-	Receiver Operating Characteristics
TIN	-	Triangulated Irregular Network

DSM	-	Digital Surface Model
GCPs	-	Ground Control Points
SGPT	-	Sungai Petani
USMP	-	USM Penang
BABH	-	Bandar Baharu
BAYO	-	Bayo
JUPEM	-	Department of Surveying and Mapping Malaysia
CP	-	Control Point
IMU	-	Inertial Measurement Unit
INS	-	Inertial Navigation System
AL3	-	Airborne LiDAR 3
TBC	-	Trimble Business Center
ENZI	-	Easting, Northing, Elevation and Intensity
MDL	-	Microstation Development Language
ATIN	-	Adaptive Triangulated Irregular Network
RMSE	-	Root Mean Square Error
MAE	-	Mean Absolute Error
MBE	-	Mean Bias Error
MBBC	-	Match Bounding-Box Centers
ICP	-	Iterative Closest Point
RMS	-	Root Mean Square
C2C	-	Cloud to Cloud
UAV	-	Unmanned Aerial Vehicle
SfM	-	Structure from Motion
DJI	-	Da-Jiang Innovations
BW	-	Black and White Target
RMS	-	Root Mean Square

LIST OF SYMBOLS

%	-	Percentage
km	-	Kilometer
h	-	Hour
kn	-	kilonot
cm	-	centimeter
V	-	Voltage
atan	-	Arc Tangent
mm	-	Millimeter
m	-	Meter
W	-	Watt
kg	-	Kilogram
nm	-	Nanometer
ppm	-	Parts per million
Cos	-	Cosine
Sin	-	Sine
g	-	Gram
fps	-	Frames Per Second
mAh	-	Mili Ampere Hour
m/s	-	Meter Per Second
n	-	Number of Target Points
Z_{MLS_i}	-	Elevation values obtained from MLS data
Z_{Ground_i}	-	Elevation values obtained from total station

CHAPTER 1

INTRODUCTION

1.1 Research Background

Landslide is one of the natural disasters that have a great impact on the population, socio-economic in Malaysia and is the cause of loss of human life and property (Ismail Elmahdy Samy *et al.,* 2014). The government or private sector are forced to withstand the losses and damage caused by landslide either in direct or indirect ways (Council, 1999). In fact, the landslide incident can also lead to death if landslide occurred at large scale at the housing and road area (Martire *et al.*, 2012). Malaysia is exposed to the equatorial climate which features a hot and humid climate throughout the year and is also affected by flood which is one of the main factors for the occurrence of landslides (Chan, 2015). Landslides are a common occurrence in Malaysia particularly during the rainy season or monsoon which contribute to high rainfall rates of up to 4500 mm per year (Mohamed Shaluf and Ahmadun, 2006).

According to a report dated November 5, 2017 by National Weather Centre, the Malaysian Meteorological Department (MetMalaysia), the rain that occurred on November 4 and 5, 2017 in the northern Peninsula of Malaysia was very heavy and caused a flood. Affected areas included Bayan Baru, Sungai Pinang, Balik Pulau, Batu Feringghi, Bayan Lepas and several areas in Seberang Prai. All these areas are located in the state of Penang. According to this report, heavy rain accompanied by strong winds caused floods in almost all areas and some areas experienced severe soil erosion. This phenomenon proves that high temperatures and humidity can cause changes to the soil texture and also weaken the soil structure that can lead to landslides.

However, most residents are not cautious and concerned about the sensitivity of hillside areas that are always vulnerable to landslides (Lin *et al.*, 2017). In Malaysia, for example, in Hulu Klang, Selangor, landslides occurred in urban areas caused by development works carried out on hillside areas (Farisham, 2007). According to Weng Chan (1998), the effects of rapid development leading to landslides have caused changes and disruption of physical systems such as hydrological cycle modification due to urbanization, housing development in hillside and deforestation.

In Malaysia, organizations that are often involved in landslide management are the Mineral and Geoscience Department (JMG), the Malaysia Remote Sensing Agency (ARSM), the Public Works Department (JKR), the Department of Irrigation and Drainage (JPS) and the Department of Environment (DoE). These organizations are involved in mitigation and detailed preparation to deal with the possibility of landslides. In order to establish cooperation among the above organizations in addressing the complicated landslide problem, an easy model known as the Collaborative Disaster Management System (Almohaifer *et al*.) has been developed. This system has proven to be an effective way to collaborate in terms of sharing information through a digital information system approach helping to disseminate and provide information related to forecasts of landslides.

