

**ADDIS ABABA UNIVERSITY**  
**SCHOOL OF GRADUATE STUDIES**  
**SCHOOL OF EARTH SCIENCES**



**Integrated geological and geophysical studies to investigate the landslide zones and study its impact: a case along the road section within Kurar Kebele, Dejen woreda, Central Ethiopia**

**A Thesis Submitted to School of Graduate Studies of Addis Ababa University**  
***In partial fulfillment of the requirements for the Degree of Masters of Sciences***  
***(Environmental Geology and Geo-hazard)***

**By: Tesfaye Chala**

**ADDIS ABABA UNIVERSITY**

**Addis Ababa Ethiopia**

**June 2017**

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This is to certify that the thesis prepared by Tesfaye Chala entitled: “**Integrated geological and geophysical studies to investigate the landslide zones and study its impact: a case along the road section within Kurar Kebele, Dejen woreda, Central Ethiopia**” and submitted in partial fulfillment of the requirements for the Degree of Master of Science (*Environmental Geology and Geo-hazard*) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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## **ABSTRACT**

### **Integrated geological and geophysical studies to investigate the landslide zones and study its impact: a case along the road section within Kurar Kebele, Dejen woreda, Central Ethiopia**

**Tesfaye Chala Korma**

Addis Ababa University

The current integrated geological and geophysical investigations were conducted in Kurar Kebele of Dejen Wereda, Central Ethiopia, to map the subsurface geological features, delineate and characterize the landslide affected sections and generate inputs assisting to recommend possible mitigation measures. To deal with this problem electrical resistivity sounding, seismic refraction methods were applied along with geological mapping and assessment of landslide prone areas. The study results revealed three layers with distinct physical characteristics, particularly electrical resistivity and density. The uppermost colluvial deposit is characterized by relatively enhanced resistivity values with slightly wide ranges (17-95  $\Omega$ -m) reflecting its heterogeneous nature in terms of grain size, moisture content and degree of compaction. This resistive layer is underlain by a very conductive and relatively impermeable bed (layer) composed of silt, clay and marl. From its resistivity responses this layer is inferred to contain considerable amount of moisture content /fluid. Compared to the second, the third layer is resistive and is attributed to weathered and fractured limestone.

Geological mapping and remote sensing data analyses (raster calculation) indicated that in this area about 83% of the landslides occurrences are associated with the upper unconsolidated talus materials (colluvial deposits) and only 17% with the limestone. Such phenomena are encountered over landforms characterized by slope angles (gradient) ranging from  $10^{\circ}$  to  $45^{\circ}$  and wherever occurred they caused huge damages on infrastructures and natural environment, including farm lands and immensely affected the socio economic conditions. Rainfall intensity and distribution that recharges the ground as well as human activity (poor land use practices, deforestation, and excavation) are found to be the major triggering factors that slope instabilities with subsequent mass movements. Rotational slides and debris slide are the common manifestations triggered by rain fall.

**Key words:** landslide, natural environment, rotational slide, debris slide

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## **Acronyms**

DEM - Digital Elevation Model

GSE - Geological Survey of Ethiopia

GPS - Global Position System

Bh - Borehole

NS - North-South

NE - North-East

SW - South-West

VES - Vertical Electrical Soundings

UTM – Universal Transverse Mercator

## CHAPTER ONE

### 1. INTRODUCTION

#### 1.1 Background of the study

Landslide is one of the most destructive natural hazards that cause different level of injuries, life loss as well as damages on built and natural environment (Pan et al., 2008; Kanungo et al., 2006). In the Ethiopian highland landslide-generated hazards have claimed about 300 lives, damaged over 500 km asphalt road, 200 homes and devastated in excess of 500 hectares of agricultural land farm, including in the Abay Gorge (Lulseged Ayalew, 1999).

Landslides have widespread distribution in Ethiopia and result in different hazard level and extents often they occur in hilly and mountainous terrains and they were triggered by different influencing factors, such as rugged morphology, physically weak lithologies, very scarce land cover (barren land), poor land use practices and wide distribution of surface and groundwater associated with seasonal floods (Kifle Woldearegay, 2013 and Bekele Abebe et al, 2010). As a consequence in many parts of Ethiopian highlands landslide-induced hazards are the most destructive natural phenomena that cause property damages, including failures of engineering structures, human sufferings, environmental degradation and loss of fertile agricultural farm lands (Lulseged Ayalew, 1999, kifle Woldearegay, 2013, Tenalem Ayenew and Giulio Barbieri, 2005, Lulseged Ayalew and Hiromitsu Yamagishi, 2004 and Lulseged Ayalew 2000).

The present study area is located in Abay Gorge, just on the way between Gohatsion and Dejen, just within the road section of Kurar Kebele, Dejen Wereda, Central Ethiopia. Mesozoic sandstone, gypsum, limestone and overlain by Tertiary basalt cover the area (Getaneh Assefa, 1991). The outcropped lithologies of the area are highly weathered limestone interbedded with soft rocks silt, shale and marls (Getaneh Assefa, 1991). Meanwhile, the colluvial deposits are overlying the clay and shale, which are practically impermeable.

In order to minimize threats and/or damages due to landslides and thereby safeguard life and property losses from imminent geo-hazard events, it is critically essential to identify and in

detail investigate the affected areas so as to acquire adequate knowledge that helps to develop and implement appropriate mitigation measures (Anbalagan, 1992).

Therefore, this research is attempted to map the subsurface conditions of the landslide affected area around Kurar Kebele of Dejen Woreda and forward possible mitigation measure that may help to alleviate the observed problem.

## **1.2 Description of the study area**

### **1.2.1 Location and Accessibility**

The research area is situated within the Abay Gorge, in Kurar Kebele, Dejen Woreda of East Gojam Zone, Central Ethiopia. It is about 215 km from Addis Ababa, at the 27<sup>th</sup> km mark from Gohatsion town and can be accessed through the Addis Ababa-Gohatsion-Dejen asphalt road. Geographically, it is bounded in between UTM coordinates 406,600-409,000m Easting and 1,120,400-1,116,000m Northing, and has a total areal coverage of about 6.2 km<sup>2</sup> (Figure 1.1). Due to difficult terrain conditions, most of the traverses were made following foot paths and landforms with gentle slopes.

According to National Meteorological Agency the climate of the present area is considered as Subtropical (Weyna-dega) with average mean annual rainfall 1128.05 mm to 1062.28 mm (Annex II). Rainfall plays a great role in increases of groundwater, moisture content and initiate landslides phenomenon in the area which has thick colluvial underlies by soft geological material (Lulseged Ayalew and Yamagishi, 2004).

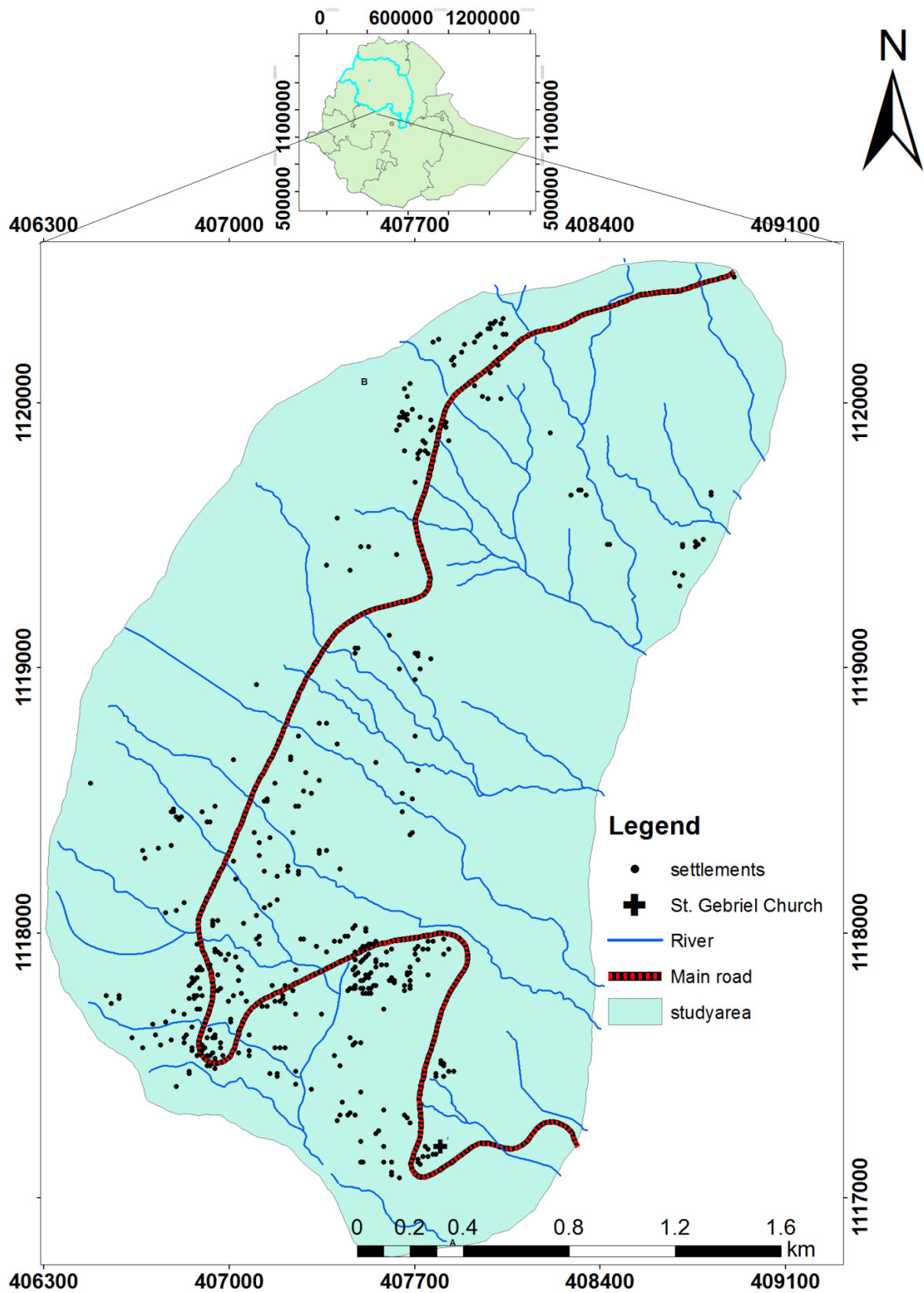


Figure 1. 1 Location map of the study area

### 1.2.2 Physiography

The study area is characterized by undulated landform with elevation ranging from 1700 to 2550m above sea level. The topographical features are represented by valleys, flat area and cliff with slope gradient varying from gentle to steep slope. The gentle and flat lands are densely populated and cultivated mainly by maize, teff and sorghum. Some parts of the area are also covered by bushes and the rest is a barren land. Uncontrolled drainage pattern and flood erode toes of unstable slopes and thereby facilitates the sliding process. The topographic map of the area produced from 30m resolution DEM data is presented in Figure 1.2.

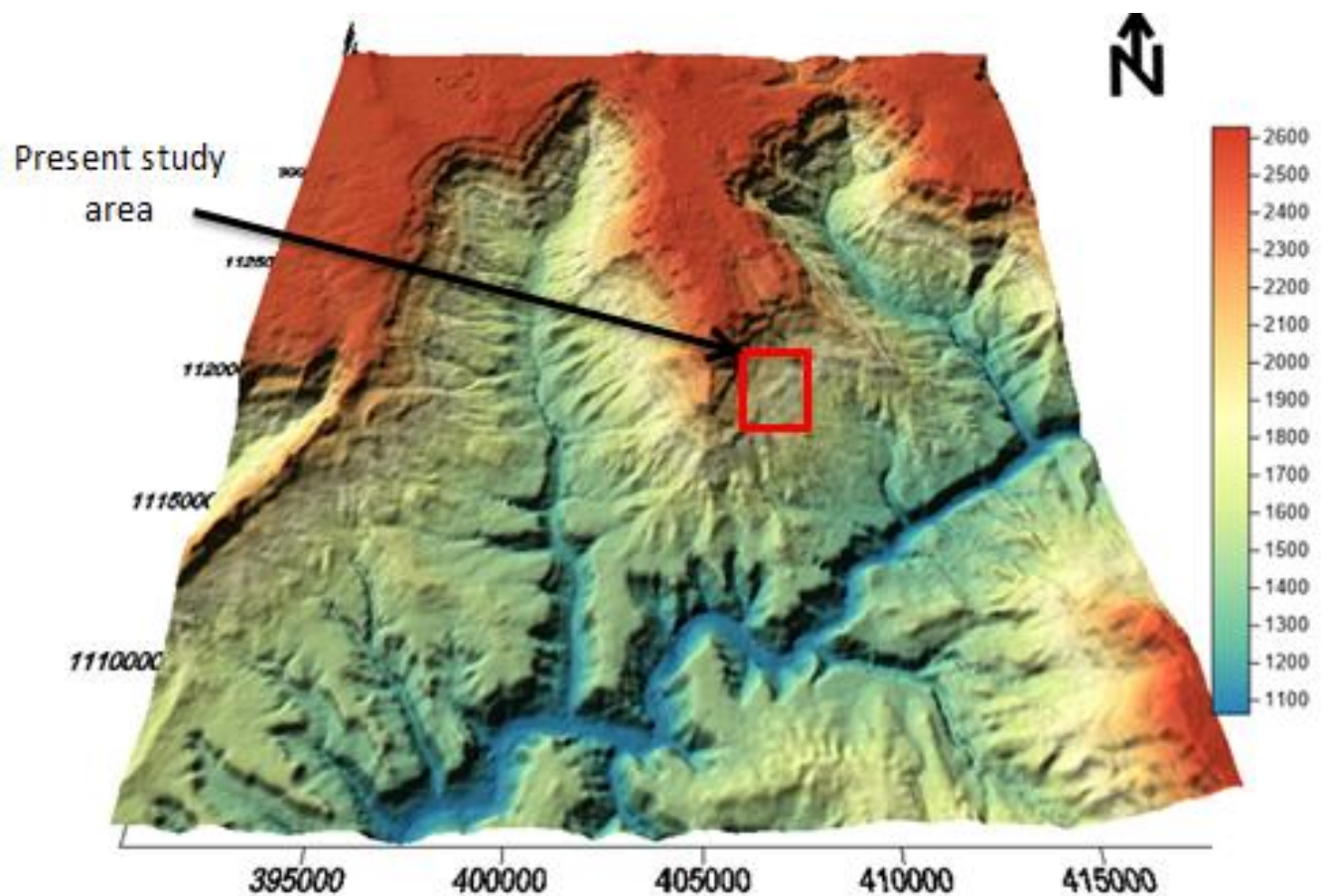


Figure 1. 2 Physiography of study area

### **1.3 Problem statement**

Landslide-generated hazard is one of the major geo-environmental problems that cause considerable damages on built infrastructures and natural environment. It endangers the wellbeing of the society, particularly the local peoples living near the toe of steep slopes prone to active land. Many active landslides exist along road section and surrounding with different level and mode of failure (Lulseged Ayelew, 1999 and GSE, 2010). Often landslides occurred during rainy season, from mid-July to August.

Currently in this area landslide-generated problems are becoming serious concerns to local people and administration as well as federal government bodies (Figure1.3). The frequent damage of the road and other social utilities has significantly increased maintenance costs. Besides, wastage of fertile farm lands make local people's life very difficult, even unbearable though due to lack of alternative they still live and continued farming in highly landslide-susceptible slopes. Hence, adequate understanding of the locations, extents, and landslide triggering / aggravating factors is essential to develop mitigation measures that contribute to safeguard human life and built sustainable engineering structures.



Figure 1.3 Field photos illustrating landslide problem a) completely damaged road; b) damaged grass land and soil; c) destructive agricultural land with sorghum and d) completely damaged local home

## **1.4 Research Objectives**

### **1.4.1 General objectives**

The main objective of this research was to investigate the landslide-affected zone and determine the extent and causes that pose risk to the natural environment and the road connecting NW Ethiopia with Central part.

### **1.4.2 Specific objectives**

- Map the subsurface geological features within the study area, delineate vertical/lateral extents of landslide affected section and investigate their physical characteristics;
- Determine possible slip surface and the mechanism of slope failures;
- Identify the critical section with instability and stability condition along selected road section;
- Assess the impact of land slide on infrastructures and natural environment and built infrastructures.

## **1.5 Significance of the study**

The present study can help to:

- ❖ upgrade the information and better awareness on landslide impacts, particularly rural peoples who live near to the toe of the hill slopes;
- ❖ provide information that help to disseminate early hazard warnings and thereby reduce casualties (deaths & injuries), suffering and natural environmental destruction;
- ❖ acquire tangible data/information that demonstrate how human activities can facilitate and increases landslide hazard and based on which it will be possible to educate them on how to minimize the socio-economic loss and natural environment damage due to the landslide in the area;
- ❖ obtain data and develop possible recommendations to reduce the impact of landslide;

## **1.6 Beneficiaries**

This research will be useful for local and Federal Government bodies, civil engineers, consultants, contractors, who are involved in budget allocation, designing/developing civil

engineering structures, their implementation and supervision. The cumulative efforts of these bodies will play a decisive role to maintain the road's functionality. Moreover, this study will provide inputs to environmental conservationists and add valuable information for researcher who works in the same geological formation. Finally, the successful implementation of the research outputs will make the local communities in the surrounding areas beneficiary through realization of stable environment.

## **1.7 Research Methods**

The research method includes activities that take place both in office (desk work) and field to achieve the mentioned objectives. To achieve this, the research is planned to be executed in three separate phases: Desk study (pre-field work), fieldwork and post-field work.

**Pre-field works:** were started from review the literature relevant to the title and collection of relevant data from different source which support the present study. Collection of high resolution (5m) Spot and Landsat 15m resolution of satellite image, topographic map of scale 1:50000 to determine surface features, land use and land cover and topographic condition. Preparation morphological map (slope gradient and elevation map) from topographic and DEM, slope material from previous work and land use and land cover produced from satellite image to delineate general overview of study area.

Results of eleven (11) borehole log data has been used to define the subsurface lithological condition, moisture content of material, and thickness of sliding mass, grain size of material to depth and down the slope of different borehole depth of 25 - 40m. For clear understood the general subsurface condition, geological cross section has been prepared based on the thickness of sliding mass that were overlies to the depth.

Mean annual rainfall has been collected to determine effect of rainfall on slope such toe erosion, modifies drainage.

Table 1 Borehole log data of different depth

No.	Easting	Northing	Elevation	BH-log name	BH-depth
1	407860	1117336	1722	BH 27-11	25
2	407892	1117895	1772	BH 28-21	25
3	407916	1117969	1778	BH 28-31	25
4	407922	1117948	1777	BH 28-32	40
5	407852	1117751	1762	BH 28-11	25
6	407979	1117351	1709	BH 27-12	25
7	407793	1117327	1734	BH 27-21	25
8	407829	1117318	1733	BH 27-22	25
9	407845	1117290	1723	BH 27-23	25
10	408239	1117151	1661	BH 26-21	25
11	407715	1117334	1746	BH 27-09	40

(Source: GSE)

**Field work:** has been conducted to generate primary data using different geophysical techniques. The specific methods employed electrical resistivity and seismic refraction has been conducted to study the general subsurface condition of the landslide affected area and to determine possible slip surface, thickness of sliding mass, extent, depth to weak zone or layer that are related to landslide problem along the critical selected road section.

Post-Field Work - Data processing using different softwares and tools and interpretation, thesis compilation and presented by graph, map, model curve and tables.

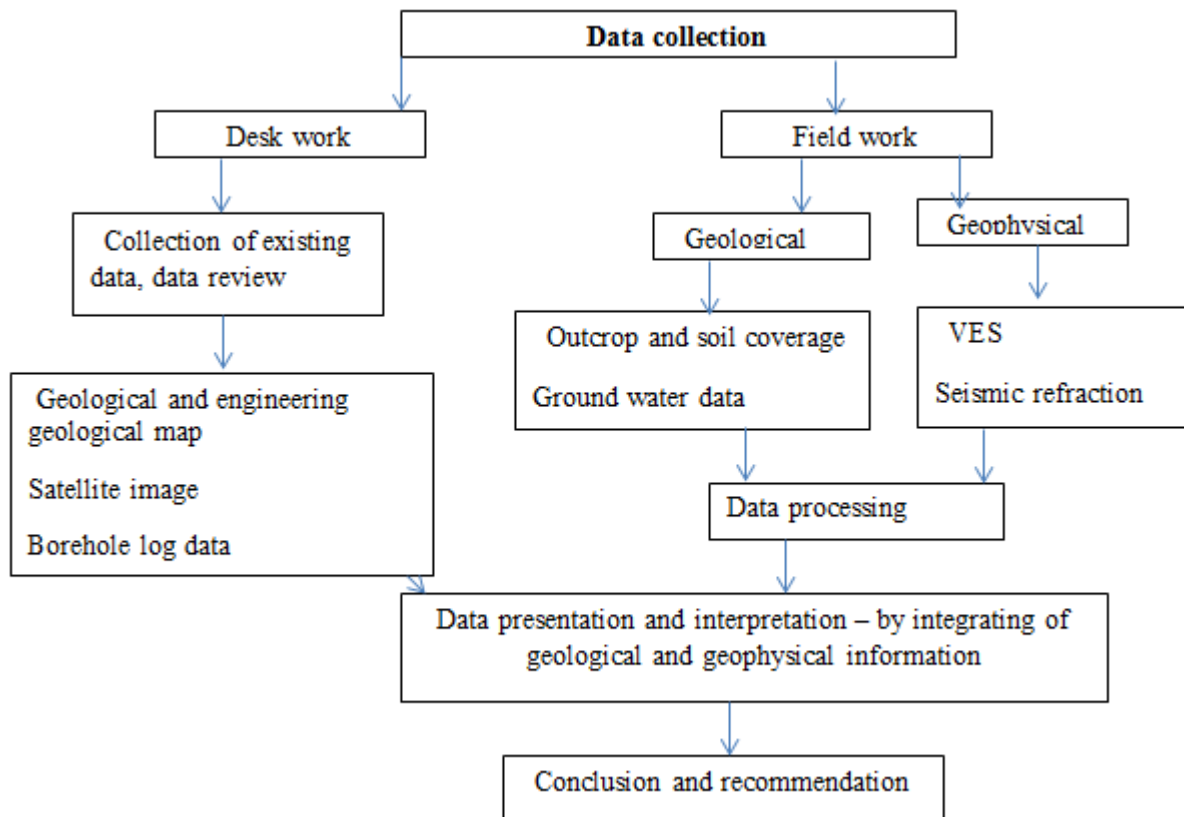


Figure 1. 4 Flow chart methodologies applied for investigation

### 1.8 Review of the previous works

Many researchers have worked a lot to identify the nature, causes and intensity of landslides in the different parts of Blue Nile along the Gohatsion to Dejen road section and its surrounding for different purpose. Many of them indicate that the magnitude of landslide occurrences and its resulting damage to road, agricultural land farm and local home have been increasing from time to time and there are still active landslide hazard especially along the main road in the area.

Lulseged Ayalew (1999) discussed that the relation between the mechanism of landslide and rainfall in the highlands of Ethiopia including Blue Nile or present study area.

GSE (2010) also study to prepare geological and engineering geological maps along the road from Gohatsion to Dejen.

Lulseged Ayalew and Hiromitsu Yamagishi (2004) have studied slope failure on the part of the Blue Nile basin sections from Gohatsion to Yet Nora, a small village about 8-km north of Dejen. The purpose of the study is to examine mainly the impact of landslides and

rock falls to the development. They also detects types of landslides in the region include deep-seated rotational slumps, massive translational slides, progressive creep movements, debris sliding and mudflows.

Shiferew Ayele et al. (2014) using GIS and remote sensing tools and stated the landslide disaster on disruption in traffic movement and endangered the people life and their property in the area. Also the indicate that rock fall, toppling, debris slide and rotational failure of colluvial material are some of the common land instability manifestations observed in the area.

Birhanu et al., 2017 using GIS based expert evaluation approach for evaluation and mapping of land slide hazard zones around Alem Ketema town, in the Jema and Wenchit gorges which were parts of the Blue Nile gorge. The landslide types recorded in these studies include: i) Rock falls, (ii) Rock slides, (iii) Soil slides, and (iv) Debris flows.

According to Bekele et al (2010) bedrock lithological and slope morphological could generate different types of landslide and rock fall in mountainous area contains; i) on the steep slope modeled in hard rock like basalt, limestone and sandstones affected by fast moving mass movement like rock fall, toppling, rock sliding are common (Varnes, 1978; Dikau et al., 1996). ii) On the clay material like clay, shale and marl sedimentary formation (e.g. Gohatsion formation), colluvial deposits at the foot of steep slopes and thick weathered layers on volcanic bedrock and leading simple and multiple retrogressive rotational sliding, earthflow and mudflow triggered by heavy rain fall were expected (Canuti et al., 1986; Vernes, 1978; Dikau et al., 1996) which is true for present area.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 General

Landslides hazard problem are one of the major natural disasters in the world. It is a common phenomenon especially in a tectonically fragile and sensitive mountainous terrain like Ethiopia. According to (Kifle Woldearegay, 2013 and Bekele Abebe et al. 2010) stated that the widespread distribution of landslides in Ethiopian highland is mainly related to the occurrence of several predisposing factors such as rugged morphology, high relief energy, and the nature of the outcropping rocks. These due to complexes in geomorphologic, hydrological, and geological setting, the hilly and mountain a terrain of the Ethiopian landmass has been frequently affected by landslides (Kifle Woldearegay, 2005 and Lulseged Ayalew, 1999).

#### 2.2 Types of Landslide

Landslide may be classified into various categories based on mode of movement, material involved, speed of movement and other. According to (Varnes, 1978) landslide is classified based on the types of material involved (Rock, Earth, Soil, Mud and Debris) and types of movement (fall, topple, slide, spread, flow) and complex class of movement which contains two or more different mode movement acting downslope movement of the landslide mass.

Table 2 Landslide classification (Varnes, 1978)

Type of movement		Types of materials		
			Engineering soils	
		Bedrock	Predominantly coarse (debris)	Predominantly fine (earth)
<b>Falls</b>		Rock fall	Debris fall	Earth fall
<b>Topples</b>		Rock topples	Debris topples	Earth topples
<b>Slides</b>	Rotational	Rock slides	Debris slides	
	Translation	Rock slides	Debris slides	Earth slides
<b>Flows</b>		Rock flow (deep creep)	Debris flow	Earth flow
<b>Complex</b>		<b>combination of two or more types of movement</b>		

(Source: USGS, 2004)

### **2.2.1 Rock fall**

Fall is the detachment (freely down movement) of soil or rock or both from a steep slope or cliff along a surface on which little or no shear displacement has occurred. It triggered might be by natural process under cutting of slope, drainage erosion, weathering and human activity like excavation the toe of slope during road construction and repairs and increases agricultural practice along the landslide susceptible area. Since the falling material has high speed down the slope, it can damage engineering structure (road, pavement), damage vehicles; livestock's and damage all objects on the falling-line (USGS, 2004).

### **2.2.2 Topple**

A topple is a forward rotation out of the slope of a mass of soil or rock around a point or axis below the center of gravity of the displaced mass. It may occur due to rain water percolated in to cracks of rock and human activities (like undercutting, excavation) and natural activity (like weathering) (USGS, 2004).

### **2.2.3 Slide**

A slide is a downslope movement of a soil or rock mass occurring on surface of rupture due to different factors. According to (Varnes, 1978) slide was classified as rotational and translational slide.

#### **Rotational landslide**

This type of landslide is occurs in the very weak frock mas or regolith material is moved slowly when due to rotational mechanism is self-stabilizing as the gravitational driving force weakening with increases displacement (Vernas, 2013). Rotational landslide is not controlled by structure. The morphology is characterized by a prominent main scarp, a characteristic back-tilted bench at the head and limited internal deformation. Usually slow to moderately slow and may common in the area.

#### **Translational landslide**

In this type of landslide rock mass and soil is moved along the planar rupture surface. According to Vernas (2013) translational landslide is structurally controlled and has little or no internal deformation. Also he stated that planar sliding mechanism is not self-stabilizing and sliding is rapid when compared to rotation sliding and lead high damage to properties and natural environment.

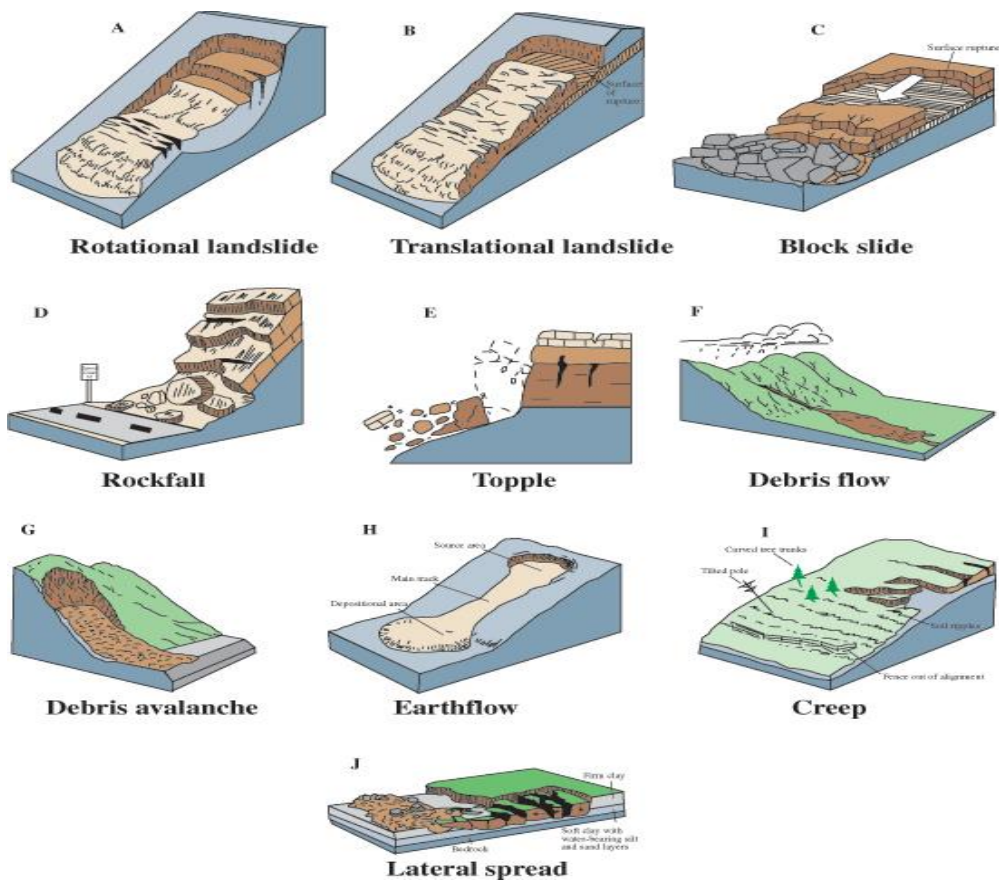


Figure 2. 1 Figure 2.1 Schematic representation of types of landslide movements (Keller, 2012)

## 2.3 Causative Factors of landslide

The variation of topographic feature (morphological) and geological material of the earth's surface is accountable for the occurrence of landslide and distribution due to different external and internal process which can affect the slope stability (Ref). The major contributed causative factors that triggering landslide for the present study is discussed as follows;

### 2.3.1 Geological factors

Landslide activity is critically influenced by the nature and a type of geological material (comprise of soil and rock) underlies (Thomson, 1971 as site in Fikire Girma et al., 2015). Lithological units, structural, discontinuities and different type's soil deposit are considered as basic contributing important geological factor that affect the slope stability and are important for landslide hazard studies (Dai and Lee, 2002).

In saturated conditions, incompetent or unconsolidated material may fail under overburden weight and high pore-water pressures, resulting in a deep-seated rotational-type failure. Translational slides commonly are controlled structurally by surfaces of weakness such as; faults, joints, bedding planes, and contacts between bedrock and overlying deposits (Sidle and Ochiai, 2006).

Generally landslide phenomenon is influenced by the following geological factors:

- (i) Type and engineering-geological properties of soils and rocks, their distribution, and the effect of groundwater on these properties. Lithological units, such as; basalts, silt and shale and limestone have different shear strength (Upreti and Dhital, 1996).
- (ii) Geological structures such as bedding, joints and faults are potentially weak planes in a slope. However, this structure is not clearly seen in the present study area. Their strength is generally less as compared to the strength of the surrounding intact rock.
- (iii) Weathering condition plays an important role. Mechanical and chemical weathering changes the strength parameters of the rock and soil considerably which also change the physical properties of rock and soil.

### **2.3.2 Role of vegetation**

It was well understood that vegetation influences the slope stability in two ways: through hydrological effects and mechanical effects. First hydrological effects involve the removal of soil

water by evapotranspiration through vegetation, which lead to an increase in soil reduce the pore-water pressure and increase in the soil shear strength. Second the shear strength of the soil is also increased through the mechanical effects of the plant with deep roots trees protects the underlying soil from raindrop impact and surface wash and reduce slope erosion (Greenway, 1987). Therefore, vegetation help to reduce in soil moisture and Removing vegetation from the slope tend to increases both density of debris slide and the amount of material moving down the slope (Cannon and Gartner 2005; Jakob 2000).

### **2.3.3 The role of hydrology**

Hydrology is directly or indirectly involved in inducing of landslides landslide phenomenon in highland and rugged mountain area. The presence of rainwater and groundwater condition play great role in order to decreases shear strength of slope material and thereby increasing

the probability of initiating landslides in the sloppy area (Lulseged Ayalew and Hiromitsu Yamagishi, 2004).

According to Nelson (2010) described that the addition of water from rainfall adds weight to the slope. Water can percolate into the soil or rock and fill a fracture which increases the weight of the soil. Weight is force, and force is stress divided by area, so the stress increases and this can lead the mass movement or landslide down to the slope.

### 2.3.4 Geomorphic factors

Morphology depend on the slope gradient of the surface by variable deep cut gorge with sharp escarpments, high cliff, and steep slope with different topographic features has a great influence inducing land sliding and rock falling (Lulseged Ayalew and Hiromitsu Yamagishi, 2004). As the slope steepness increases the probability of slope increases i.e. steep slopes (Figure 2.3) are often associated with rock fall and debris, which are the very rapid down slope movement of soil, rock, and organic debris (Anbalagan, 1992). According to Dai and Lee (2002) indicated that as slope gradient increases the shear stress to slope and lead to slope failure in the area of underlies by soft geological formation (clay, shale and marls) by decreasing shear strength of the slope.

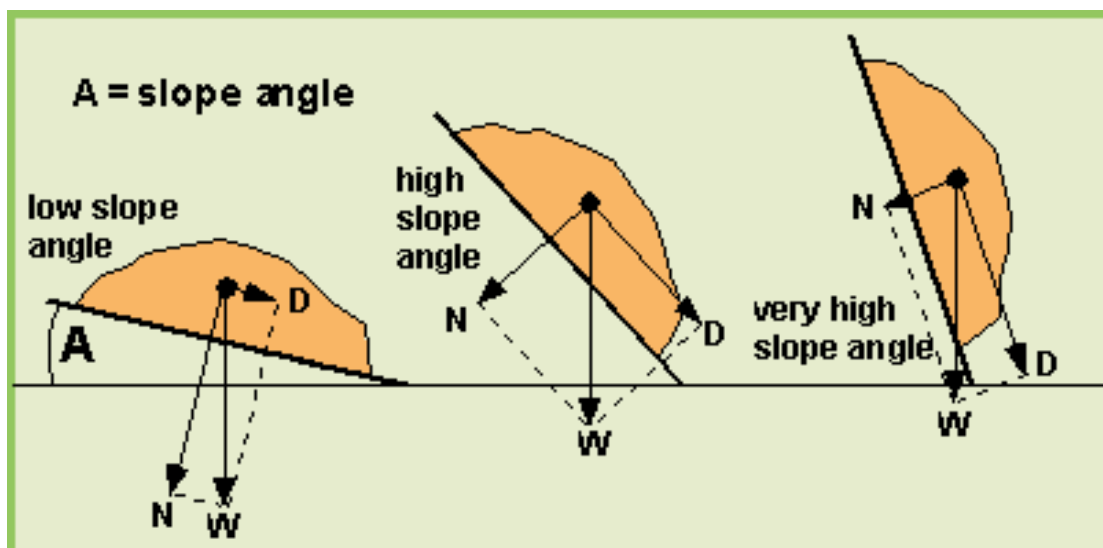


Figure 2. 2 shows an increase the slope angle “A” results increases the driving force “D” (Rai et al., 2014)

Generally, according to Lulseged Ayalew and Hiromitsu Yamagishi (2004) stated that the slope gradient ranged from  $10^{\circ}$  to  $35^{\circ}$  as deep-seated rotational and debris slides and greater than  $45^{\circ}$  rock fall expected.

### **2.3.5 Gravity**

Gravity is one of the most the driving forces responsible for mass wasting or slope failure. The effect of gravity is resolvable in two component forces, the normal force, is perpendicular to the slope and indicates that the blocks ability to stay in place because of frictional consideration

The other force is called shear force, is parallel to the slope and indicates the blocks ability to move (Edward and Keller, 2008). The steeper the slope it has the greater shear force and lead to slope or block to slide. However, when the friction force is greater than the shear force the block or slope stable or not slide (ref).

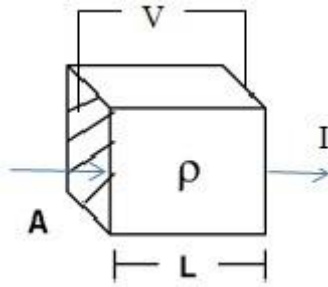
## **2. 4 Geophysical Investigation**

Geophysics is the science of measurement of physical property variations directed towards investigation of the subsurface either for various applications, including landslides and related geo-environmental researches (Telford et al. 1990; Schrott et al. 2003; Reynolds 2011 as site in Jaeger, et al., 2013). In landslide studies, geophysical methods are used to determine the approximate thickness of the landslide debris using different techniques, such as resistivity and seismic refraction that are based on the determination of electrical resistivity/conductivity and velocity of elastic waves that provide insight about characteristics of the underlying earth materials (Giovanni Battista pellegrini, Nicola Suria, 1995). In this research two geophysical techniques, namely electrical resistivity and seismic refraction, were applied

### **2.4.1 Principles of Resistivity Method**

Consider electrically uniform cube of length 'L' in which the current 'I' passing and material in the cube resist this current passing through it which resulting in potential drop 'V' between the opposite face.

The resistivity 'R' is directly proportional to the length 'L' of resistive material and inversely proportional to the area of cross-section 'A' equation (3.1).



$$R \propto \frac{L}{A} \quad R = \rho \frac{L}{A} \quad (3.1)$$

where  $\rho$ , the constant of proportionality is known as the electrical resistivity.

According to Ohm's law, the ratio of potential drop to apply to current  $\left(\frac{V}{I}\right)$  defined as resistance which given by:

$$R = \frac{\Delta V}{I} \quad (3.2)$$

where  $\Delta V$  is the potential difference across the resistance and 'I' is the electric current through the resistance. By combining equation 1 and 2 gives:

$$\rho = \frac{L}{A} \left(\frac{V}{I}\right) (\Omega - m) \quad (3.3)$$

### Electrode configuration of electrical resistivity survey

There are many ways of electrode arrangement, but common arrangements including Wenner, Schlumberger and the Dipole-Dipole. However, for the present study Schlumberger electrode configuration was selected. In this case two potential electrode (P1 and P2) and two current electrodes (C1 and C2) can be placed over the ground in symmetrical manner as the following:

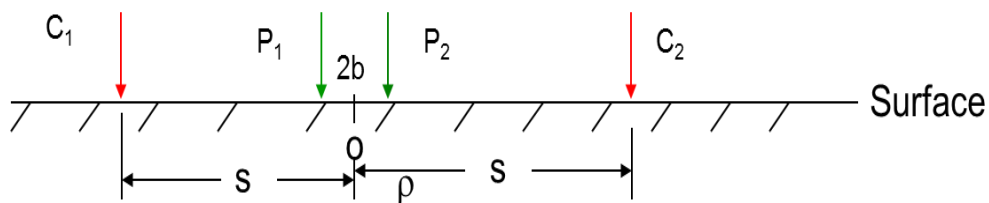


Figure 2. 3 Schlumberger electrode configurations

Where  $r_1 = s - b$ ;  $r_2 = s + b$ ;  $r_3 = s + b$ , and  $r_4 = s - b$  and gives the following equation:

$$\Delta V = \frac{I\rho}{2\pi} \left( \frac{1}{s} - b - \frac{1}{s} + b \right) - \left( \frac{1}{s} + b - \frac{1}{s} - b \right) \quad (3.4)$$

$$\Delta v = \frac{I\rho}{2\pi} \left[ \frac{2b}{s^2 - b^2} \right] \quad (3.5)$$

$$\rho a s = \pi \left( \frac{s^2}{2b} - \frac{b^2}{2b} \right) \left( \frac{\Delta V}{I} \right) \quad (3.6)$$

where the geometrical factor in this case is  $\pi (s^2 - b^2)/2b$ . The ratio  $\Delta V/2b$  is the potential gradient or the intensity of electric field.

#### 2.4.2 Electrical Properties of Earth Materials

Our planet earth's has made of huge variation of different mineral and rock composition which made the earth's material to had variation in physical properties. This huge variation also varies in electrical resistivity which made electrical resistivity techniques possible. Variations in the electrical resistivity of Earth materials, both vertically or laterally, produce variation in the relations between the applied current and the potential distribution as measured on the surface and provide the information about the thickness, extent and general geological information of the subsurface materials.

Earth's materials that are geologically different also electrically different and such differences are distinguished by the variation of electrical property within the earth's interior. Thus, the electrical resistivity of the rock and/or soil depends on the physical properties of the lithologies and fluid contents in the pore space of the geological material (Emmanuel, et al, 2011).

Moreover, electrical resistivity of the earth's material is affected by degree of weathering, porosity, permeability fracturing and types of material fill the fracture, types of water filling spaces, mineral composition and grain size of geological materials (Robert and William, 1981). Hence, the resistivity of different rock types is different based on factors control it for example The resistivity of igneous and metamorphic rocks is high ( $10^3$ - $10 \times 10^6 \Omega\text{-m}$ ), whereas resistivity of sedimentary rocks that are more porous and contain high amount of fluid/moisture. Normally they have low resistivity values compared to igneous and metamorphic rocks. Their values depend on the degree of compaction (porosity and permeability of rock), grain sizes, degree of fracturing, percent of fracture, and properties of fluid filling fractures/pore spaces as well as clay content that reduces resistivity ranges. Unconsolidated materials, such as colluvial, alluvial deposit that are susceptible for sliding

are characterized by low resistivity values (Lee, et al., 2012). Generally, resistivity of sedimentary rocks ranges from 1 to  $10 \times 10^4 \Omega\text{-m}$  (Tables 4.1).

Table 3 Resistivity's of different rocks types taken from (Loke, 1999)

Rock types	Resistivity ( $\Omega\text{-m}$ )
<b>Metamorphic/Igneous rocks</b>	$5 \times 10^3 - 10^6$
Slate	$6 \times 10^2 - 4 \times 10^7$
Gneisses	8- $10 \times 10^3$
Marble	$1 \times 10^6 - 1 \times 10^7$
Quartzite	$1 \times 10^6 - 1 \times 10^8$
Basalt	$5 \times 10^3 - 1 \times 10^5$
Andesite	$5 \times 10^3 - 1 \times 10^5$
<b>Sedimentary Rocks</b>	
Sandstone: · Saturated with fresh water · Saturated with saline water	$1 \times 10^5 - 1 \times 10^6$ $3 \times 10^1 - 2 \times 10^2$ 1-10
Clay: · Saturated with fresh water · Saturated with saline water	$1 \times 10^3 - 1 \times 10^5$ $1 \times 10 - 1 \times 10^2$ 1-10
Gypsum	$1 \times 10^5 - 1 \times 10^7$
Shale	$20 - 2 \times 10^3$
Limestone	$50 - 4 \times 10^2$
Unconsolidated (colluvial and alluvial)	Varies based on their parent rock

### 2.4.3 Producers of Resistivity Surveys

Regardless of the specific electrode spread employed, there are two procedures in resistivity survey work in the field. The particular method to be used depends on whether one is interested in resistivity variation within depth which is called Vertical Electrical Sounding (VES) or with lateral extent called Electrical Profiling (EP). Profiling provides information about lateral variations of resistivity, while VES, also called electrical drilling, provides information about the vertical resistivity variations (Loke, 2001). In this research Vertical Electrical Sounding has been used to investigate the subsurface conditions of the landslide affected area.

The study of landslides involves slopes steepness, different types of geological material overlies the bedrock, the thickness of overburden and physical parameter of this materials. Thus, geophysical techniques help to measure the physical parameters of subsurface geological materials and reveal resistivity contrast between the slide debris and the unaffected mass (Caris and Van Asch, 1991; Meric et al., 2005; Lapenna et al., 2005 as cited in Fisseha and Mewa, 2016). The main objective of geophysical survey is to determine the information

about the thickness, extent and general geological information of the subsurface materials by measuring the resistivity and signal distribution in the slope material on surface.

#### 2.4.4 Seismic refraction method

##### Principle of seismic refraction

This method worked by applying artificial vibrator (for this study sledgehammer) to generating seismic waves which causes the particle of earth's material to stretched temporarily out of it position. The waves pass through the subsurface geological material might be return back to the surface by refraction which detected by geophone on the surface. The arrival time of different waves at different time traveling through different density of earth's material (rock and soil) reach at geophone was help to determine the nature of material, extent and may identify strength or compactness of geological formation of subsurface at different depth.