Apart from the landslide information system, there are many methods used to monitor landslide events. According to Liu and Wang (2008) there are three basic types of monitoring that can be used, namely instruments, measurements and visuals. Instrumentation involves the installation of equipment for periodic reading, which is intended for continuous data collection including piezometric groundwater measurements and inclinometers. Measurement approach involves physical measurements to detect surface movements in unstable area. The surveying equipment such as theodolites, levels, total station and electronic distance measurement (EDM) can be used to measure the coordinates of the control points that will provide data regarding the movement of the ground. Meanwhile, visual monitoring methods involve the use of notes or pictures. Some aerial pictures are also used as it is one of the most effective ways to monitor landslides by using soil samples and visual inspection in the field. This study also mentioned using aerial photogrammetry to obtain coordinates of point of interest, to generate contour map and to get the cross-section plan of landslides. In addition, it helps to perform quantitative analysis of the slope morphology and to determine landslide movement vectors.

With the increase of the current economic magnitude, there is a need to find the best, fastest and most effective way to monitor landslides (Chae *et al.*, 2017). Issues about landslides can be solved in a more significant way as many professional and scientific fields have been influenced by the development of new technologies that facilitate their use and are acceptable (Scaioni, 2015). According to Babić *et al*, (2012) one of the measurement methods exposed to this technology change is geodesy. This is because the paradigm of geodesy been significantly changed by the possibility of free access of satellite imagery, publicly access databases, low-cost GPS devices and free connection to site information such as Land Parcel Information Systems (LPIS). In addition, the transition of spatial information from 2D to 3D or even 4D, by introducing the new laser scanning technologies in landslide study also give effects to the changes related to geodesy (Babić *et al.*, 2012).

Light Detection and Ranging (LiDAR) technology such as Terrestrial Laser Scanning (TLS) (Barbarella *et al.*, 2015) and Airborne Laser Scanning (ALS) (Stumpf *et al.*, 2015) were currently used in the monitoring of landslide phenomena (Joyce *et al.*, 2014). The latest technology in LiDAR, that can be used to monitor landslide is Mobile Laser Scanning (MLS) (Lindenbergh and Pietrzyk, 2015). MLS provides fast, accurate, cost effective, data completeness and is very efficient in collecting landslide data which also can reduce the time consumption required by conventional methods (El-Sheimy, 2005). MLS is a technique (Szulwic and Tysiąc, 2017) where mobile platform has been used to capture and as a source of geospatial data (Szulwic *et al.*, 2015).

The MLS method becomes complementary to the LiDAR data captured using the airborne and terrestrial laser scanning methods in terms of data completeness and level of details (Kukko, 2013). The MLS system can be installed on moving platform such as bicycles (Blankenau *et al.*, 2018), cars, trolleys for railways (Yang and Fang, 2014) and boats (Vaaja *et al.*, 2013). It is very flexible in capturing spatial data while driving or crossing the path (Xiao *et al.*, 2016). This method also provides accurate (at survey grade accuracy) and geo-referenced 3D data (Guan *et al.*, 2016). The data gained from MLS system can be processed using GIS software and various types of spatial analysis methods can be carried out for mapping and monitoring of landslide phenomena (Puente *et al.*, 2013).

In addition, geospatial technology has begun to play an important role in the in-depth study of recent landslide occurrence. Geographic Information Systems (GIS) has become the most useful tools to speed up the processing stage and is capable of dealing with large amounts of data regarding the landslide assessment (Feizizadeh and Blaschke, 2011), landslide monitoring (Huang *et al.*, 2016), hazard awareness (Li and Li, 2012), and susceptibility mapping (Feizizadeh *et al.*, 2011). In addition, various types of methods in GIS have been used to model the landslide and produced the landslide zone map (Matori *et al.*, 2012) including the generation of Digital Terrain Model (DTM) (Razak *et al.*, 2013).

Hence, the combination of GIS and laser scanning technologies in landslide monitoring application provide more advantages especially to prepare for early warning of the triggered landslide (Xu, 2015). Both technologies make all information regarding landslide hazard assessment easier to access, giving more accurate and high-resolution data including landslide early risk awareness. Accurate landslide data and early detection warning system are the most important information especially to public and government sectors at local and international levels (Shahabi and Hashim, 2015).

1.2 Problem Statement

Recently, Malaysia has experienced rapid population growth and hence the rapid development of residential areas. This situation will encourage housing developers to build residences in new areas and hilly terrain areas (Salleh *et al.*, 2015). However, development activities in hilly terrain will cause slope instability that will cause landslide tragedy if the area is not seriously monitored (Huat and Ali, 2012).