The propagation of seismic velocity of earth's material (rock and soil) might be influenced by different geological material such as consolidation rock/soil material, fracture, weathering, degree of water content or groundwater condition and cementation etc. might be reduce or increases the velocity of rock or soil. The generally the velocity increases within consolidated material and very low in the loose materiel like colluvial, alluvial and loose sand (Mussett and Khan, 2000) (Table 3.3).

Table 4 Seismic velocities for rocks (Mussett and Khan, 2000)

Rock types	Vp (km/sec)
<b>Unconsolidated sediment</b>	
Clay	1.0-2.5
Sand , dry	0.2-1.01
Sand saturated	1.5-2.0
<b>Sedimentary rocks</b>	
anhydrite	6
Chalk	2.1-4.5
Coal	1.7-3.4
dolomite	4.0-7.0
Limestone	3.9-6.2
Shale	2.0-5.5
Salt	4.6
Sandstone	2.0-5.0
<b>Igneous and metamorphic rock</b>	

Basalt	5.3-6.5
Granite	4.7-6.0
Slate	3.5-4.4
Ultramafic rock	7.5-8.5

Seismic refraction based on the boundary across which there was velocity contrast, and then the direction of travel of the wave changes on entry to the new medium. The amount of change in direction has been governed by the contrast in seismic velocity across the boundary according to Snell's law (figure 2.4). The method was dependent on there being an increase in velocity with depth.

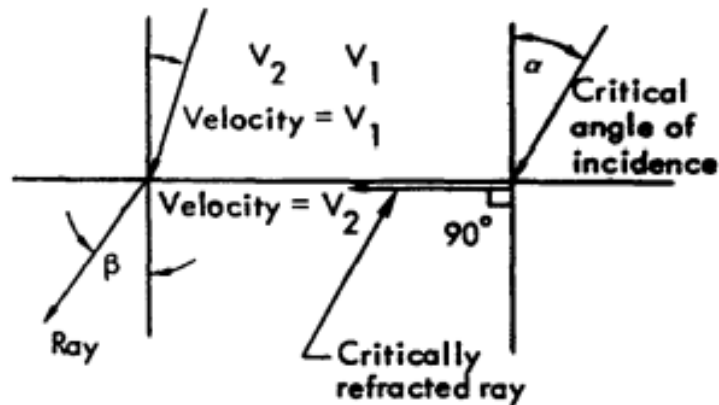


Figure 2. 4 Snell's Law and refraction of ray transmitted across boundary between two media with different velocities ( $V_2 = 2V_1$ ) (Redpath, 1973)

Where  $\alpha$  is denoting the incident angle,  $\beta$  the refraction angle of the travel path with respect to the boundary normal and  $V_1$  is the propagation velocity of upper medium and  $V_2$  is the propagation velocity of lower medium. In the important special case:

when  $\beta = 90^\circ$ , i.e.,  $\frac{\sin \alpha}{\sin 90^\circ} = \frac{V_1}{V_2}$  then,  $\alpha$  is called the critical angle of incidence.

Snell's Law and elementary trigonometry are used to derive two fundamental equations of seismic refraction theory (Nettleton, 1940, pp. 249-254).

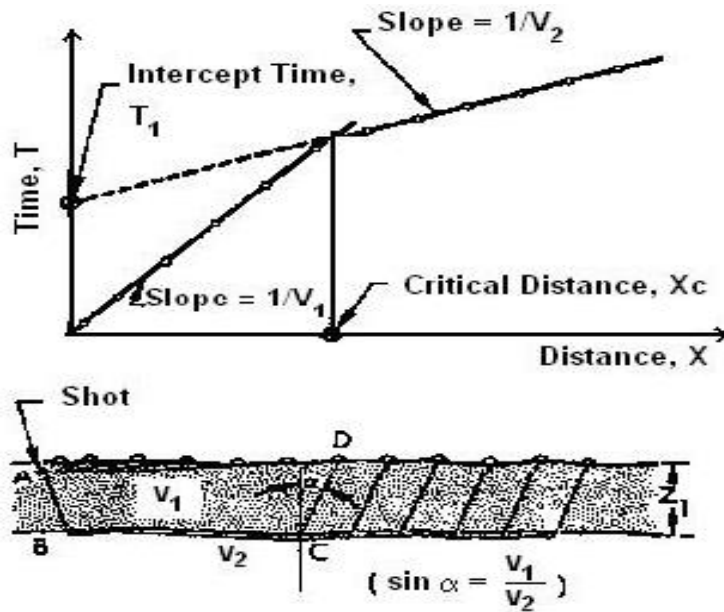


Figure 2.5 Simple two layer case with plane, parallel boundaries and corresponding time-distance curve (Redpath, 1973)

Suppose strata consist of one horizontal low velocity ( $V_1$ ) layer underlain by one high velocity ( $V_2$ ) layer on the Figure 3.12.

1. The depth  $Z_1$  of the low velocity layer is given by the equation:

$$Z_1 = (T_i/2 - V_1 V_2 / (V_2^2 - V_1^2)) / \sqrt{(V_2^2 - V_1^2)} \quad 3.7$$

2. For depth of  $Z_2$  three layer s given by equation refracted along the top of  $V_2$  (layer 3).

$$Z_2 = 1/2 \left[ T_{i2} - \frac{2Z_1 \sqrt{V_2^2 - V_1^2}}{V_2 V_1} \right] \left( \frac{V_1 V_2}{\sqrt{V_2^2 - V_1^2}} \right) \quad 3.8$$

## CHAPTER THREE

### 3. GEOLOGY OF THE STUDY AREA

#### 3.1 Regional Geological Setting

The Ethiopian Mesozoic sediment occurs mainly into Northwestern plateau which includes Danakil Alps, Tigrai region (Mekele basin), Blue Nile Basin (present study area) and southeastern plateau including Ogaden Basin which separated by Ethiopian Main rift Valley and Afar Depression (Getaneh Asefa, 1991 and Russo et al., 1994). The Northwestern covers major part of the country and characterized by highland relatively 1500 to 4000m and the southeastern plateau occupied by Ogaden Basin relatively lies below 1000m which characterized by descending to the Indian ocean (Getaneh Asefa, 1991). The history of Mesozoic sedimentation related to the beginning of break-up of Gondwanaland during Paleozoic-Jurassic times which largely fault-controlled (Lulseged Ayalew and Hiromitsu Yamagishi, 2004).

Abay gorge (Blue Nile basin) is created during the intra-continental rift stage which related to the beginning of Gondwanaland break-up (Russo et al., 1994). According to Russo et al (1994) states that Blue River basin, which is thick about 1200m and capped by Tertiary flood basalts, is including from the bottom to top, five units: Lower sandstone (Adgrat Sandstone)-represents post rift deposition which was fluvial sedimentation, Shale and Gypsum unit also called Gohatsion Formation (Getaneh Asefa, 1981) - deposited at the beginning of marine transgression, Antalo Limestone – represents the product of a major transgression, muddy sandstone (Mugher sandstone), and Upper sandstones (Debra libanos sandstone) - deposited by regression system or withdrawal of the sea.

These formations contain different rock units with long cliffs of sandstone, limestone interbedded with shale and marl and gypsum intercalated with relatively soft units of mudstone, shale, and marl (Getaneh Asefa, 1981) which susceptible for mass movement. The frequently occurrence of landslide and rock fall hazard within this area due to series of tectonic disturbances during the geological past, together with drainage-aided surface erosion (Lulseged Ayalew and Hiromitsu Yamagishi, 2004).

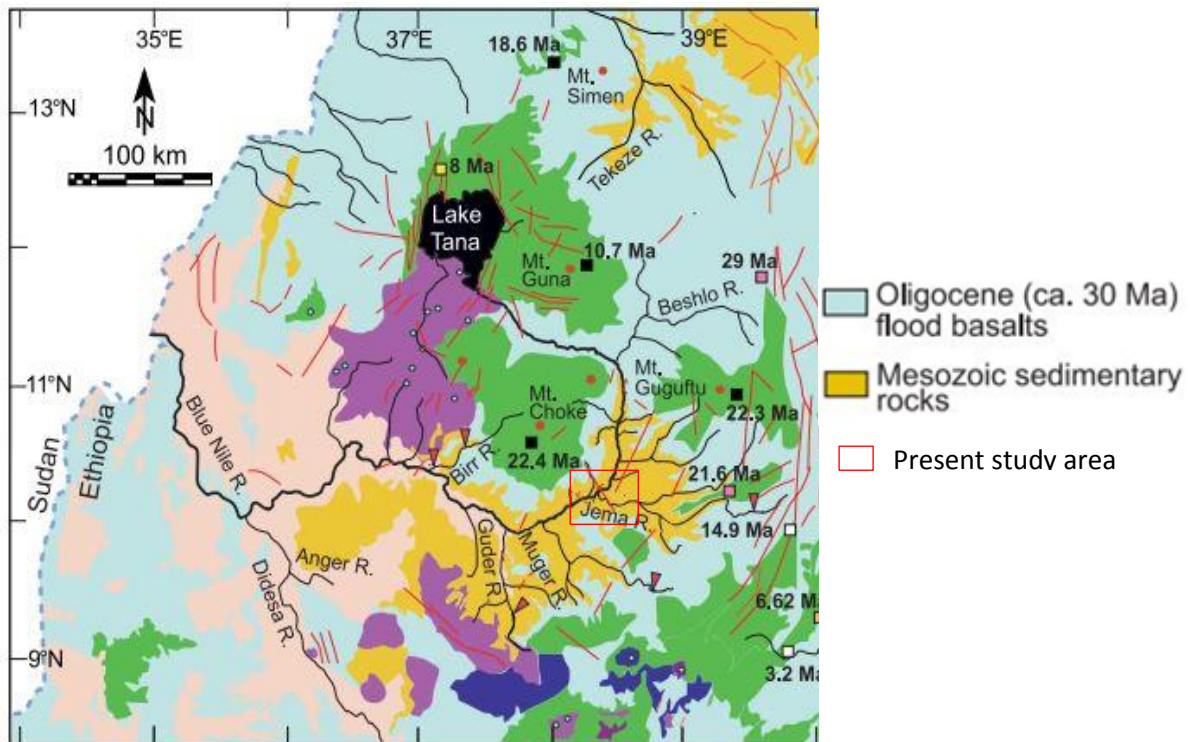


Figure 3. 1 Regional geology of the present study area (Tefera et al., 1996)

### 3.2 Local geology

In the present area there are different rock unit such as, sandstones, gypsum, limestone units overlain by Tertiary basalt (Getaneh Assefa, 1991).

#### 3.2.1 Lower sandstone

This unit is underlie unconformable by Paleozoic sediment and overly by shale and gypsum units or called Gohatsion formation (Getaneh Asefa, 1981). It is about 200m-400m thick and probably deposit in fluvial and deltaic environment and equivalent to Adigrat sandstone in Tigray, Ethiopia. It is characterized by reddish, medium to coarser grain size with planer cross bedding dip angle varies from  $15^{\circ}$ - $25^{\circ}$  which general trends towards SE direction (Russo et al., 1994).

#### 3.2.2 Gypsum unit

This unit, also called as Gohatsion formation (Getaneh Asefa, 1981), is interbedded between the lower shale units and overlying by upper shale units which is thick about 150m to 250m thick near the road (EGS, 2010). The gypsum, dolomite and associated shale's are deposited in shallow lagoon and supra-tidal environments (Getaneh Asefa, 1991 and Russo et al.,

1994). The middle part of Gohatsion Formation is characterized by the intercalation of marlstone, mudstone, dolostone with fine grain size (Russo et al., 1994).

### **3.2.3 Limestone**

Limestone units is one of the fossiliferous and thin bedded to thickly bedded limestone at the upper part of the area. The lower and the middle part consist of marl limestone, marl, and silt (soft formation) limestone with thickness of 200m and the upper part is characterized by massive thick (Russo et al., 1994). This unit is deposited in the open marine to shallow shelf environment and about 400m thick and equivalent with Antalo limestone of Tigray area, Ethiopia (Getaneh Asefa, 1991 and Russo et al., 1994).

### **3.2.4 Volcanic rock units**

This rock unit covers the upper part of the study area. It characterized by massive, vertically widely spaced joints, dark in color and fine grain size and presence of well-developed columnar structure and susceptible to detachment and falling apart in to blocks and boulders which could moves long distance toward the lower area (Ayelaw and H, 2004).

### **3.2.5 Colluvial Deposits (Quaternary deposits)**

Colluvial deposits is a general term referring to loose, heterogeneous soils deposited by mass and continuous down slope creep, usually collecting at the base of slopes or hillsides. Colluvial deposit consists of gravel, boulder, block and some sand or soil of unsorted, unstratified and heterogeneous mixture of sizes the soil materials, transported by landslides or slow surface movement (creep) due to gravitational force.

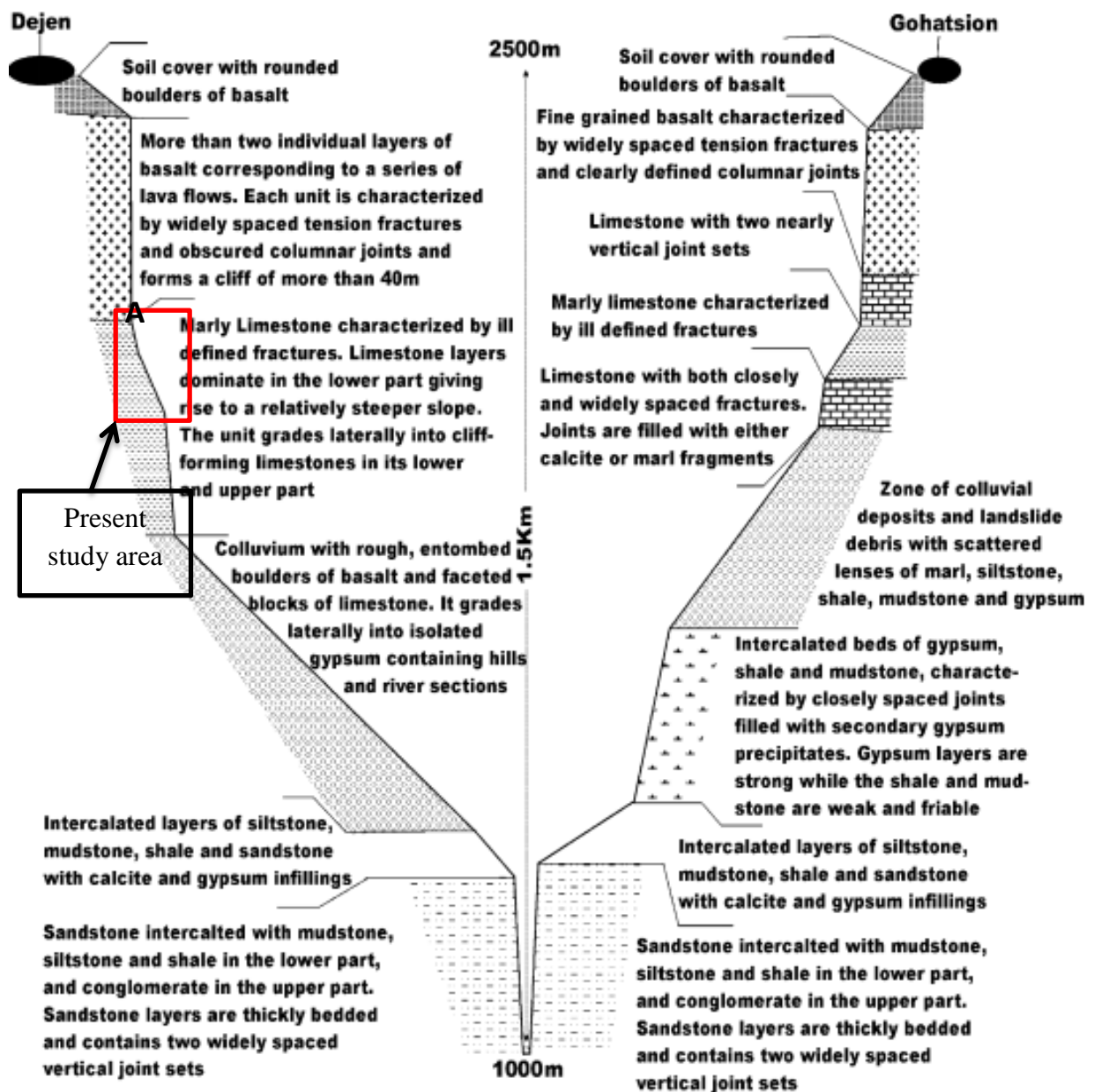


Figure 3. 2 Schematic geological section of the Abay River gorge along Gohatsion to Dejen (Lulseged Ayalew and Hiromitsu Yamagishi, 2003 after modified from Lulseged Ayalew, 2000), A) shows present study area

## CHAPTER FOUR

### 4. GEOLOGICAL AND GEOPHYSICAL INVESTIGATION

#### 4.1 Geological studies

In addition to anthropogenic factors (human activities), landslide phenomena are determined by such natural processes as compositions of earth materials (lithologies) that mainly define their physical and chemical parameters, slope morphology, elevation, land use and land cover, hydro-geological condition, amount of rain fall, porosity, permeability, degree of weathering and fracturing. These and other related factors influence the engineering properties (like shear strength) of rocks/soils and eventually adversely affect the stability of the slopes (Raghuvanshi et al., 2014 and Thomson, 1971 as site in Fikire Girma et al., 2014).

Borehole data obtain from the Geological Survey of Ethiopian (Table 1.1) indicates that in the research area the soils underlying the uppermost unconsolidated (colluvial) materials are fine grained and has different engineering properties. They are composed of large quantity of silt, mud and clay (shale) are the most trouble making ones for engineering structure as they possess shrinking and expanding nature depending on the moisture content that easily fluctuates based on seasonal variations.

##### 4.1.1 Lithological

###### 4.1.1.1 Limestone

This horizontally interbedded unit is represented by marl limestone, marl, and silt limestone with variable thickness, highly fractured and well exposed near by the completely damaged road that faces towards NE. The interbedded materials within the limestone are characterized by yellowish gray color, very weakly cemented, thinly bedded and moderately-highly weathered. On the landslide damaged road and within the interbedded layer cracks average spaces of 10-30cm are (Figure 3.1).

###### 4.1.1.2. Silt, clay and shale

These units underlie the thick colluvial materials and they are very fine grained, highly weathered and weakly cemented or soft nature. Their average thickness varies from about 10 to 20m. Their fine grained nature allows them to concentrate more fluid/moisture within the overlying units and thereby contributes to the increasing effect of pore water pressure,

especially during rainy season, and thereby decreases the shear strength of the slope materials.

Correlation of borehole log data with geophysical survey results shows that this layer composed of fine grained material and shows low resistive values. Hence the conductive materials underlying the thick colluvial deposit make the slope unstable by acting as impermeable bed saturating the slope and leading to its failure.

#### **4.1.1.3 Basalt**

This unit is found on the northwestern and northern margins of the study area (Figure.3.2). It is characterized by fine-medium grained, dark-black color, moderately weathered and columnar structure. Gravels and boulders derived from these basalts cover the upper, to some extent the lower, parts of the study area.

#### **4.1.1.4 Colluvial material**

Most part of the study area is covered by unconsolidated colluvial material with heterogeneous character in grain size ranging from fine to larger boulder, weakly cemented or low to no cohesive nature and has low shear strength. Extensive agricultural practice takes place within this deposit distributed along and down the slope.

Hence, it is easily for rain water to percolate down and cause sudden fluctuation groundwater level that minimizes the shear strength of slope material. During field investigation different sizes of cracks (about 10-40cm spacing) have been observed at the toe of the sliding mass. Based on raster calculations more than 83% landslide problem was found to occur within the colluvial materials and the remaining 17% is associated with the limestone intercalated area (Table 3.1).

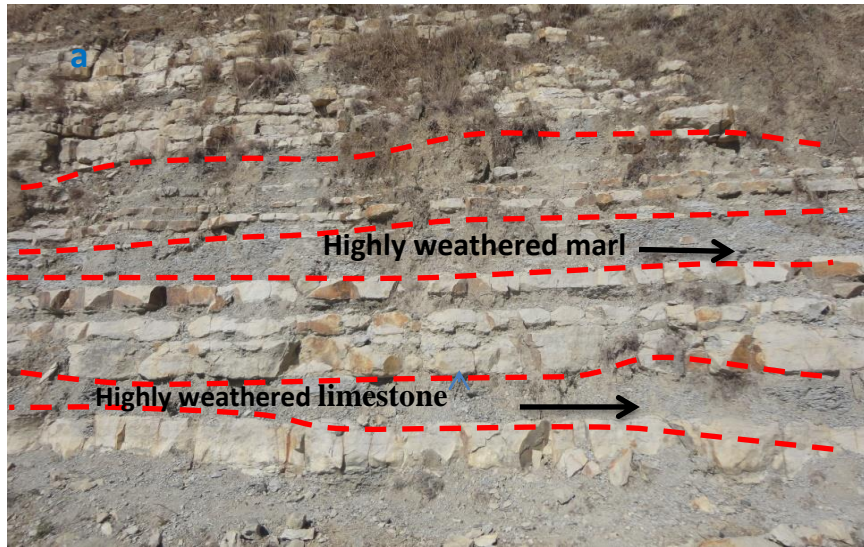
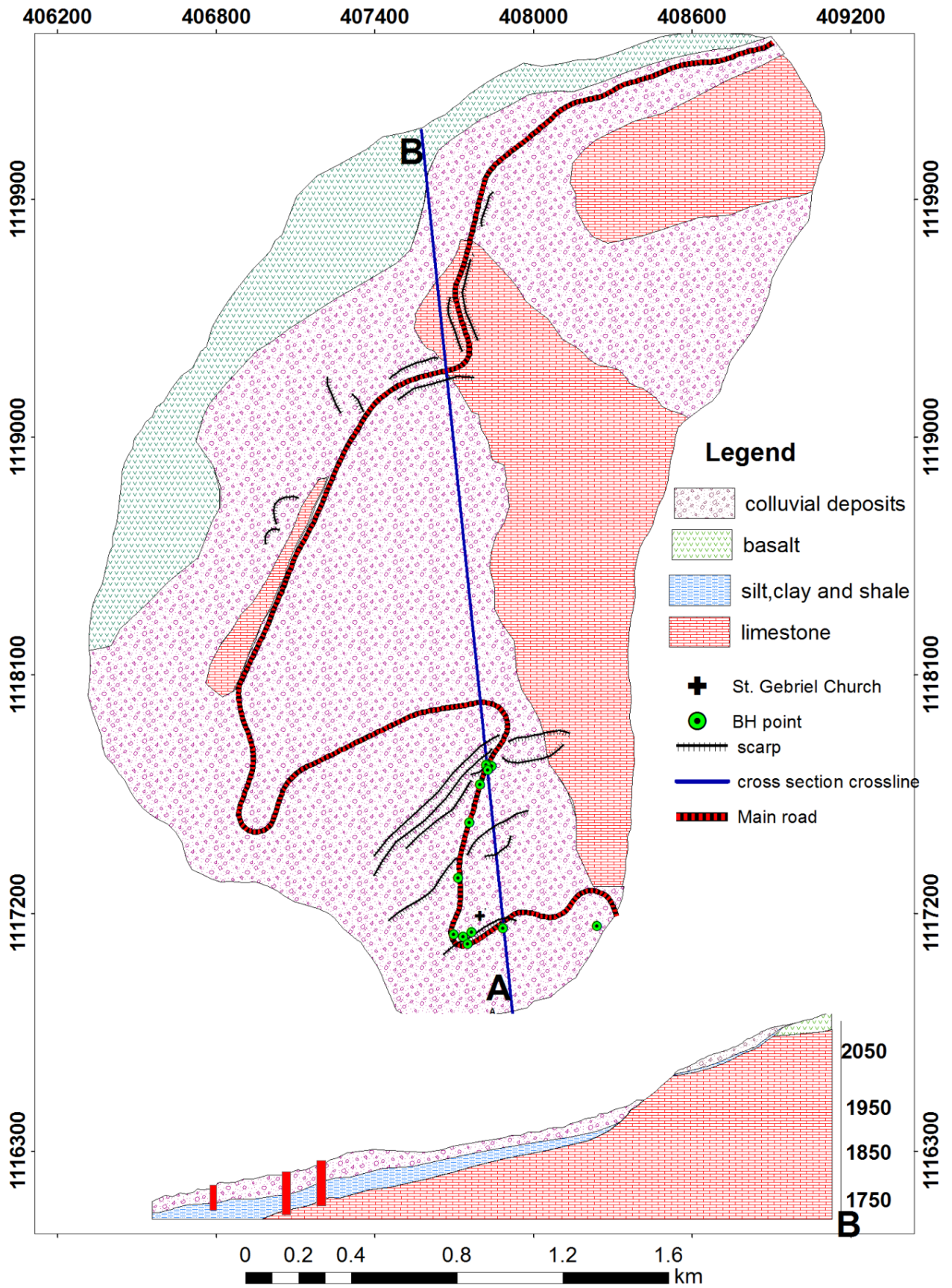


Figure 4. 1 Field photos illustrating lithologies a) highly weathered limestone interbedded with marl; b) Highly weathered limestone; c) Colluvial material saturated by seepage; d) dry colluvial material



### 4.1.2 Hydrogeology factors

Groundwater is one of the triggering factors directly or indirectly involved in inducing of landslides activities. Rain water which recharges the soil and increases lateral and vertical movement of groundwater within the slope material is controlled by the characteristics of the underlying geological material.