Generally, landslides are often associated with negative impacts that not only lead to property damage but also loss of human life (Alimohammadlou *et al.*, 2013). Therefore, the on-going study of this phenomenon is very important in reducing the negative impacts especially on human life. In this modern age, the availability of the latest technology such as LiDAR has been introduced to solve the problem of landslide occurrence (Guzzetti *et al.*, 2012).

Landslides are one of the most serious issues that need to be addressed and these problems need to be dealt with immediately before it gets worse (Jayasingha, 2016). It is very important to periodically monitor the activities of landslides (Skrzypczak *et al.*, 2017). If there is a possibility of occurrence of landslides, the party responsible for addressing this problem should immediately take appropriate remedial action (Lateh and Govindasamy, 2012). To overcome this problem, the data relating to landslide events must be collected accurately and efficiently (Santangelo *et al.*, 2015).

In the early 1990s, the landslide mapping and monitoring works were carried out using traditional survey methods (Gili *et al.*, 2000). The surveying instrumentations such as total stations and levelling were used to acquire spatial data from the ground while aerial photogrammetry was used to acquire data from airborne space. In the new revolution, Global Positioning System (GPS) was applied for ground survey while Airborne Laser Scanning (ALS) has become a popular technology for digital surface mapping from airborne space. In 2000s, the Terrestrial Laser Scanning (TLS) technology was introduced for ground surveying. In modern era, LiDAR technology introduced another laser-based surveying technology known as Mobile Laser Scanning (MLS) in order to fill the gap between traditional surveying method, TLS and ALS (Botes and Geomatics, 2013).

The advanced technology in Geographic Information System (GIS) provides more satisfying spatial analysis and the results can be used for better decision-making process in many applications. The spatial analysis tools in GIS are very useful in terms of collecting, visualizing, storing, manipulating, displaying as well as analysing all factors that are involved in landslide activities. In addition, GIS can handle large amount of spatial data rapidly and in more effective ways due to many landslide data layers that need to be overlaid together for spatial analysis purposes.

In this study, the occurrence of landslides is related to the type of slope of the area. There are two types of slope that are exposed to landslide occurrence, which are steep slope and composite slope (Tang *et al.*, 2015). By using a vehicle-based MLS, the scanning process of steep slope can be done perfectly as shown in Figure 1.1. Vehicle-based MLS requires special tracks (road, highway, rails and etc.) to run the vehicle for data collection purposes. With this limitation, an engine-based MLS is always faced with the problem of the scanning process of composite slope where there are areas that are not exposed to laser reflections as shown in Figure 1.2.

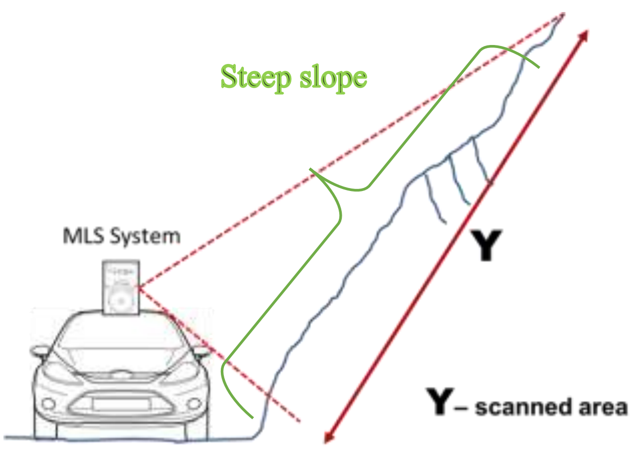

Figure 1.1 Limitation of Mobile Laser Scanning (MLS) data collection – scanning of the *steep slopes* area

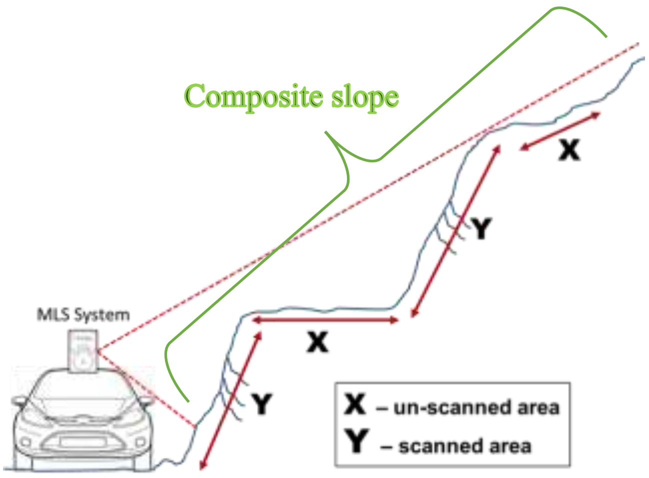

Figure 1.2 Limitation of Mobile Laser Scanning (MLS) data collection – scanning of *composite slope* area