Results of field investigations, specifically geological and geophysical, and already available drilling data indicate that the slope material within the study area show significant variations in grain size and properties of earth materials down the slope and within the depth. As a result, the upper part of the area is covered by unconsolidated coarser materials (gravels and boulders) act as recharging zone due to their high permeability and morphological appearance. However, silt clay and shale's are impeding the vertical percolation of rain water due to their low permeability, and hence forces the rain water to flow laterally.

Because these fine grained materials acts as impermeable bed, during the rainy seasons (between July and August) the groundwater level rises and saturates the slope and causes sudden rise in pore water pressure. This phenomenon completely reduces the shear strength of the sliding material on the slope and resulting in slope failure or slope material sliding. Emerged springs and seepage zone observed within the landslide affected zone or along critical slope section are clear evidence that justify the groundwater to be the main agent that triggers the landslide in this area.

### 4.1.3 Slopes

Slope gradient, which directly proportional to gravitation pull, is important topographic factors influence the occurrences of landslide activity (Ayalew and Yamagishi, 2004). For present study, the slope gradient is divided based on the topography of the area into five class's as: steep slope ( $35^{\circ}$ - $45^{\circ}$ ), moderate steep slope ( $25^{\circ}$ - $35^{\circ}$ ), gentle slope ( $15^{\circ}$ - $25^{\circ}$ ), and very gentle slope ( $5^{\circ}$ - $15^{\circ}$ ), relatively flat (0-5). The steeper slope found northwestern to north margin and the flat covers south central of study area. The slope map was extracted from DEM (digital elevation model) of 30m resolution using Arc Map-GIS tool (Figure.3.3). The most of destructive landslide were occurs within slope between moderate steep to steep slope ( $15^{\circ}$ - $35^{\circ}$ ) and some were between very slop to gentle slope ( $5^{\circ}$ - $15^{\circ}$ ) with low damage.

#### **4.1.4 Land use and land cover**

Land use and land cover types were indirect indication factors influencing landslide activity due to barren and sparsely vegetation are susceptible to erosion and weathering of rock units or soil (Anbalagan, 1992). As a result, most of the present study area covered by sparsely and barren land and used for extensive agricultural practice which increases the moisture content of the soil of the slope material. Hence, the absence of deep rooted and moderate vegetation around critical slope, increasing of extensive agricultures practice due to rapid growth number of population in the area, above and below landslide affected area main causes for the increases the landslide occurrence.

These activities easily facilitate for the saturation of slope material and resulting slope failure or slide. Land cover and land use map was prepared from Landsat satellite image comprised with field investigation using ERDAS IMAGINE 14 software by using supper classification (Figure.3.3).

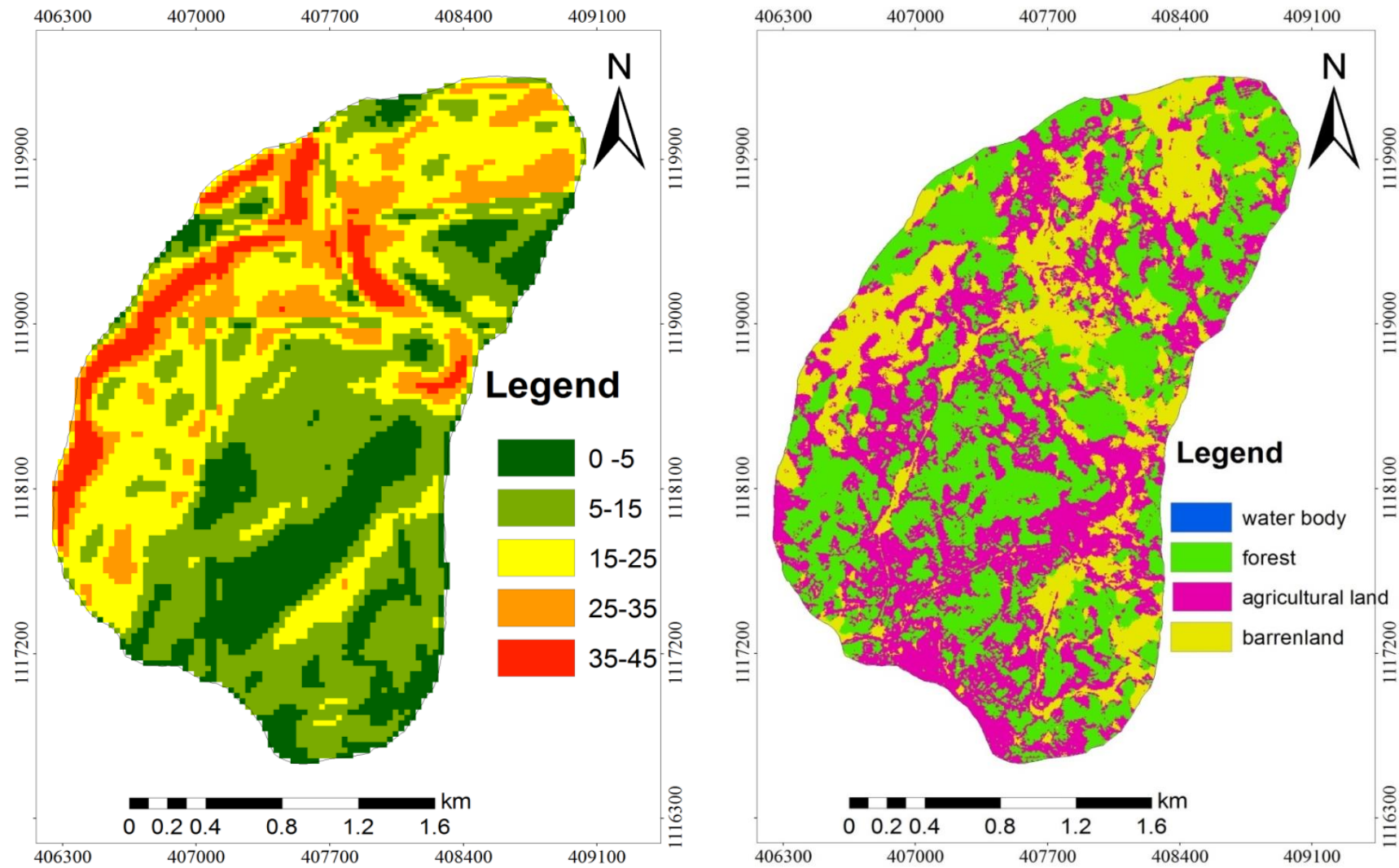


Figure 4. 3 Map showing landslide influencing factors a) slope map and b) land use and land cover

#### **4.1.5 Elevation**

The influence of elevation on the initiating landslide was considered in terms of weathering and erosion. The highest area affected by surface run off or uncontrolled surface water erosion the toe of the slope. The minimum elevation 1700 -2250m and about 90% of landslide hazard occurred between the elevations 1750-2000m.

#### **4.1.6 Rain fall**

Rainfall is one of the seasonal triggering factors which affect the stability of slope material and mechanism of landslide generation in the present study area. It results in increases the surface run off and damaged ditches structure, retain structure, drainage line (pattern) and increases the moisture content to slope material which rise pore water pressure above the critical value and lead the slope failure. According to rainfall data taken from metrological agency shows that the area has mean annual rainfall 1128.05-1062.28 mm (attached in annexures III) and increases from June to September. As results, the landslide movement happened started from early August to end of August. Thus, rainfall is considered as main triggering factors for the recent landslide in present study area.

#### **4.1.7 Human activities**

Human activities may result directly or indirectly triggering landslide phenomenon during work to modify their lives. The increasing human activities, such as intensive agriculture, removing bushes (vegetation) from slope, modify slope and land use changes, slope excavation for improper ways to repair road or maintenance were increases the potential instability of the slope (Figure 3.4). All of this activity reduces the shear strength of the slope and increases both density of slide and the amount of material moving down the slope. The increasing in number of population maximize human activity along the landslide prone area which multiple the intensity of landslide hazard and raises effect on natural environment and socio-economic at high rates.



Figure 4. 4 Field photos illustrating human activity along landslide prone area a) dumping waste down the slope; b) removing bushes from slope; c) slope excavation and d) Generate rock fall

#### 4.1.8 Mechanism of landslide

The mechanism of slope movement (landslide) are controlled by slope gradient, thickness of overburden (colluvial material) and moisture content of fine grained underlies material. Rain fall and the abscesses of vegetation (barren land) are the main factors determine the occurrences and intensity of landslide activity in the present study area. Thus, to determine the mechanisms (types) of landslide movement in the area about seven parameters has been analyzed above.

Accordingly in the soft lithological material like highly weathered fine grained (clay, silt and shale) overlies by thick colluvial deposits area, rotational sliding, debris slide and others were expected during rainy season (Vernes, 1978; Dikau et al., 1996). Hence, in the study area rotational slide and debris slide manifestation triggered by rain fall were identified during the field investigation and by analysis slope material and morphological analyzed.

Thus, the presence of coarse grain, low or no cohesive of shallow depth (1.5-3m) colluvial deposit develop on moderate to steep slope ( $25^{\circ}$ - $45^{\circ}$ ) and leads debris types of landslide shown on (Figure3.5b). This type of movement has been seen at the northern margin of the study area.

The morphological appearances characterized by main scarp, back-tilted bench at the head and concave upward, found between  $5^{\circ}$ - $25^{\circ}$  or very gentle to moderate steep slope gradient and thick colluvial material (10-14m) which moved slowly considered as rotational mechanism triggered by rain fall (Figure 3.5a). This type of movement was common in the southern margin of present study area and in some part of central.



Figure 4. 5 Field photo illustrate mechanism of landslides a) rotation slide and b) debris slide

#### 4.1.9 Landslide characterization and distribution

The characterizations and distribution of landslide in the area were identified based on a combination of field observation with the results of geological and geophysical survey. Hence, the N-NW margin (upper part) of the area are characterized by highly destruction of road, retain well, ditches and agricultural land. Hence, two electrical resistivity traverse line and one seismic refraction survey has been carried out in this area and resulted presences of very conductive layer or high moisture content overlies by colluvial material in which thickness increases down the slope presented in Figure 3.7 as zone E. This areas clearly recognizable evidence presence of active landslides has been shown on surface including, tilted vegetation, tilted electric pole, emerge of spring water and seepage, crack on road along the landslide affect area and highly susceptible to landslide hazard. Hence, the adverse damage to road and agricultural land will be expected in the future and this area considered as unstable area or zone.

The central part of are is flat area or nearly very gentle to gentle with  $5^0$ - $15^0$  slope gradients considered as low to no landslide damaged and mass movement process. This area covers the middle of the study and relatively considered as stable area (Figure 3.7 D).

The lower part or southern part has been characterized by moderate to high damage on local home, church and collapse of road and recognized as unstable zone (Figure 3.7 C). Thus, two electrical resistivity traverse line and one seismic refraction survey has been carried out and reveal very conductive layer or high moisture content overlies by thick coluvial material. From surface indicator like crack on the wall of house, church, in agricultural land and spring water near to damaged local home indicate that the presence of active landslide and may moderate to high damage on local home and road will be expected in the futures.

Hence, as the result indicates that most of recorded land slide occurred within: unconsolidated or colluvial material, limestone, gentle to steep slope ( $15^0$ - $45^0$ ), agricultural land and barren land or no vegetation.

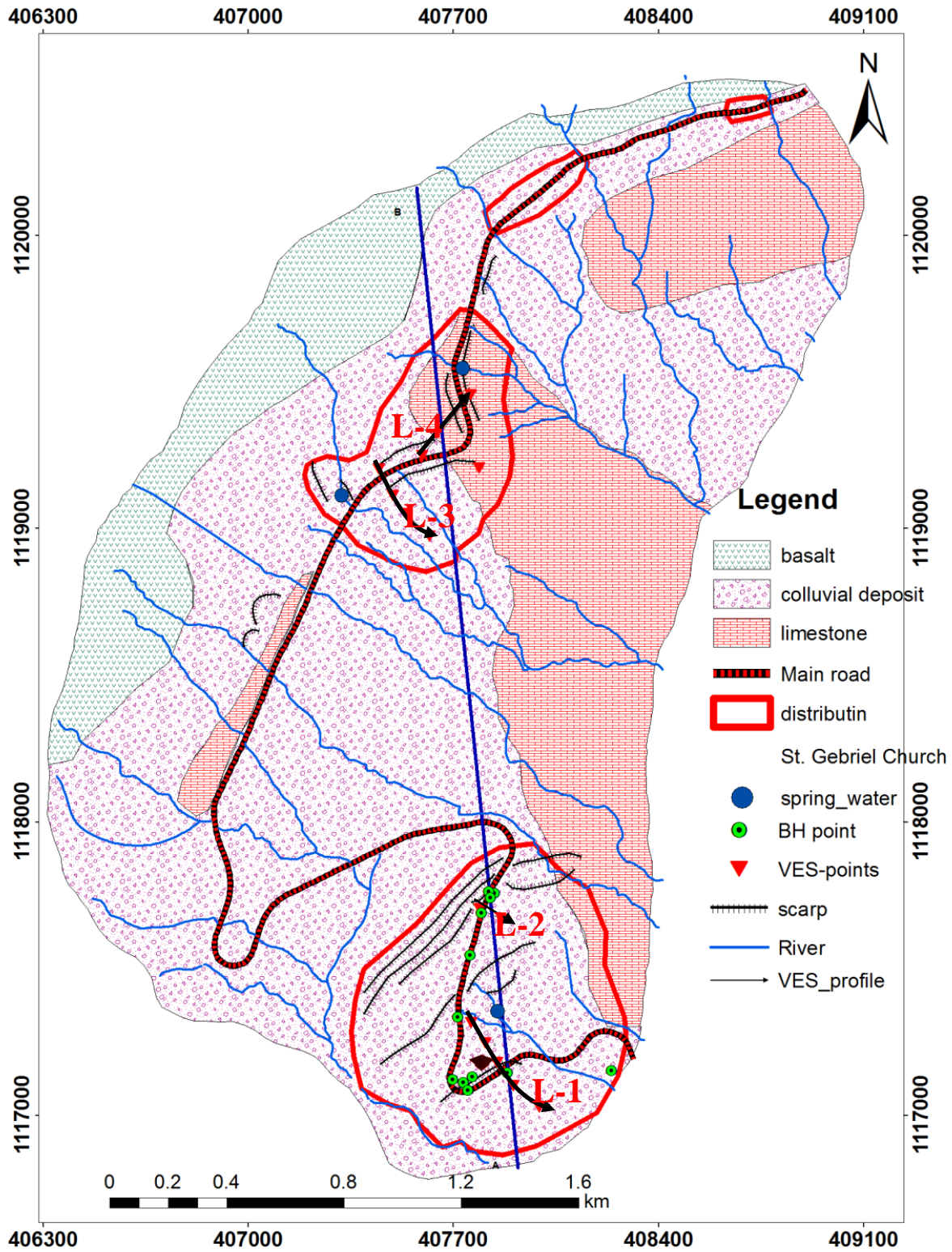


Figure 4. 6 Landslide distribution map and VES points

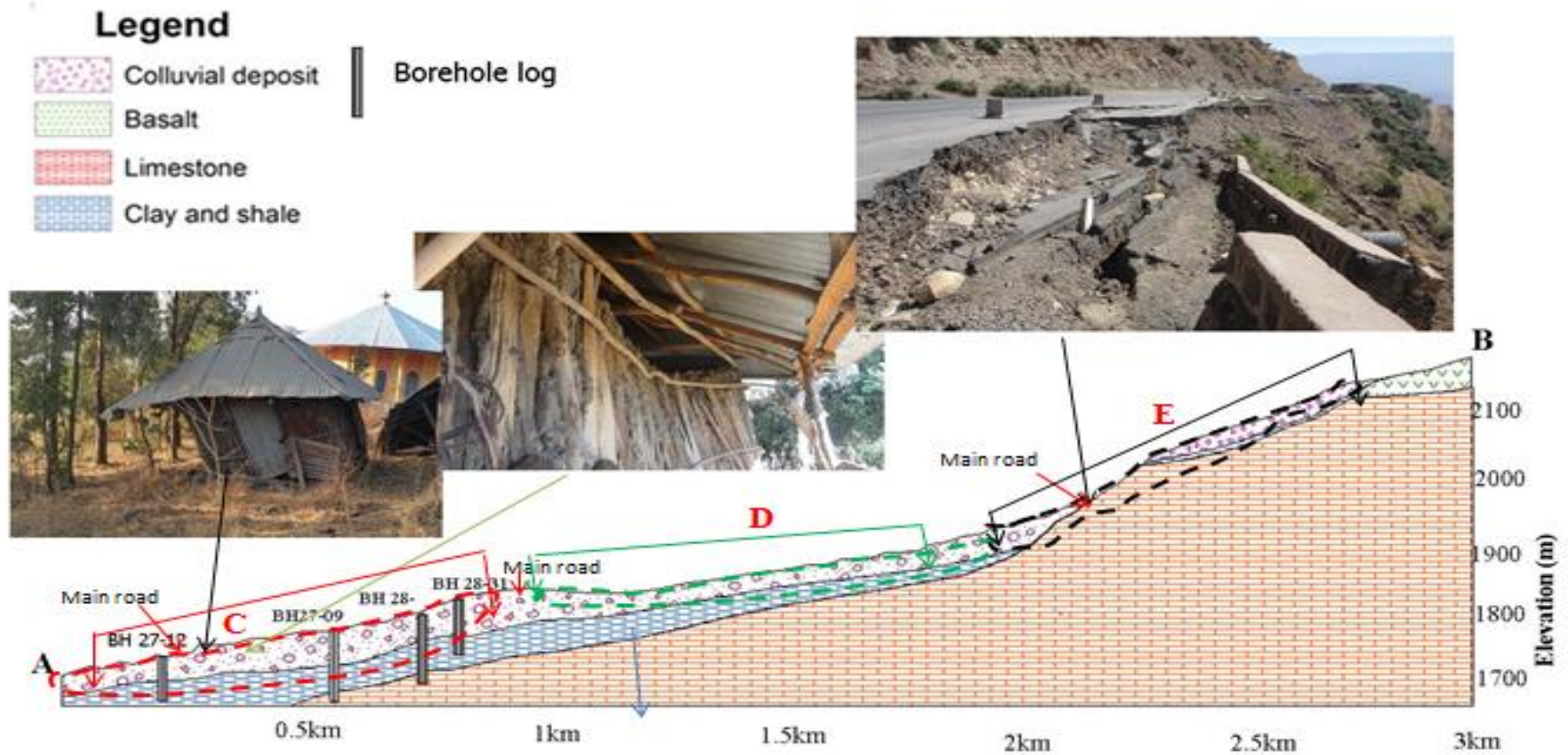


Figure 4. 7 Cross section illustrating of different zone of landslide a) the upper part or unstable zone; b) central part or flat area relatively stable and c) lower part unstable area

Where A and B are cross section line; C and E area unstable area and D relatively stable

Table 5 Landslide characterization and distribution in the present study area (raster calculation)

Class name	area in km <sup>2</sup>	Area in percent (%)
<b>Lithology</b>		
Limestone	0.373899	17.71929043
Basalt	0.000268	0.012700675
Colluvial deposit	1.754989	83.16994641
<b>Land use and land cover</b>		
Barren land	0.580108	27.49165452
Agricultural land	0.769443	36.46434996
Vegetation	0.668467	31.67903877
Water body	0.01	0.473905799

#### 4.1.10 Landslide impact assessment on natural environment and infrastructures

Landslide triggered by different factors were results a serious geo-environmental problem that causes adverse effects to natural environment and properties of local peoples. It could be change, modify and interrupt topographical features. In this area morphological changes or topographical change, land covers change (vegetation or grassland) and modify drainage line mainly and infrastructure, agricultural land considered as effects of landslide.

Morphologic/topographic change is one of the main effects of landslide observed during field investigation which causes for physical damage of surface features of the earth includes degradation and mass (rock and soil) of the slope. The soil mass moved down the slope covers springs water located downslopes ( toe of the slope) and the sediment accumulation in stream channel causes for modification the direction of flow of the water. These are associated with land covers change or denuding the vegetation covers on the slope area and results in an accelerated erosion rate and multiple the landslides hazard. In addition to loss of vegetation causes for the denuded down cause grass land, loss of topsoil and results barren land. These are the main consequences of landslide movement within this area damaged to agricultural land at large scale. The fertile soil from the slope and cultivated area and resulted declines the crop productivity. This phenomenon's lead famine and poverties and suffers future life of local people. Indirectly landslide impacts to natural environment lead the economic disruption to local people, social and the development of the country by decline agricultural productivity, developmental infrastructure and increases the cost to replacement.

Generally, in the area of study various factors such as a growing population and extensive farming pressures encourage rapid land-cover changes; land degradation (rock and soil) movement increases and displaces local people from the area.

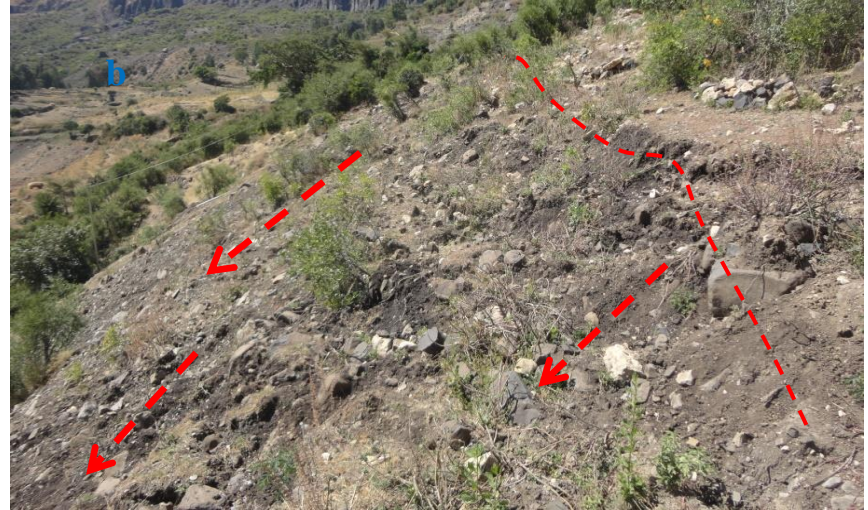


Figure 4.8 Field photos illustrating of landslide impact to natural environment a) completely damaged main road; b) completely damaged agricultural land; c) landslide damaged grass land and soil and d) morphological change

## 4. 2 Geophysical Investigation

### 4.2.1 Data acquisition and Processing

#### 4.2.1.1 Data acquisition

The field data acquisition using this technique has been carried out by the Schlumberger electrode configuration employing the *Scintrex Automatic Resistivity Imaging System (SARIS)* resistivity meter. For this purpose current is injected in to the ground through two electrodes (A and B) and the potential difference is measured by another pair of electrodes, M and N (Telford et al., 1990; Lowrie, 1997 as cited in Fisseha and Mewa, 2016). The maximum separation the current electrode was  $AB/2=150\text{m}$ . The measured potential difference demonstrates the effects of different geological materials within the area of current distribution. In this study four traverse lines (three lines oriented NW-SE and one line E-W) were surveyed and resistivity data has been collected from 14 stations (Figure 3.10).



Line 3 : VES-7 point 1		
easting	nothing	elevations
407541	1119410	1984
AB/2	MN/2	$\rho_a (\Omega\text{-m})$
1.5	0.5	24.07

2.1	0.5	29.25
3	0.5	24.26
4.2	0.5	16.51
6	0.5	22.23
9	0.5	16.11
13.5	0.5	12.66
20	0.5	17.87
20	6	18.61
30	0.5	25.75
30	6	19.68
45	6	19.68
66	6	14.95
100	6	15.2
150	6	66.27

Figure 4. 9 Electrical Resistivity field measurement setup and data acquisition

### 3.2.1.2 Data processing

The measured apparent resistivity sounding data is processed using Win-Resist and IP2WIN software that determine model parameters (resistivity and thickness/depths) produced by least root mean square (RMS) error approach. In this case the RMS error was found to vary between 1.5 and 5% (see Annexures I). Finally, the results are interpreted both qualitatively and quantitatively.

The raw resistivity data is plotted as pseudo-depth section using surfer10 software that roughly demonstrates the vertical variation of measured resistivity's as a function of AB/2 and guides the construction of geo-electrical section using MapInfo software based on which the subsurface structures are quantitatively characterized.

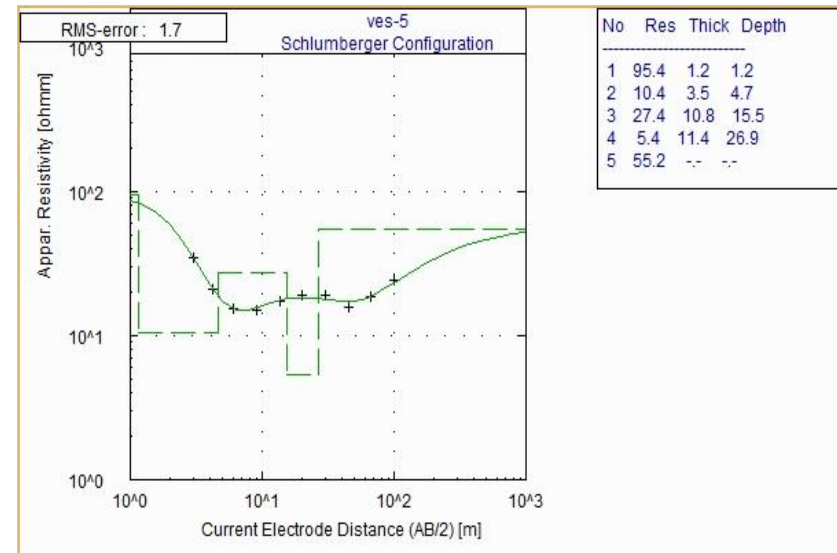
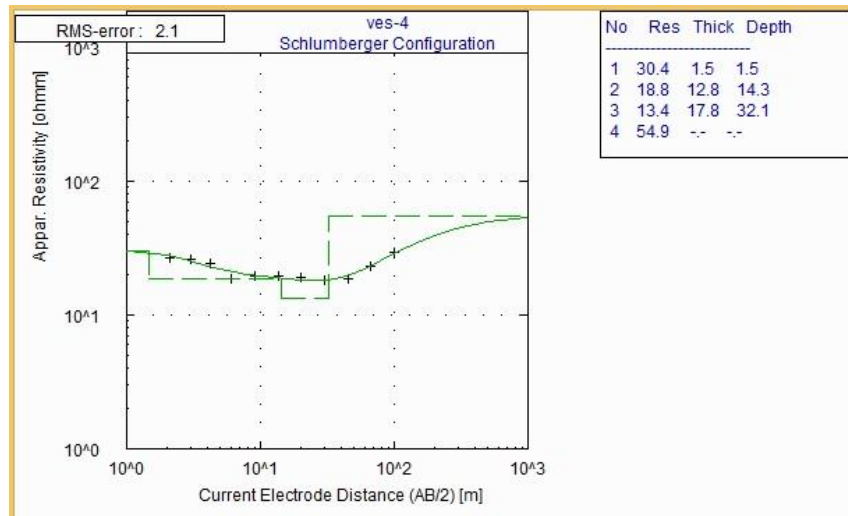
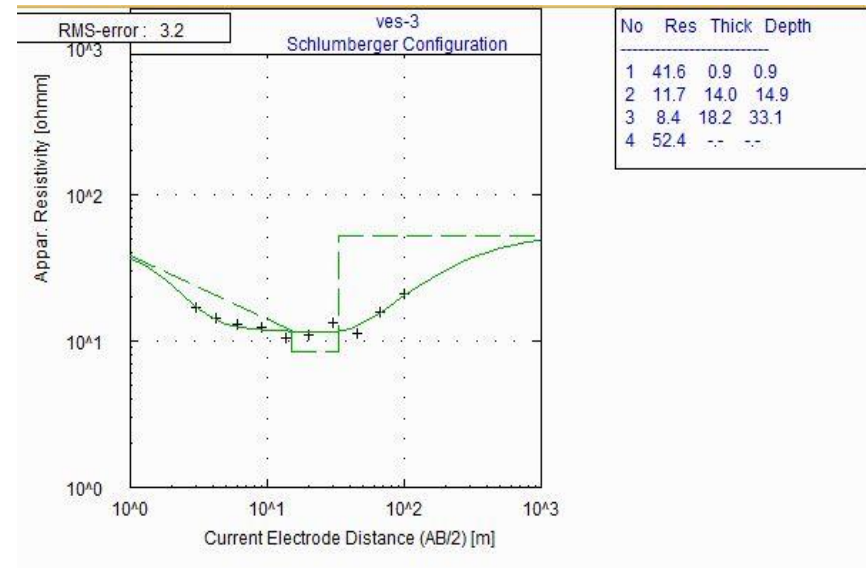
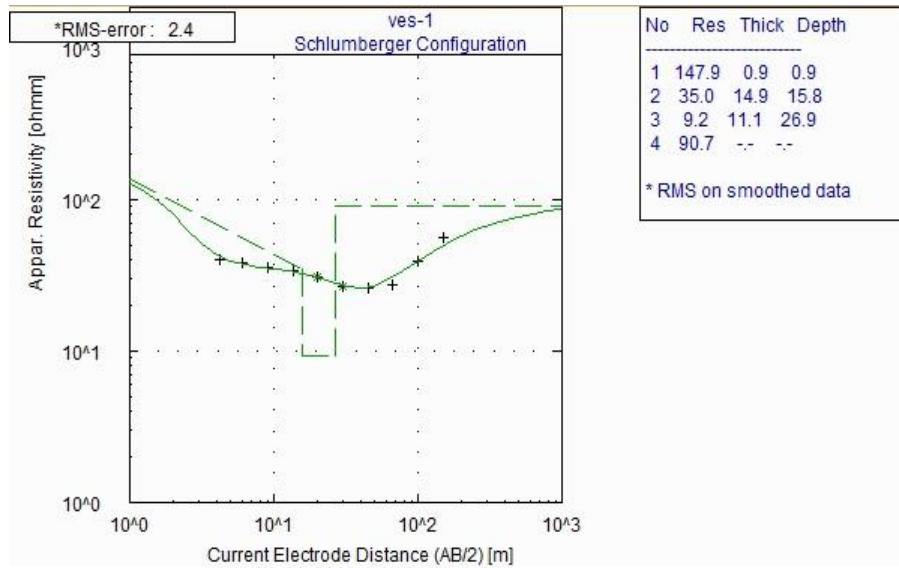


Figure 4.10 Electrical resistivity Model curves

## 4.2.2 Data acquisition and processing

### 4.2.2.1 Seismic refraction data acquisition

Select the position and bearing of traverse line on which exploration was carried out on the investigation of landslide. Installation of geophones on each survey line and spreading the cable and installation shot point over traverse line, then connect the sledgehammer switch and junction line with portable computer which used to control system and receive direct signal from the geophone.

Then, to produce the vibration to the ground, a series of hammer striking the steel plate or stacking has been took place in order to enhance the signal. The seismic vibration of the wave generated was passed through the subsurface and near surface and sensed by geophone which convert this seismic vibration or mechanical energy to electrical impulse (signal) and sent to the system (portable computer). In such a way that seismic refraction helps to provide information about the depth or thickness of overburden material and velocity variation along the spread.

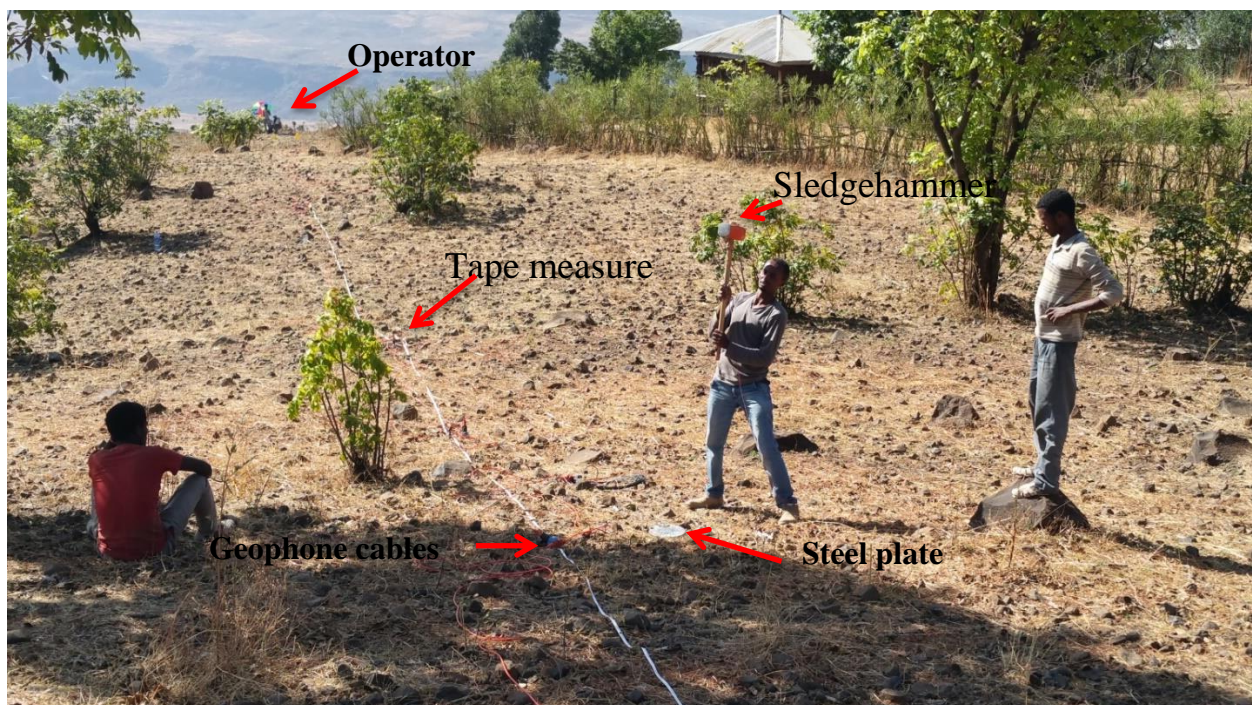


Figure 4. 11 Seismic refraction field measurement setup and data acquisition

#### 4.2.2.2 Seismic refraction Data processing

The process has been conducted with a method using travel time-curve. Arrival time of initial motion of the elastic waves from shot point to each vibration-receiving was read from measurement recorded to create the travel time curve. The shape of travel time curves reflects the velocity structures of, equivalent of velocity distribution of the underground or subsurface geology.

Accordingly the recorded signal data has been processed by software package SEISMAGER/2D with the pick-win (pinking of first arrivals) and PLOTREFA (concentration of dataset). This has been processed in PICKWIN, pick the first arrival time from the field recorded signal and draw time distance graph relationship between the geophone numbers versus the first arrival time of P-waves for each shooting point (Figure.3.15). Then using PLOTREFA tools with help saved pink point or arrival time, determine the general subsurface condition the thickness of loose material and possible number of layer, and strength or compactness of material which generate the intercept time graph as described in figure 3.15. Generally, field measurement, signal recording on portable computer, travel time data, packing the first arrival from each geophone, construct velocity model.

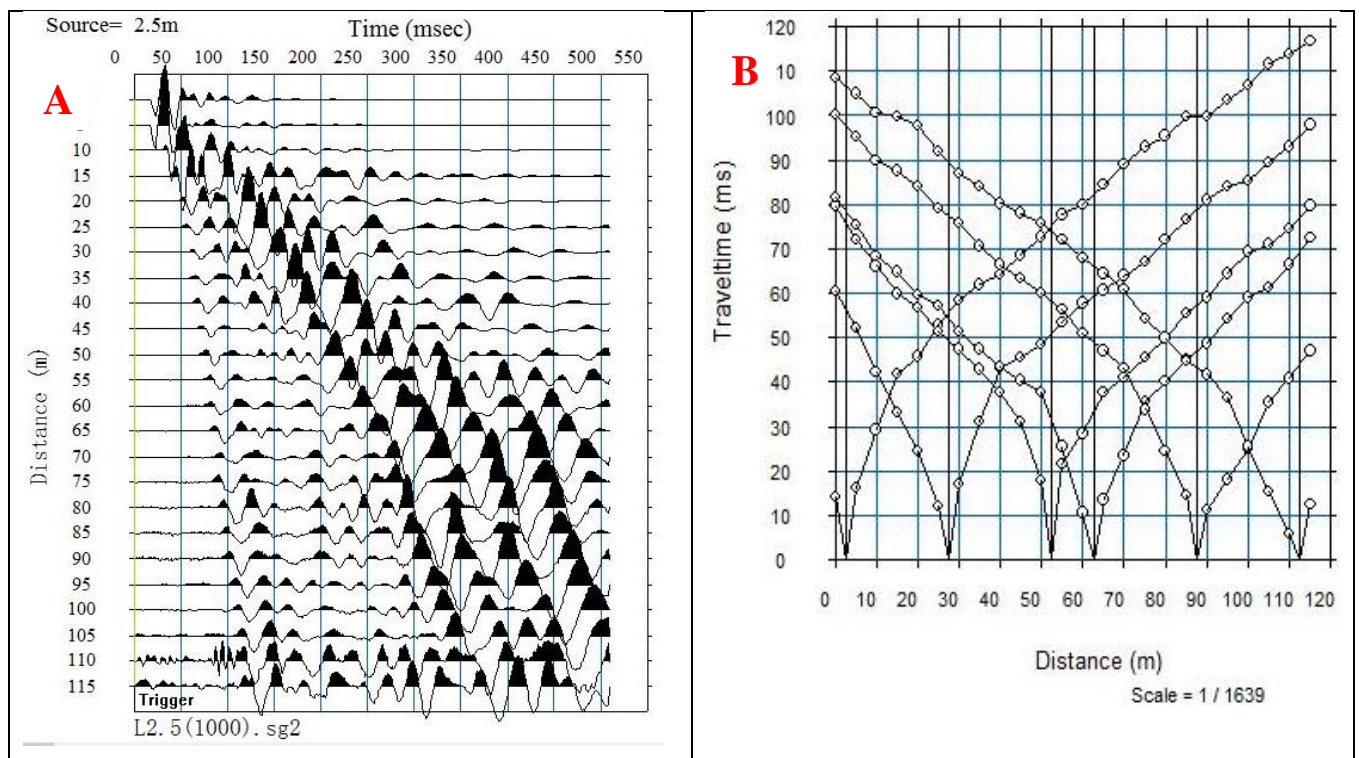


Figure 4. 12 a) Arrival times of P-waves curves for 24-channel seismic spread b) Travel-time

## CHAPTER FIVE

### 5. RESULTS, INTERPRETATIONS AND DISCUSSIONS

Resistivity sounding and seismic refraction survey data interpretation are made incorporating with results of geological investigation carried out simultaneously as well as available borehole log data for the depth up to 25m to 40m.

#### 5.1 Vertical Electrical sounding

Totally, VES data are collected using the Schlumberger array configuration from fourteen stations and processed using computer software. Each sounding (VES) curve interpreted to determine the layer parameters (resistivity of underlying material and their thicknesses). For comprehensive data analyses (quantitative and qualitative) the determined layer parameters are used to compile geo-electric and pseudo-depth sections that are discussed in the following sections.

##### 5.1.1 Line-1

The pseudo-depth section map displayed in Figure 5.1 (bottom of geo-electric section) allowed conduct qualitative data interpretation, based on which both lateral and vertical resistivity variation in the subsurface are studied. Accordingly, this section shows that at VES-9, to some extent at VES-10, a relatively high resistive feature (above 50  $\Omega$ -m) is outlined at the surface, which is underlain by a low resistive zone with wide lateral and vertical distribution. Unlike at VES-9 where low resistivity anomalies occur at depth, the resistivity amplitude VES-11 and VES-12 show a clear increasing trend with depth and thus suggest the presence a relatively hard source rock.

This line is about 373m long profile comprises five VES points, VES-8, VES-9, VES-10, VES-11 and VES-12 and the geoelectric section is displayed in Figure 5.1 (above). This line passes through the landslide zone, where the damaged St. Gabriel Church and surrounding local houses are located and crosses the main road. The result has differentiated three layers with distinct resistivity properties reflecting variation in grain size, moisture content and weathering condition of the underlying formations.

Accordingly, the uppermost layer is delineated by variable resistivities that range between 17 and 92  $\Omega$ -m, and its thickness changes from about 10 to 16m. This resistivity variation characterizes the heterogeneous nature of the upper unconsolidated talus deposit.

The second layer is characterized by very low resistivity values (5-11  $\Omega$ -m), indicating the high moisture content. Its thickness is estimated to vary from 9 to 12m. Correlation of this geophysical result with borehole log data revealed that this high electrical conductivity characterizes the fine grain materials represented by silt, mud, clay and grayish shale. Particularly, the presence of clay acts as barrier that prevents infiltration of groundwater further to depth, rather it creates conducive environment for the overlying colluvial materials to get saturated and results to slope failure. This implies that the intercalated clay layer is recognized as the possible location serving as rupture surface (slip surface).

Similar to the first, the third layer has also shown moderate resistivity responses (19-90  $\Omega$ -m) likely associated with weathered and fractured limestone. It is distributed starting from a depth of about 30-40m BH 27-09.