Therefore, this study was carried out to solve those problems by introducing the human-based MLS in order to scan the un-scanned composite slope area. Both vehicle-based and human-based MLS scanned data were integrated using a specific data merging method, which was then used to detect the landslide movement. The combination of these two types of data acquisition approach in monitoring is very important for the landslide data completeness as well as to provide a better understanding, which is of great help within the landslide area in terms of kinematics and failure mechanism (Jaboyedoff *et al.*, 2012).

Hence, this research was carried out using MLS technology by applying the vehicle-based and human-based method of scanning as to monitor the movement of an active landslide area at Kulim Hi-Tech Local Authority, Kedah. The MLS data was acquired in two epochs which is within one month interval. The research also evaluated the capability of MLS technology in rapid data acquisition of landslide area. The two epochs of MLS data at first was registered in order to align both data using several registration methods before carried out the surface deviation analysis between the clouds. In this study, two types of registration methods such as match bounding-box centers (MBBC) and iterative closest point (ICP) were used to prove which one is the best registration methods to be used for landslide surface movement detection. Besides, several local surface model methods also been used in this study in order to register the clouds as accurate as possible (Oniga *et al.*, 2016) for a better surface deviation analysis result.

Apart from that, this research was also carried out using Total Station (TS) survey in order to get the three-dimensional (3D) coordinates of the well distributed target points setup on the ground. Also, landslide study using Mobile Laser Scanning is still new and not yet widespread in Malaysia. Thus, by comparing data obtained from MLS and TS using several analysis tools in GIS will help to prove the capabilities of MLS and to help in making a good decision for landslide hazard awareness.

1.3 Research Aim

The aim of this research is to investigate landslide surface movement area using mobile laser scanning (MLS) and GIS spatial analysis methods.

1.4 Research Objectives

The objectives of the research are:

1. To define and identify the suitable approach used by mobile laser scanning (MLS) to acquire uncovered area of the landslide surface.
2. To produce landslide movement maps and analyze the movement of the landslide surface area from the vehicle and human-based mobile laser scanning (MLS) data using three-dimensional surface deviation and GIS spatial analysis methods.
3. To evaluate the accuracy of the landslide surface movement from the mobile laser scanning data using ground surveying technique.

1.5 Research Questions

The research questions that will be solved in the study are listed in Table 1.1.

Table 1.1 Research questions related to the study

Research Aim	Research Objectives	Research Questions
To investigate landslide surface and movement using mobile laser	To define and identify the suitable approach used by mobile laser scanning to	How does MLS system acquire three-dimensional

scanning (MLS) and GIS spatial analysis methods.	acquire uncovered area of the landslide surface.	data of the landslide surface? What is the approach used by MLS to acquire un-covered area of the landslide surface?
	To produce landslide movement maps and analyse the movement of the landslide area from the vehicle and human-based mobile laser scanning (MLS) data using three-dimensional surface deviation and GIS spatial analysis methods.	How can landslide movement maps be generated using GIS spatial analysis methods? What are the types of movement maps that can be produced using vehicle and human-based MLS data? What are the most suitable three-dimensional surface deviation techniques to be used to detect the movement of the landslide surface area? What is the most suitable GIS spatial analysis technique to be used to detect the movement of the landslide surface?

	To evaluate the accuracy of the landslide surface movement from the mobile laser scanning data using ground surveying technique.	How can the accuracy of MLS landslide movement output be evaluated with the output from ground surveying technique? What is the most effective statistical technique to be used in the comparison analysis of both MLS and ground surveying landslide movement outputs?

1.6 Research Scopes

The scopes of the research are divided into several sections which are study area, software and equipment.

1.6.1 Study Area

The study area (Figure 1.3) is located at Kulim district in the state of Kedah, Malaysia. This area is managed by the Kulim Hi-Tech Local Authority which currently running an investigation into several complaints that have been made by the residents of Taman Haruan due to the land slip cases. The size of the study area is 3600 m^2 (90m x 40m) with an area gradient of 50 degrees (°). Most of the areas are covered by grass and the height of the slope is about 15 meters. Figure 1.4 shows the image view of study area.