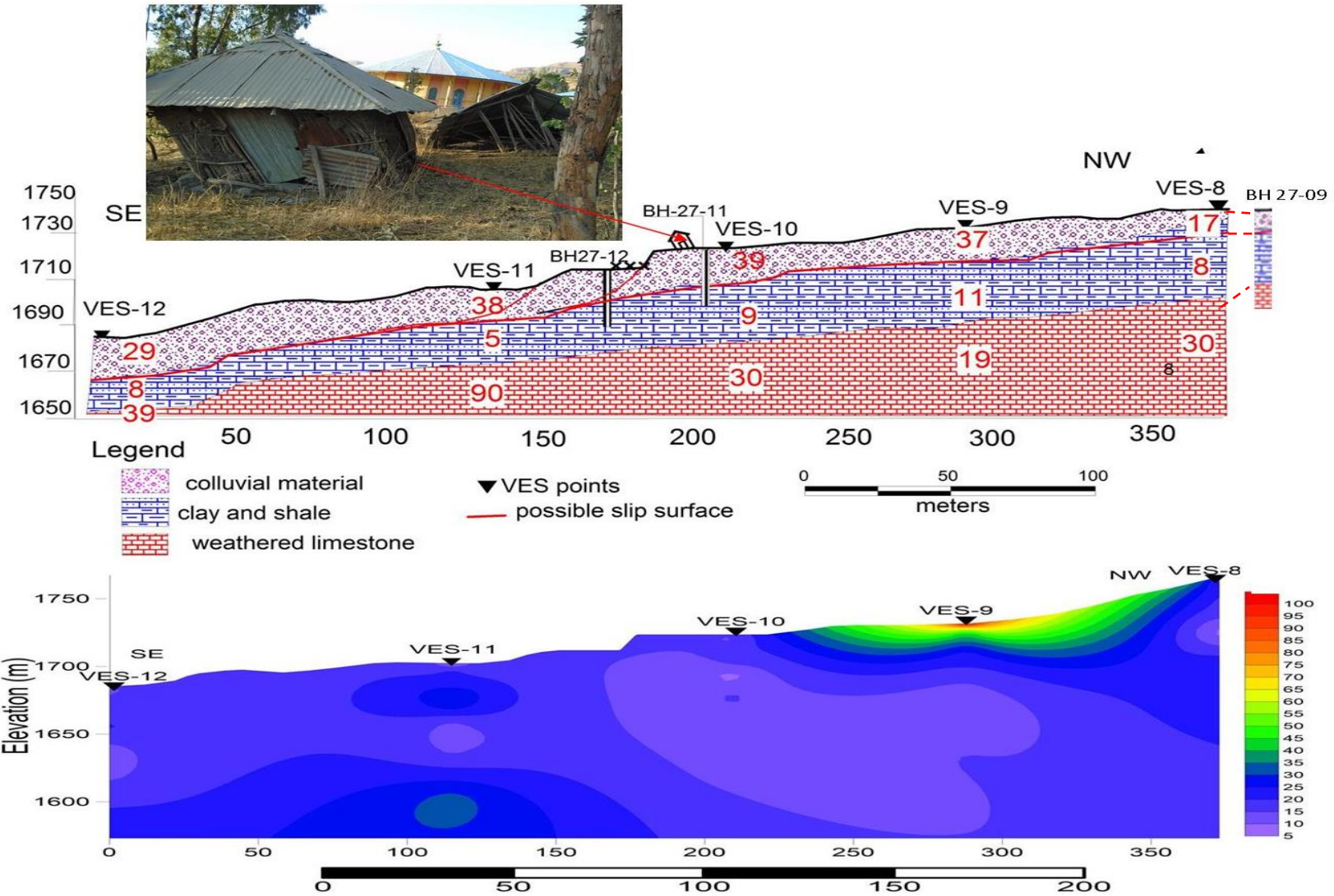


Figure 5. 1 Geo-electric section; Pseudo-depth section of line 1 and completely damage local home

### 5.2.2 Line-2

The pseudo-depth section constructed for this profile (Figure 5.2 bottom) shows that the resistivity responses on the surface are relatively high and then at the middle the amplitude decreases and then the resistivity responses again show a slight increment with depth. This indicates the nature of the subsurface formations has variation in composition, moisture content and degree of weathering and fracturing.

This line is nearly 90m long profile is consisted of two sounding stations, namely VES-13 and VES-14, and aligned NE-SW across a landslide affected zone that intercepted the main road, created scarp and highly cracked surface on the road and farm land. The geo-electric section produced for this profile is displayed in Figure 5.2 (above pseudo-depth section). The results revealed that the subsurface resistivity distributions are classified in to three groups representing three layers with contrasting responses.

Accordingly, the top layer with resistivity values between 45 and 64  $\Omega$ -m and 10-12m thickness range is associated with the upper poorly sorted colluvial deposit, whose thickness significantly increases from SE to NW.

The second layer is relatively very conductive, 8  $\Omega$ -m, and its thickness increases from 10m at VES-14 to 12m at VES-13. This low resistivity response is due to a bed dominated by clay. Between the two VES points the morphology of this bed is nearly flat with slight inclination towards VES-13.

The bottom layer with a resistivity range of 63-84  $\Omega$ -m is mapped from about 25m at VES-14 to 40m depth at VES-13. This depth estimation based on geophysical data closely correlates with borehole data obtained from BH 28-31 and BH 28-32 located nearby the survey line and where fractured and weathered limestone was intercepted at a depth of 32-40m.

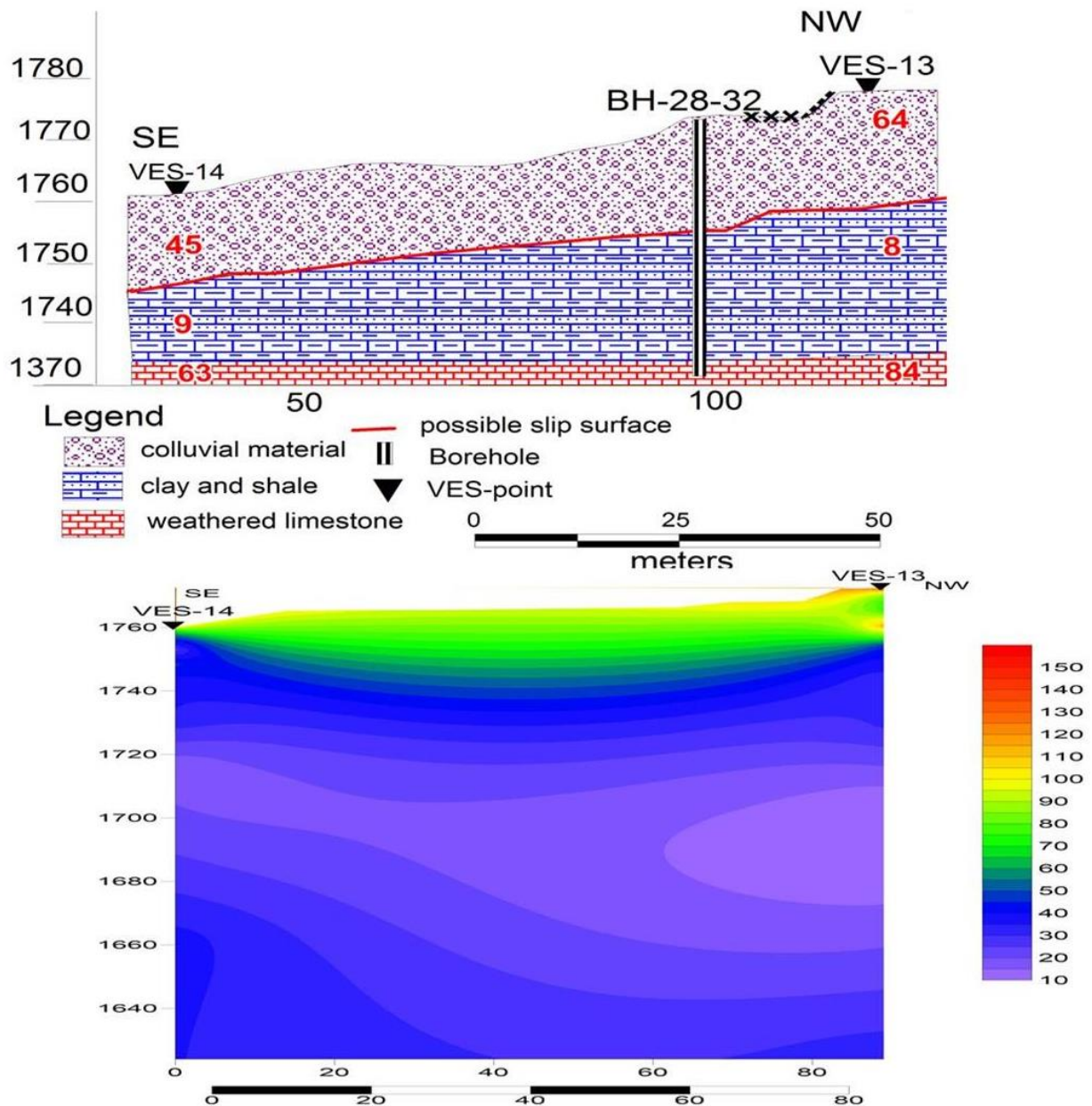


Figure 5. 2 Geo-electric section and Pseudo-depth section of line 2

### 5.1.3 Line-3

The pseudo-depth section map is displayed in Figure 5.3 (bottom) show resistivity variation both laterally and vertically. Accordingly, this section shows that at VES-5 and VES-4 has a relatively high resistive feature (above 39-90  $\Omega$ -m) is outlined near the surface, which is underlain by a low resistive zone with wide lateral and vertical distribution. The top and bottom layer of map shows relatively high resistivity while the middle part shows relatively low resistivity value which shows that this layer is geologically represents weak formation. However, beneath VES-7 the relatively high resistive feature (above 100  $\Omega$ -m) is outlined this may represents hard the geological formation.

Line-3 is trending to NW- SE and contain four sounding points, VES-7, VES-4, VES-5 and VES-6, and the geo-electric section produced using the interpreted layer parameters is displayed in Figure 4.3. This 290m long profile is aligned accross a moderately steep to gentle slope whose slope angle ranges between 30° and 45°.

The subsurface is represented by three geo-electric layers that have similar characteristics to those identified on profiles 1, and 2. Hence, the uppermost layer has shown a moderate resistivity range varying between 32-92  $\Omega$ -m. Its thickness is relatively small that varies from about 1.5 to 3m and such contrast is due to the highly heterogeneous character of the unconsolidated colluvial deposit composed of coarse grained materials, gravels and basaltic boulders.

The second layer shows very low resistivity (5 - 28  $\Omega$ -m), suggesting that it contains considerable amount of moisture content. Its thickness changes from about 8 to 12m. Geologically, this conductive layer is consisted mixture of fine grained silt, clay and at some road and stream cut sections boulders of weathered limestone (Figure 5.3).

The third relatively resistive bed is delineated by 39-110  $\Omega$ -m and these moderate values are associated with the response of a weathered and fractured limestone bed whose surface shows a slight inclination towards SE, i.e., to the valley side. Exposures of this bed are observed at stream and road cut sections.

Due to steepness of the surface morphology, the uppermost unconsolidated materials and the intermediate conductive layer slides over the relatively hard/resistive limestone bed. Therefore the interface between the second and the third layers represents the main slip surface. Close to VES-4 a wooden house is seen being affected by the landslide and similarly about 100m, even less, from that house agricultural land is moderately damaged. Here the surface morphology is relatively steep with a slope gradient of about 30°-45°.

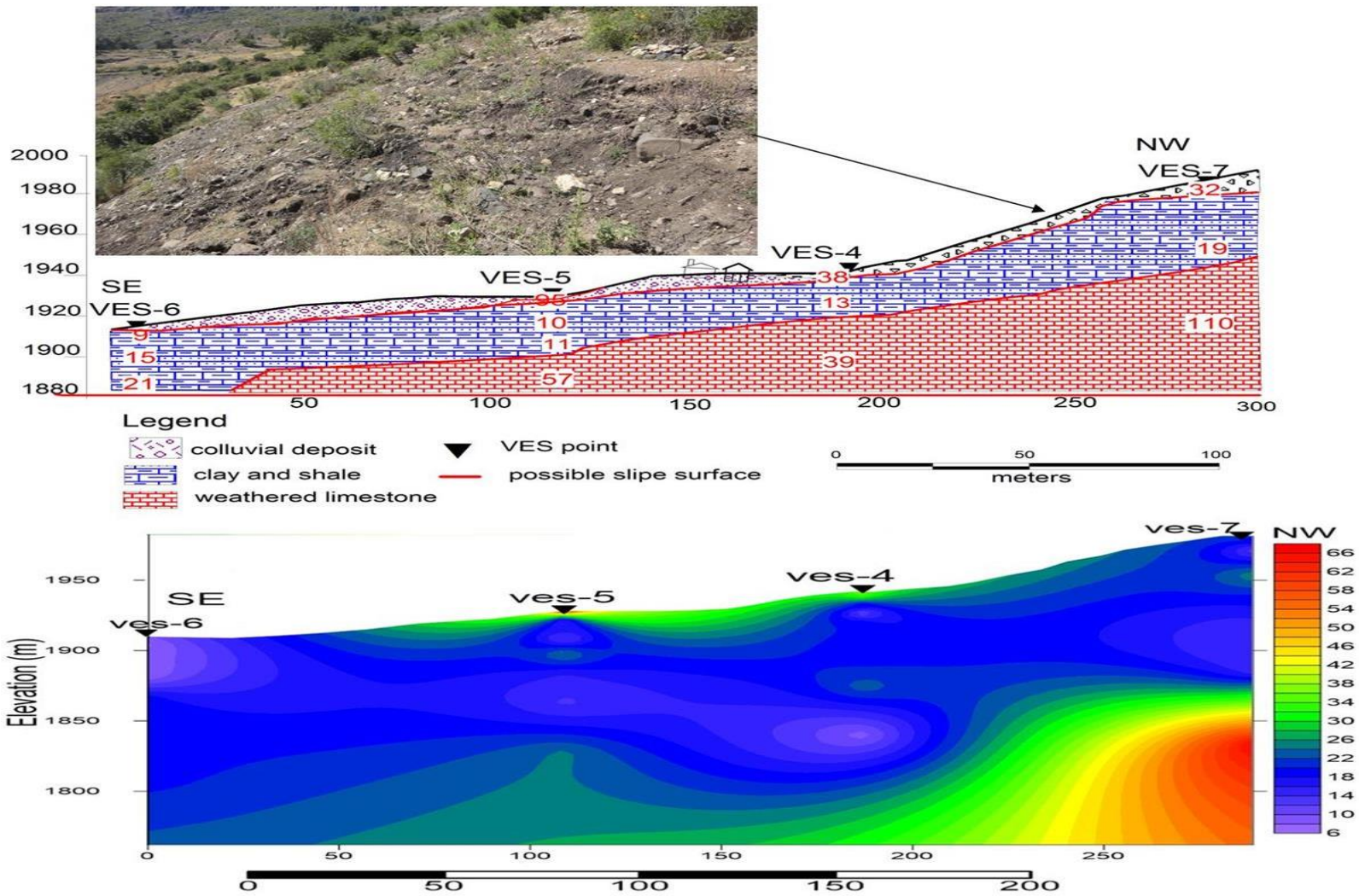


Figure 5.3 Geo-electric section; pseudo-depth section of profile and landslide damaged agricultural land

#### **5.2.4 Traverse line 4**

The pseudo-depth section of this line (Figure 4.4 bottom) shows that the resistivity responses on the surface are relatively high and then decreasing to the depth. But at VES-1 relatively response high resistivity and low at VES-3.

This profile is about 264m long and includes two sounding points, VES-3 and VES-1 that area oriented in E-W direction. It crosses the main road section highly affected by landslide. The geo-electric section in Figure 5.4 shows a similar characteristics to the ones discussed above.

Accordingly, the colluvial deposit is differentiated by enhanced resistivity response (42-145  $\Omega$ -m) and has thickness that changes from about 0.5 to 12m. On the other hand, the second layer which contains high moisture content are found to be very conductive (8-15 $\Omega$ -m) and its thickness changes from about 5 to 10m.

Compared to the resistivity of the overlying second layer the third layer shows moderately enhanced responses that vary from 50 to 150 $\Omega$ -m. These relatively values are associated with weathered and fractured limestone bed, which formed outcrops at the toe of cut sections.

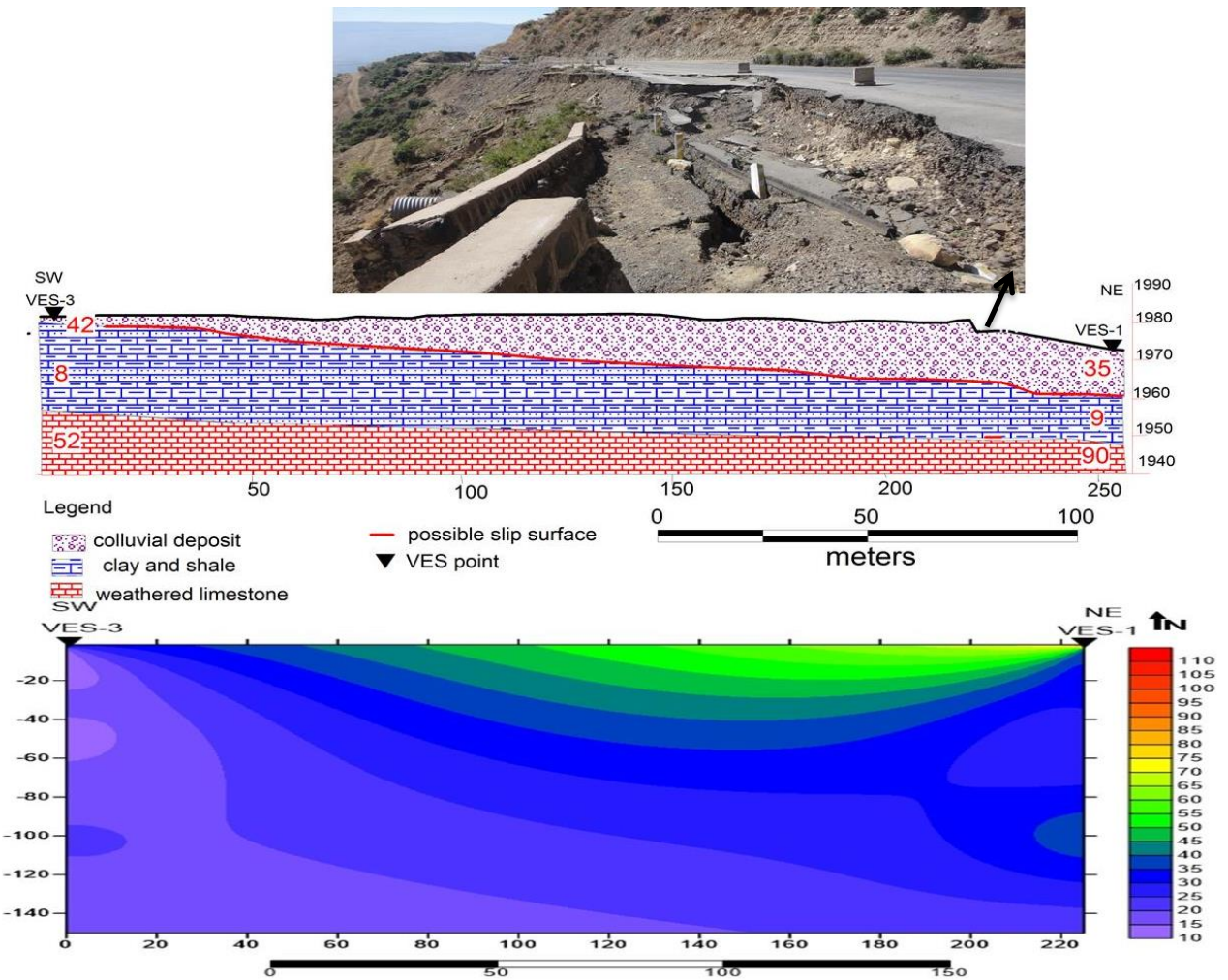


Figure 5. 4 Geo-electric section and pseudo-depth section of line 4

### 5.3 Seismic refraction data Interpretation

In general interpretation of seismic refraction has been implemented based on a travel-time inversion and velocity with the subsurface geological condition. Along the resistivity survey also seismic survey has been conducted and also delineates the presence of three different layers the same as geophysical and geological based on their velocity contrast.

#### Line 1

Seismic refraction survey line 1 has been conducted over total profile length of 115m along sounding line 1 above with same direction NW to SE. According to figure 5.5 shows that the velocity of the top layer has lows velocity 300m/s (0.3km/s) which indicate that the unconsolidated/low compacted material covers the upper most layer. As moved from top to bottom the velocity increases this shows that the adjacent layer has higher velocity range than the first due to the saturated and compacted formation has high velocity than the

unconsolidated dry materials. As results, this layer has medium velocity ranges 1200m/s (1.2km/s). According to borehole log data this second velocity layer corresponding to saturated clay intercalated soil. The third layer has been shows higher velocity than the two layers. This may relatively massive and compacted which considered as weathered limestone comprised to borehole data.

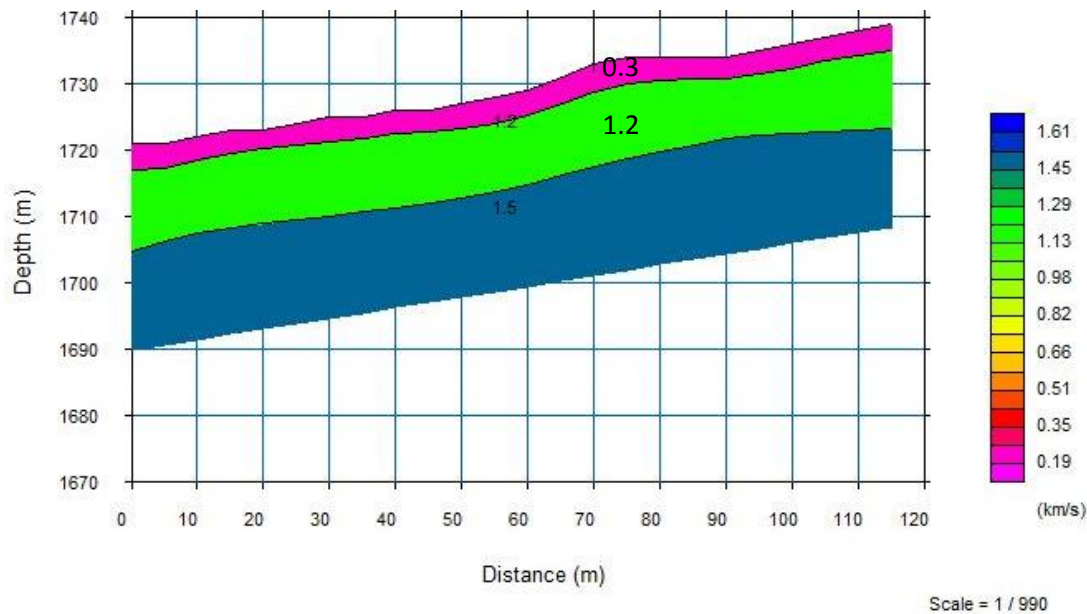


Figure 5. 5 Velocity model of line 1

## Line 2

This survey line is covers about 60m long and located at the sounding line-4 VES-1 and oriented the same as sounding line-4 E-W direction. Accordingly top layer shows low velocity 300m/s which corresponding to unconsolidated material. However, the second layer shows relatively high velocity 700m/s compare to the top layer which indicated the higher level of soil compaction.

The third layer shows relatively high velocity (1800m/s) and is attributed to a limestone bed which has a moderately strong rock mass strength. This indicates the low velocity layer which corresponding to unconsolidated material underlies by relatively hard rock. During rainyseason this hard formation hold

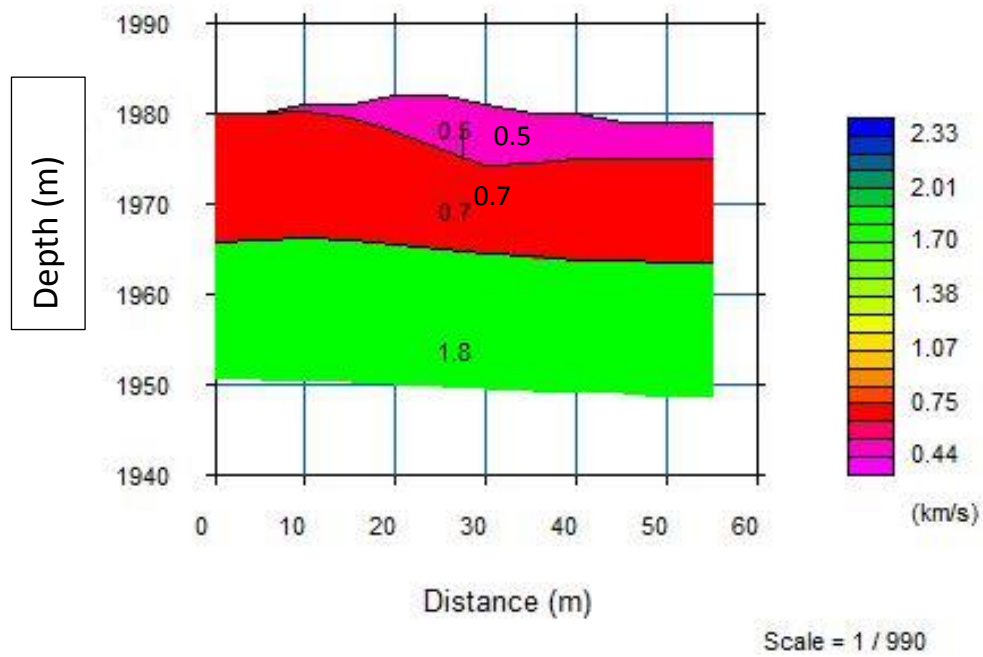


Figure 5. 6 Velocity model of line 2

## CHAPTER SIX

### 6. CONCLUSION AND RECOMMENDATION

#### 6.1 Conclusion

Integrated geological and geophysical investigation (specifically electrical resistivity and seismic refraction) were carried out to characterize landslide prone area, determine their extents and identifying triggering/aggravating factors posing serious impacts on the natural environment and built structures along the main road section within Kurar Kebele of Dejen Woreda, Central Ethiopia.

Based on analyses of both datasets the following conclusions are forwarded:

- i. The geophysical results have identified three distinct layers with contrasting responses. Accordingly, the top layer with relatively high resistivity values (17-95  $\Omega$ -m) and 1.5-14m thickness is unconsolidated moderately dry colluvial deposit. The second conductive layer (5-19  $\Omega$ -m) having a thickness of 5-12m is attributed to a clay bed containing high amount of moisture / fluid content. The third layer is more resistive than the second (19-110  $\Omega$ -m) and it is attributed to the limestone bed. Comparison of these geophysical results with borehole data revealed very close correlations.
- ii. Close assessment of geological cross section and geo-electrical section suggested that the possible slip surface that plays the key role in the landslide process is associated with excessive content of clay intercalated with silt and shale underlying the poorly sorted colluvial deposit. This clay-rich bed / layer has a thickness of 5-12m and characterized by very low electric resistivity values (5-19  $\Omega$ -m) unlike the underlying relatively stable limestone layer with a response of (19-110  $\Omega$ -m). The velocity variation ranging 300m/s 500m/s also characterizes this layer as water saturated slipping zone.
- iii. Majority of the landslides occur over areas with slope gradient between  $10^0$ - $45^0$ , over barren land, and lands where extensive farming is taking place. In this regard, the N-NW margin of the area is characterized by wide manifestations of cracks, springs and seepages that trigger and activate the sliding process considered as unstable zone.

Besides, the central part, which is relatively flat ( $5^{\circ}$ - $8^{\circ}$  slope angle) is considered as stable zone with only scattered sliding mass without significant destructions, whereas the southern part with low ground level is characterized by moderate-high destruction of local houses, collapse of road section and generally recognized as unstable zone.

- iv. The main landslide inducing factors are found to be rainfall, presence of physically soft (weak) lithologies, relatively high slope angle, presence of groundwater that percolates at shallow depth, human activities that severely affecting poor land cover and land use practices, excavations of the toe parts of the landslide affected section. Overall, two types of land mass movements are identified, namely rotational slide and debris slide.
- v. Landslide has direct impact on the natural environment causing topographical change; land covers change (vegetation or grassland), land degradation, mass wasting (soil and rock) and socio-economic crises, damages of infrastructures and disruption of traffic flows, reduction of agricultural productivity and leads famine and poverties and suffers future life of local people.

## **6.2 Recommendation**

1. According to present study result, the upper part of the lithologic section is considered as highly landslide affected zone. Therefore, before the construction of any kind of engineering structures adequate treatment of slopes is recommended in order to ensure the safety and sustainability of the structures.
2. The local person have reported that rain fall and subsequent flooding near or over critical slope sections highly erodes the toe of the slope and cultivated land. Hence, it is recommended to prepare a proper engineering design to manage the drainage by constructing trench drains, collect improper drain from critical slope, diverting water to the main drainage systems.
3. During the field work intensive deforestation / removing vegetation from the critical slope sections was observed that immensely contributes to the sliding process and road damage. Hence, it is recommended to make utmost efforts to improve the awareness of the local people about environmental safety and support them to plant deep-rooted trees, take soil conservation measures, and minimize settlement and farming on steep slopes.

4. Generally, in this area and surrounding the highly destruction of road will be expected due to the toe of the road and slope eroded and the upper part of the road is highly cracked or opened about 0.5-1.5m space particularly near to the millennium (2000) bridge. It is recommended that a stakeholder have to take mitigation measure in time unless the road connecting the central part of the country with Northern western part will be disconnected in a few years.

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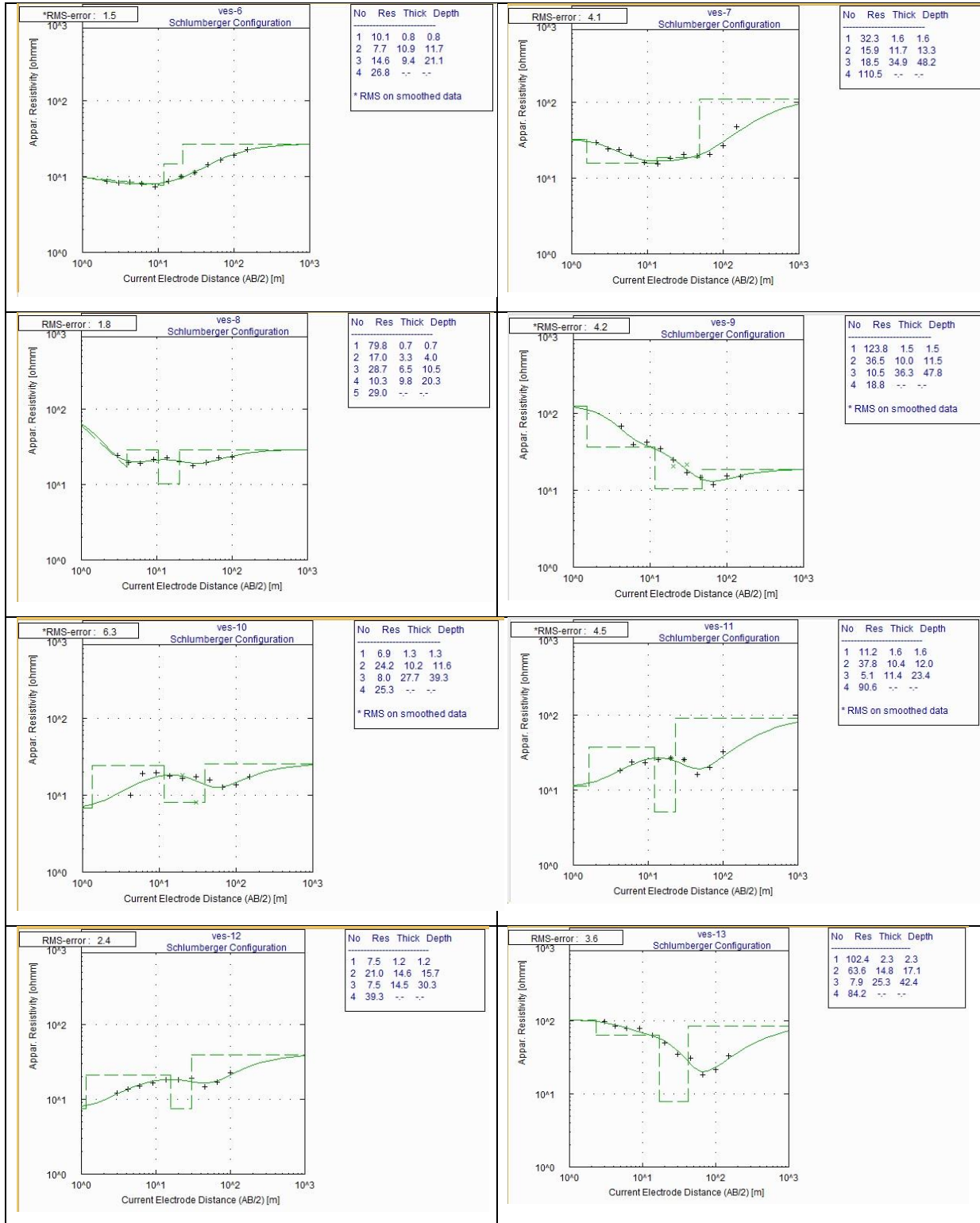
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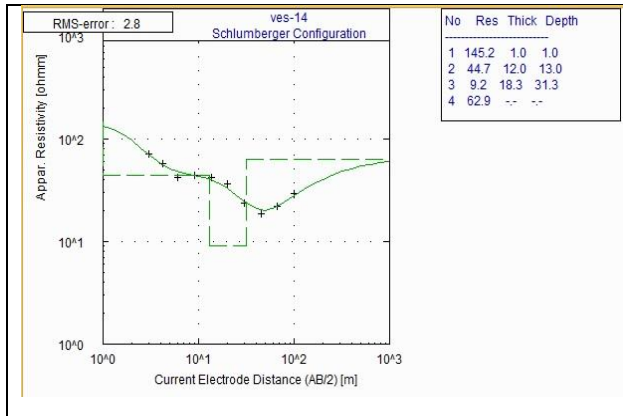
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# Annexures

## I. Model curves of each sounding





## II. VES data recorded during field work

Line1

Location point VES data						Line 1 pseudo depth section					
eastin	nothing	elevations					x	y	z	Z1	Ro_a
g											
<b>40785</b>	<b>111752</b>	<b>1740</b>	<b>AB/</b>	<b>MN/</b>	<b>Ro_a</b>						
<b>6</b>	<b>1</b>		<b>2</b>	<b>2</b>							
		VES8	1.5	0.5	74.6		0	1770	1.5	1768.	74.6
			2.1	0.5	42.2		0	1770	2.1	1767.	42.2
			3	0.5	24.3		0	1770	3	1767	24.3
			4.2	0.5	15.2		0	1770	4.2	1765.	15.2
			6	0.5	17.39		0	1770	6	1764	17.39
			9	0.5	21.41		0	1770	9	1761	21.41
			13.5	0.5	22.8		0	1770	13.	1756.	22.8
			20	0.5	19.5		0	1770	20	1750	19.5
			20	6	20.5		0	1770	20	1750	20.5
			30	0.5	17.7		0	1770	30	1740	17.7
			30	6	18.1		0	1770	30	1740	18.1
			45	6	8.2		0	1770	45	1725	8.2

			66	6	22.6		0	1770	66	1704	22.6
			100	6	23.1		0	1770	100	1670	23.1
<b>40790</b>	<b>111745</b>	<b>1732</b>	<b>AB/</b>	<b>MN/</b>	<b>Ro_a</b>		85	1732	1.5	1730.	103.1
<b>5</b>	<b>2</b>		<b>2</b>	<b>2</b>						5	
		VES9	1.5	0.5	103.1		85	1732	2.1	1729.	94.3
										9	
			2.1	0.5	94.3		85	1732	3	1729	69.3
			3	0.5	69.3		85	1732	4.2	1727.	67.63
										8	
			4.2	0.5	67.63		85	1732	6	1726	39.06
			6	0.5	39.06		85	1732	9	1723	41.9
			9	0.5	41.9		85	1732	13.	1718.	34.9
									5	5	
			13.5	0.5	34.9		85	1732	20	1712	25.1
			20	0.5	25.1		85	1732	20	1712	20.3
			20	6	20.3		85	1732	30	1702	21.3
			30	0.5	21.3		85	1732	30	1702	17.1
			30	6	17.1		85	1732	45	1687	14.7
			45	6	14.7		85	1732	66	1666	11.8
			66	6	11.8		85	1732	100	1632	15.3
			100	6	15.3		85	1732	150	1582	14.9
			150	6	14.9		164	1723	1.5	1721.	13.83
										5	
<b>40794</b>	<b>111738</b>	<b>1723</b>	<b>AB/</b>	<b>MN/</b>	<b>Ro_a</b>		164	1723	2.1	1720.	17.21
<b>6</b>	<b>4</b>		<b>2</b>	<b>2</b>						9	
		VES1	1.5	0.5	13.83		164	1723	3	1720	16.59
		0									
			2.1	0.5	17.21		164	1723	4.2	1718.	9.98
										8	
			3	0.5	16.59		164	1723	6	1717	18.9
			4.2	0.5	9.98		164	1723	9	1714	19.8
			6	0.5	18.9		164	1723	13.	1709.	17.65
									5	5	

			9	0.5	19.8		164	1723	20	1703	16.42
			13.5	0.5	17.65		164	1723	20	1703	18.41
			20	0.5	16.42		164	1723	30	1693	8.13
			20	6	18.41		164	1723	30	1693	17.37
			30	0.5	8.13		164	1723	45	1678	15.74
			30	6	17.37		164	1723	66	1657	12.77
			45	6	15.74		164	1723	100	1623	13.5
			66	6	12.77		164	1723	150	1573	17.5
			100	6	13.5		258	1702	1.5	1700. 5	12.12
			150	6	17.5		258	1702	2.1	1699. 9	13.17
<b>40800</b>	<b>111730</b>	<b>1702</b>	<b>AB/</b>	<b>MN/</b>	<b>Ro_a</b>		258	1702	3	1699	14.1
<b>0</b>	<b>7</b>	VES1 1	<b>2</b>	<b>2</b>			258	1702	4.2	1697. 8	18.26
			2.1	0.5	13.17		258	1702	6	1696	23.58
			3	0.5	14.1		258	1702	9	1693	23.06
			4.2	0.5	18.26		258	1702	13. 5	1688. 5	17.77
			6	0.5	23.58		258	1702	20	1682	29.87
			9	0.5	23.06		258	1702	20	1682	23.45
			13.5	0.5	17.77		258	1702	30	1672	29.17
			20	0.5	29.87		258	1702	30	1672	21.4
			20	6	23.45		258	1702	45	1657	13.2
			30	0.5	29.17		258	1702	66	1636	14.58
			30	6	21.4		258	1702	100	1602	32.35
			45	6	13.2		373	1685	1.5	1683. 5	15.33
			66	6	14.58		373	1685	2.1	1682. 9	14.91
			100	6	32.35		373	1685	3	1682	12
<b>40809</b>	<b>111723</b>	<b>1685</b>	<b>AB/</b>	<b>MN/</b>	<b>Ro_a</b>		373	1685	4.2	1680.	15.3

<b>0</b>	<b>6</b>		<b>2</b>	<b>2</b>						<b>8</b>	
		VES1 2	1.5	0.5	15.33		373	1685	6	1679	15.2
			2.1	0.5	14.91		373	1685	9	1676	16.4
			3	0.5	12		373	1685	13. 5	1671. 5	18.3
			4.2	0.5	15.3		373	1685	20	1665	17.73
			6	0.5	15.2		373	1685	20	1665	18.79
			9	0.5	16.4		373	1685	30	1655	20.73
			13.5	0.5	18.3		373	1685	30	1655	17.3
			20	0.5	17.73		373	1685	45	1640	13.78
			20	6	18.79		373	1685	66	1619	14.2
			30	0.5	20.73		373	1685	100	1585	22.39
			30	6	17.3						
			45	6	13.78						
			66	6	14.2						
			100	6	22.39						

Line2

VES location point			Line 2 VES data			Line 2 pseudo depth section				
eastin g	nothing	elevation s	AB/ 2	MN/2	Ro_a	x	y	z	z1	Ro_ a
<b>40788</b>	<b>111790</b>	<b>1774</b>								
<b>5</b>	<b>9</b>	VES13	1.5	0.5	152.3	0	177 4	1.5	1772. 5	152. 3
			2.1	0.5	83.7	0	177 4	2.1	1771. 9	83.7
			3	0.5	96.92	0	177 4	3	1771	96.9 2
			4.2	0.5	84.02	0	177 4	4.2	1769. 8	84.0 2

			6	0.5	77.99	0	177 4	6	1768	77.9 9
			9	0.5	77.97	0	177 4	9	1765	77.9 7
			13.5	0.5	114.7	0	177 4	13. 5	1760. 5	114. 7
			20	0.5	44.4	0	177 4	20	1754	44.4
			20	6	56.53	0	177 4	20	1754	56.5 3
			30	0.5	32.77	0	177 4	30	1744	32.7 7
			30	6	37.04	0	177 4	30	1744	37.0 4
			45	6	30.65	0	177 4	45	1729	30.6 5
			66	6	13.6	0	177 4	66	1708	13.6
			100	6	14.6	0	177 4	100	1674	14.6
			150	6	33.38	0	177 4	150	1624	33.3 8
<b>40796</b>	<b>111787</b>	<b>1762</b>	<b>AB/</b>	<b>MN/2</b>	<b>Ro_a</b>	89	176	1.5	1760.	118.
<b>3</b>	<b>2</b>		<b>2</b>				2		5	5
		VES14	1.5	0.5	118.5	89	176 2	2.1	1759. 9	83
			2.1	0.5	83	89	176 2	3	1759	72.1 8
			3	0.5	72.18	89	176 2	4.2	1757. 8	57.6 2
			4.2	0.5	57.62	89	176 2	6	1756	42.5 7
			6	0.5	42.57	89	176	9	1753	27.3

							2			7
			9	0.5	27.37	89	176	13.	1748.	46.7
							2	5	5	8
			13.5	0.5	46.78	89	176	20	1742	36.2
							2			3
			20	0.5	36.23	89	176	20	1742	55
							2			
			20	6	55	89	176	30	1732	34.6
							2			7
			30	0.5	34.67	89	176	30	1732	18.4
							2			8
			30	6	18.48	89	176	45	1717	17.3
							2			
			45	6	17.3	89	176	66	1696	22.3
							2			
			66	6	22.3	89	176	100	1662	36.9
							2			7
			100	6	36.97					

Line3

VES location point			line 3 VES Data			Line 3 pseudo depth section					
easting	nothing	elevations									
<b>407541</b>	<b>1119410</b>	<b>1984</b>	<b>AB/2</b>	<b>MN/2</b>	<b>Ro_a</b>						
			1.5	0.5	24.07	y	z	z1	x	y	Ro_a
			2.1	0.5	29.25	1984	1.5	1982.5	0	1982.5	24.07
			3	0.5	24.26	1984	2.1	1981.9	0	1981.9	29.25
		VESS-7	4.2	0.5	16.51	1984	3	1981	0	1981	24.26
			6	0.5	22.23	1984	4.2	1979.8	0	1979.8	16.51
			9	0.5	16.11	1984	6	1978	0	1978	22.23
			13.5	0.5	12.66	1984	9	1975	0	1975	16.11
			20	0.5	17.87	1984	13.5	1970.5	0	1970.5	12.66
			20	6	18.61	1984	20	1964	0	1964	17.87

			30	0.5	25.75	1984	20	1964	0	1964	18.61
			30	6	19.68	1984	30	1954	0	1954	25.75
			45	6	19.68	1984	30	1954	0	1954	19.68
			66	6	14.95	1984	45	1939	0	1939	19.68
			100	6	15.2	1984	66	1918	0	1918	14.95
		1940	150	6	66.27	1984	100	1884	0	1884	15.2
<b>407590</b>	<b>1119320</b>	<b>VES4</b>	<b>AB/2</b>	<b>MN/2</b>	<b>Ro_a</b>	1984	150	1834	0	1834	66.27
			1.5	0.5	34.24	1940	1.5	1938.5	102	1836.5	34.24
			2.1	0.5	25.9	1940	2.1	1937.9	102	1835.9	25.9
			3	0.5	35.9	1940	3	1937	102	1835	35.9
			4.2	0.5	24.4	1940	4.2	1935.8	102	1833.8	24.4
			6	0.5	18.7	1940	6	1934	102	1832	18.7
			9	0.5	19.39	1940	9	1931	102	1829	19.39
			13.5	0.5	10.75	1940	13.5	1926.5	102	1824.5	10.75
			20	0.5	20.1	1940	20	1920	102	1818	20.1
			20	6	18.3	1940	20	1920	102	1818	18.3
			30	0.5	19.2	1940	30	1910	102	1808	19.2
			30	6	17.1	1940	30	1910	102	1808	17.1
			45	6	18.7	1940	45	1895	102	1793	18.7
			66	6	23.2	1940	66	1874	102	1772	23.2
		1928	100	6	8.9	1940	100	1840	102	1738	8.9
<b>407636</b>	<b>1119257</b>	<b>VES5</b>	<b>AB/2</b>	<b>MN/2</b>	<b>Ro_a</b>	1928	1.5	1926.5	180	1746.5	60.24
			1.5	0.5	60.24	1928	2.1	1925.9	180	1745.9	48.44
			2.1	0.5	48.44	1928	3	1925	180	1745	34.71
			3	0.5	34.71	1928	4.2	1923.8	180	1743.8	21.26
			4.2	0.5	21.26	1928	6	1922	180	1742	15.42
			6	0.5	15.42	1928	9	1919	180	1739	15.17
			9	0.5	15.17	1928	13.5	1914.5	180	1734.5	17.26
			13.5	0.5	17.26	1928	20	1908	180	1728	12.45
			20	0.5	12.45	1928	20	1908	180	1728	18.42
			20	6	18.42	1928	30	1898	180	1718	25.26
			30	0.5	25.26	1928	30	1898	180	1718	17.18

			30	6	17.18	1928	45	1883	180	1703	15.81
			45	6	15.81	1928	66	1862	180	1682	13.66
			66	6	13.66	1928	100	1828	180	1648	24.38
			100	6	24.38	1912	1.5	1910.5	289	1621.5	12.72
<b>407715</b>	<b>1119181</b>	<b>1912</b>	<b>AB/2</b>	<b>MN/2</b>	<b>Ro_a</b>	1912	2.1	1909.9	289	1620.9	8.71
			1.5	0.5	12.72	1912	3	1909	289	1620	8.28
		VES6	2.1	0.5	8.71	1912	4.2	1907.8	289	1618.8	8.46
			3	0.5	8.28	1912	6	1906	289	1617	8.15
			4.2	0.5	8.46	1912	9	1903	289	1614	7.4
			6	0.5	8.15	1912	13.5	1898.5	289	1609.5	9.02
			9	0.5	7.4	1912	20	1892	289	1603	9.45
			13.5	0.5	9.02	1912	20	1892	289	1603	10.35
			20	0.5	9.45	1912	30	1882	289	1593	7.95
			20	6	10.35	1912	30	1882	289	1593	10.98
			30	0.5	7.95	1912	45	1867	289	1578	18.94
			30	6	10.98	1912	66	1846	289	1557	19.37
			45	6	18.94	1912	100	1812	289	1523	19.06
			66	6	19.37	1912	150	1762	289	1473	22.7
			100	6	19.06						
			150	6	22.7						

Line4

VES location point			Line 4VES data			pseudo depth section				
easting	nothing	elevation	AB/	MN/	Ro_	x	y	z	z1	Ro_
		s								
<b>407854</b>	<b>111966</b>	<b>1977</b>	<b>2</b>	<b>2</b>	<b>a</b>	0	1977	1.5	1975.	106.
	<b>3</b>								5	2
		VES1	1.5	0.5	106.	0	1977	2.1	1974.	94.1
					2				9	
			2.1	0.5	94.1	0	1977	3	1974	49
			3	0.5	49	0	1977	4.2	1972.	40.4
									8	

			4.2	0.5	40.4		0	1977	6	1971	36.2
			6	0.5	36.2		0	1977	9	1968	36
			9	0.5	36		0	1977	13.5	1963. 5	34.1
			13.5	0.5	34.1		0	1977	20	1957	32.1
			20	0.5	32.1		0	1977	20	1957	30
			20	6	30		0	1977	30	1947	31.6
			30	0.5	31.6		0	1977	30	1947	25.7
			30	6	25.7		0	1977	45	1932	26.1
			45	6	26.1		0	1977	66	1911	27.4
			66	6	27.4		0	1977	100	1877	39.4
			100	6	39.4		0	1977	150	1827	20.3
			150	6	20.3		264	1986	1.5	1984. 5	44.3
<b>407690</b>	<b>111945</b>	<b>1986</b>	<b>AB/ 2</b>	<b>MN/ 2</b>	<b>Ro_ a</b>		264	1986	2.1	1983. 9	22.6
		VES3	1.5	0.5	44.3		264	1986	3	1983	16.9
			2.1	0.5	22.6		264	1986	4.2	1981. 8	14.2 2
			3	0.5	16.9		264	1986	6	1980	13.1
			4.2	0.5	14.2 2		264	1986	9	1977	12.5
			6	0.5	13.1		264	1986	13.5	1972. 5	13.1 9
			9	0.5	12.5		264	1986	20	1966	10.4 3
			13.5	0.5	13.1 9		264	1986	20	1966	11.8
			20	0.5	10.4 3		264	1986	30	1956	19.9
			20	6	11.8		264	1986	30	1956	14.9
			30	0.5	19.9		264	1986	45	1941	11.4
			30	6	14.9		264	1986	66	1920	15.9

			45	6	11.4		264	1986	100	1886	20.8
			66	6	15.9						
			100	6	20.8						

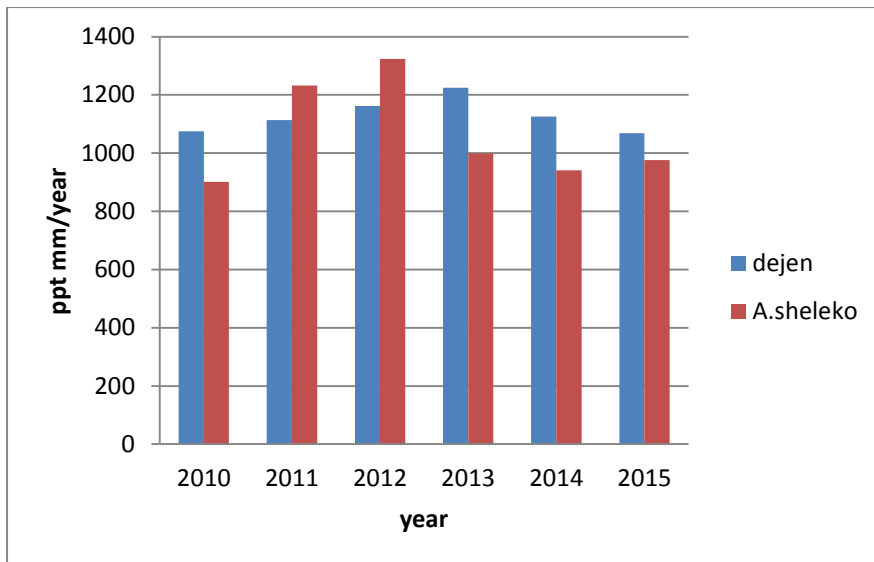
### III. Rain fall data

#### 1. Dejen rainfall

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	annual av.
2010	0	4.7	93.3	87.2	174.7	77.6	240.3	275.6	79	14	28.2	0	1074.5	89.5417
2011	0	0	100	44.8	0	151.2	195.2	360.6	149	0	113.1	0	1113.8	101.255
2012	0	0	100	44.8	28.7	137.9	322.8	294.1	220	1.4	11.8	0	1161.9	96.825
2013	0	0	15.4	14.1	122	172.4	351.4	310.7	118	110	9.9	0	1224.1	102.008
2014	0	39	19.6	95.6	53	0	279	227.4	286	88	38.4	0	1125.4	102.309
2015	0	4.1	10.4	0	185.2	89.9	129.6	319.4	167	30	110.4	23	1068.6	89.05

#### 2. Abay sheleko

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov.	Dec	Total	annual av.
2010	3.1	2.1	47.7	83.5	115	111.8	168.4	369.4	-	-	-	-	901	112.62
2011	7.4	0	59.7	27.5	138.9	153.1	220	276.6	187.4	0	162.1	0	1232.7	102.72
2012	0	0	58.5	69.7	33.9	198.5	367.7	348.1	201.8	37.2	8.7	0	1324.1	110.34
2013	-	-	-	-	-	-	215.8	288	223.8	266	5.4	0		0
2014	0	11.6	0	76.4	117.7	64.5	194.8	233.3	215.3	0	27.5	0	941.1	78.425
2015	0	-	0	0	163.6	130.5	132.2	268.8	157.4	0	123.3		975.8	81.316
2016	-	-	-	-	-	69.5	195.3	-	-	-	-	-	264.8	132.4



Annual precipitation of Dejen and Abay sheleko from 2010-2015

#### IV. Borehole log data

Borehole name	BH27-11		Location	Around 1km from Goha Tsion, Abay Gorge area, National road 3		Latitude	10.06.234		
Organization	Geological Survey of Ethiopia, JICA Study Team			Duration	作業日報確認		Longitude	38.09.325	
Surveyer	Shoji Tsuchiyama			Core appraiser	Shoji Tsuchiyama		Drilling operators	作業日報確認	
Elevation (m)	1722.0m		Depth (m)	25.0		Drilling rig, Engine, Pump		作業日報確認	
Angle	Vertical	Direction	Gradient	Remarks		Installation of borehole inclinometer			

Scale (m)	Elevation (m)	Thickness (m)	Depth (m)	Column	Geology/ Soil	Colour	Relative density	Hardness	Weathering	Size	Geological logs	Groundwater level (m)	Core recovery (%)	Maximum length (cm)	Rock Quality Designation	SPT N value	In-site test							
1.0					colluvial deposit	black grey	relatively-low	soft			0.00-8.90m: colluvial deposit in black grey in color. It is dominantly composed of basaltic gravel.  In the surface layer, some tufficious gravels is found. The gravels are around 20-60mm in diameter in size , hard in hardness and sub-angular - angular in shape. (possibility of natural ground)		60											
2.0																			80					
3.0																				90				
4.0																				70				
5.0																				100				
6.0																				100				
7.0													high		hard					100				
8.0													yellow brown - black grey							100				
9.0	###	8.9	8.9																	100				
10.0			9.4		sliding soil mass (mainly silt and shale)	greenish grey		slightly high	slightly weathering	15-19 cm	8.90-9.40m: weathered silt(tuffaceous)		100	19	19									
11.0		###				greenish grey		slightly high	slightly weathering	15-19 cm	9.40-11.00m: slightly weathered silt(tuffaceous). It is composed of rock fragment - short columnar core. It sounds fozy when hammered blow to core.		100	15	26									
12.0						brownish grey					11.00-22.65m: It is dominantly composed of rock fragment core. The porous cracks by force of weathering are distinguished. The color around cracks partly become brown grey. It can check rock structure remaining. It is fractured when hammered lightly-blow to core. The hardness extent of CL class.		100											
13.0						greenish grey	slightly low		high weathering		14.10-15.35m: moderate whetered shale in greenish grey in color.		100											
14.0		14				greenish grey					15.35-17.15m: moderate whetered silt(tuffaceous) in reddish grey in color.		100											
15.0		15				greenish grey					17.15-18.50m: moderate whetered shale in greenish grey in color.		100	10	10									
16.0						brownish grey					18.50-25.00m: moderate whetered silt in reddish grey in color.		100	10	10									
17.0		17				greenish grey					20.80-21.45m: shale in greenish grey - white grey in color.		100											
18.0		###				greenish grey					22.65-25.00m: silt in brown grey in color. It is composed of rock fragment - short columnar core. The hardness extent of C <sub>L</sub> -C <sub>M</sub> class. The cracks in a horizontal direction are dominantly distinguished. At 24.60-25.00m in depth, the cracks in a vertical direction is distinguished.		100	10	10									
19.0						brownish grey							100	15	26									
20.0						brownish grey							100	21	21									
21.0						brownish grey							100											
22.0						brownish grey							100											
23.0						brownish grey							100											
24.0						brownish grey							100											
25.0	###	###	###									100												

Name of Study : THE PROJECT FOR DEVELOPING COUNTERMEASURES AGAINST LANDSLIDES IN THE ABAY RIVER GORGE																															
Borehole name		BH28-21		Location		Around 1km from Goha Tsion, Abay Gorge area, National road 3				Latitude		10.06.426																			
Organization		Geological Survey of Ethiopia, JICA Study Team			Duration		作業日報確認			Longitude		38.09.335																			
Surveyer		Shoji TSUCHIYAMA			Core appraiser		Shoji TSUCHIYAMA			Drilling operators		作業日報確認																			
Elevation (m)		1772.0m		Depth (m)		25.0		Drilling rig, Engine, Pump			作業日報確認																				
Angle		Vertical		Direction		Gradient		Remarks			Installation of Automatic water level meter (depth 24.7m)																				
Scale (m)	Elevation (m)	Thickness (m)	Depth (m)	Column	Geology/ Soil	Colour	Relative density	Hardness	Weathering	Size	Geological logs	Groundwater level (m)	Core recovery (%)	Maximum length (cm)	Rock Quality Designation	SPT N value	In-site test	Laboratory test													
																			1771.5	0.5	0.5	XXXX	Top soil								
1.0					colluvial deposit	Slightly grey/ish white - grey brown	slightly low	slightly soft	moderately		Top soil (replaced by cement for drilling)		100																		
2.0																	0.00-6.20m: mainly composed by Limestone gravels. Slightly greyish white - grey brown. The rock in core is hard, the hardness extent of CL-CM class. It is composed of rock fragment - short columnar core in entire.		100												
3.0																	In particular, 4.95-5.06m: Some andesitic gravel are partly found.		100												
4.0																				90											
5.0																				90											
6.0			6.2																	80											
7.0																				80											
8.0													greyish brown	low	soft	high-weathering		6.20-14.85m: High weathered siltstone, shale and limestone in greyish brown in color. It is dominantly composed of sandy gravel - rock fragment core. It is soft. The hardness extent of D <sub>16</sub> -D <sub>30</sub> class. In particular, 7.20-7.65m: It is composed of rock fragment - short columnar core.		90											
9.0																										90					
10.0																										90					
11.0																										100					
12.0																										100					
13.0																										100					
14.0																										100					
15.0			14.85																							100					15.25
16.0			15.65																white brown	slightly low	slightly hard	slightly weathered	fine	14.85-15.65m: slightly weathered limestone in white brown in color. The hardness extent of C <sub>16</sub> class. It sounds poor fozy when hammered lightly-blow to core.		100					labo 1
17.0	1755.0	16.50	17.00																yellow greyish brown	very low	very soft	high-weathered	fine	15.65-16.30m: high weathered shale in yellow greyish brown in color. The core columnar shape condition is sandy - sandy gravel by force of high weathering. It is very soft. The hardness extent of D <sub>16</sub> class.		100					15.40
18.0					sliding soil mass (mainly basalt and sometime contain limestone)	blackish grey	high	hard	moderately	12 - 22 cm	16.30-25.00m: sliding soil mass which moderate-weathered basalt and limestone in black grey in color. Rock fragment - short columnar core is entirely found. The hardness extent of C <sub>16</sub> -C <sub>18</sub> class. It sounds poor fozy when hammered lightly-blow to core. In particular, 19.75-20.20m and 20.85-22.40m depth: moderate weathering tuff. It is hard. The hardness extent of C <sub>16</sub> -C <sub>18</sub> class. 23.45-24.80m depth: Some tuffaceous rock fragments are partly found.								100												
19.0																										90					
20.0																										90					
21.0																										90					
22.0																										100					22.00
23.0																										100					labo 2
24.0																										100					22.15
25.0	1741.0	8.0	25.0																24.77m	100					Automatic water level meter						
																			8.Sep												

Name of Study : THE PROJECT FOR DEVELOPING COUNTERMEASURES AGAINST LANDSLIDES IN THE ABAY RIVER GORGE																			
Borehole name		BH28-31		Location		Around 1km from Goha Tsion, Abay Gorge area, National road 3				Latitude		10.06.450							
Organization		Geological Survey of Ethiopia, JICA Study Team			Duration		作業日報確認				Longitude		38.09.343						
Surveyer		Shoji TSUCHIYAMA			Core appraiser		Shoji TSUCHIYAMA				Drilling operators		作業日報確認						
Elevation (m)		1778.0m		Depth (m)		25.0		Drilling rig, Engine, Pump				作業日報確認							
Angle		Vertical		Direction		Gradient		Remarks				Installation of borehole inclinometer							
Scale (m)	Elevation (m)	Thickness (m)	Depth (m)	Column	Geology/ Soil	Colour	Relative density	Hardness	Weathering	Size	Geological logs	Groundwater level (m)	Core recovery (%)	Maximum length (cm)	Rock Quality Designation	SPT N value	In-site test	Laboratory test	
1.0	1777	0.7	0.7	X	Top soil						Top soil (replaced by cement for drilling)		80						
2.0					colluvial deposit	slightly yellow brown - slightly white brown	very low	very soft	high-weathering	15 - 16 cm	0.70-14.00m: colluvial deposit contains high weathered limestone, siltstone and shale in slightly yellowish brown - slightly white brown in color. The matrix core become in sandy sedimentation, partly argillation by force of high weathering.	80							
3.0				80															
4.0				80															
5.0				80															
6.0				90															
7.0				90															
8.0				100															
9.0				100															
10.0				90															
11.0				100															
12.0				90															
13.0				90											13.20				
14.0	1764.0	13.3	14.0								sliding soil mass (basaltic tuff-breccia)	black grey	relatively high	relatively hard	no weathering (fresh) - slightly weathering	13 - 32 cm	Partly, 10.10-10.35m, 10.55-10.70m and 11.15-11.30m: sandy gravels in core are composed.	100	
15.0				100															
16.0				100															
17.0				100															
18.0				100															
19.0				100															
20.0				100															
21.0				100															
22.0				100					21.00										
23.0				100					21.15										
24.0	1754.4	9.6	23.6		limestone	grey/ish white	slightly low	slightly soft	slightly fresh	12 cm	14.00-23.60m: sliding soil mass which composed by basaltic tuff-breccia in black grey in color.	23.0m	100						
25.0	1753.0	14	25.0								23.60-25.00m: little weathered limestone in slightly white grey - greyish white in color. It is composed of rock fragment - short columnar core. The hardness extent of C <sub>u</sub> class. It sounds poorly fozy when hammerd light-blow to core.	8.Sep	100						24.85
											At 23.75-23.90m depth, the core is lightly weathered, and sandy sediment is composed.		100	12	12	Anchor of Borehole Inclinometer	labo 2	25.00	

Name of Study : THE PROJECT FOR DEVELOPING COUNTERMEASURES AGAINST LANDSLIDES IN THE ABAY RIVER GORGE																						
Borehole name		BH28-32		Location		Around 1km from Goha Tsion, Abay Gorge area, National road 3				Latitude		10.06.443										
Organization		Geological Survey of Ethiopia, JICA Study Team		Duration		作業日報確認				Longitude		38.09.345										
Surveyer		Shoji TSUCHIYAMA		Core appraiser		Shoji TSUCHIYAMA				Drilling operators		作業日報確認										
Elevation (m)		1777.0m		Depth (m)		40.0				Drilling rig, Engine, Pump		作業日報確認										
Angle		Vertical		Direction		Gradient		Remarks		Installation of borehole inclinometer												
Scale (m)	Elevation (m)	Thickness (m)	Depth (m)	Column	Geology/ Soil	Colour	Relative density	Hardness	Weathering	Size	Geological logs	Groundwater level (m)	Core recovery (%)	Maximum length (cm)	Rock Quality Designation	SPT N value	In-site test	Laboratory test				
1.0	1776.3	0.7	0.7		top soil						0.00-0.70m: top soil or cultivation top soil, which is in slightly blackish brown. Some plant roots or organic matter are mixed. The tuffaceous and basaltic gravel in size are dominantly around 20-40 mm in diameter. The core is blackish grey in color.		90									
2.0					colluvial deposit	blackish grey	low	soft			0.70-11.80m: colluvial deposit 0.70-2.45m: It is dominantly composed of basaltic gravels, which are around 20-40mm in diameter in size. The gravels in shape are dominantly sub-rounded - rounded. The gravels in hardness are hard. Blackish grey in color.		90									
3.0																2.45-5.15m: It is dominantly composed of limestone gravels in greyish white in color. Silty - clayey soil in the matrix core is mixed. Sub-angular - angular Gravels in hardness are hard, and in size are around 30-60mm in diameter.		80				
4.0																5.15-11.80m: It is dominantly composed of hard basalt. The gravels in size are around 30-60mm in diameter. sub-angular - angular gravels in shape. The core in color is blackish grey.		90				
5.0																		90				
6.0																		100				
7.0																		90				
8.0																		90				
9.0																		90				
10.0																		80				
11.0																		100				
12.0	1765.2	11.1	11.8								limestone	greyish white	high	hard	fresh	10 - 22 cm	11.80-24.65m: It is composed of hard and fresh massive limestone.		100			
13.0																		100				
14.0																		80	18	18		
15.0																		80				
16.0																		90				
17.0																		90				
18.0																		80				
19.0																		80	10	10		
20.0																		100	15	28		
21.0																		90	18	18		
22.0																		100	10	10		
23.0																		100	22	53		
24.0	1752.4	12.85	24.65		siltstone and limestone alternation	greenish grey - brownish grey	relatively high	relatively hard	relatively weathered - relatively fresh	15 - 30 cm	24.65-40.00m: siltstone and limestone alternation in greenish grey - brownish grey in color.		100	15	38							
25.0																		100	22	33		
26.0																		100	20	20		
27.0																		100				
28.0																		100				
29.0																		100				
30.0																		100				
31.0																		100				
32.0																		100				
33.0																		100				
34.0																		100	30	78		
35.0																		100	15	25		
36.0												100	16	16								

Name of Study : THE PROJECT FOR DEVELOPING COUNTERMEASURES AGAINST LANDSLIDES IN THE ABAY RIVER GORGE																													
Borehole name		BH28-41		Location		Around 1km from Goha Tsion, Abay Gorge area, National road 3				Latitude		10.06.477																	
Organization		Geological Survey of Ethiopia, JICA Study Team			Duration		作業日報確認				Longitude		38.09.365																
Surveyer		Shoji TSUCHIYAMA			Core appraiser		Shoji TSUCHIYAMA				Drilling operators		作業日報確認																
Elevation (m)		1788.5m		Depth (m)		45.0		Drilling rig, Engine, Pump				作業日報確認																	
Angle		Vertical		Direction		Gradient		Remarks				Installation of borehole extensometer																	
Scale (m)	Elevation (m)	Thickness (m)	Depth (m)	Column	Geology/ Soil	Colour	Relative density	Hardness	Weathering	Size	Geological logs				Groundwater level (m)	Core recovery (%)	Maximum length (cm)	Rock Quality Designation	SPT N value	In-site test	Laboratory test								
1.0				X	embankment	blackish-brown	low	soft			0.00-5.30m: embankment. The matrix core is sandy clay in black-brown in color, which is mixed with some gravels. The gravels are dominantly composed of no weathered basalt and limestone in sub-angular and angular shape. The size of gravels is around 30-60 mm in diameter. The hardness of them is hard. The water content is entirely moderate.	40																	
2.0																			60										
3.0																			60										
4.0																			80										
5.0	1783.2	5.3	5.3																80										
6.0				3.8	sliding soil mass (limestone, siltstone and mudstone)	yellow-brown	low	soft			5.30-8.80m: sliding soil mass ( and/or colluvial deposit). Sandy gravels in brownish-red and yellowish brown in color, which is mixed with clay. The gravels are sub-angular and angular and around 30-60mm in diameter in size, and geological composition is dominantly limestone, siltstone and sandstone. The hardness of them is hard. The water content of clay is low. The agglomeration degree is high.	100																	
7.0																			100										
8.0																			100										
9.0																			100										
10.0																			100										
11.0																			100										
12.0																			100										
13.0																			100										
14.0																			100										
15.0																			100										
16.0											100																		
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24.0											100																		
25.0											100																		
26.0											100																		
27.0											100																		
28.0											100																		
29.0											100																		
30.0											100																		
31.0											100	13	13																
32.0											100	34	46																
33.0											100	12	12																
34.0											100	14	14																
35.0											100	12	12																
36.0	1753.0	30.2	35.5								100	20	30																

Name of Study : THE PROJECT FOR DEVELOPING COUNTERMEASURES AGAINST LANDSLIDES IN THE ABAY RIVER GORGE																					
Borehole name		BH28-11		Location		Around 1km from Goha Tsion, Abay Gorge area, National road 3				Latitude		10.06.379									
Organization		Geological Survey of Ethiopia, JICA Study Team		Duration		作業日報確認				Longitude		38.09.322									
Surveyer		Shoji TSUCHIYAMA		Core appraiser		Shoji TSUCHIYAMA				Drilling operators		作業日報確認									
Elevation (m)		1762.0m		Depth (m)		25.0				Drilling rig, Engine, Pump		作業日報確認									
Angle		Vertical		Direction		Gradient		Remarks				Installation of borehole inclinometer									
Scale (m)	Elevation (m)	Thickness (m)	Depth (m)	Column	Geology/ Soil	Colour	Relative density	Hardness	Weathering	Size	Geological logs	Groundwater level (m)	Core recovery (%)	Maximum length (cm)	Rock Quality Designation	SPT N value	In-site test	Laboratory test			
1.0	1761.6	0.4	0.4		top soil						Top soil (replaced by cement for drilling)										
2.0					colluvial deposit	black grey - dark grey	low	soft			0.40-4.70m: colluvial deposit in black grey - dark grey in color. 0.00-1.25m: It is dominantly composed of sandy gravels mixed with coarse sand. The sub-angular gravels are around 2-10mm in diameter. The gravels in geology are andesite. 1.25-2.50m: It is dominantly composed of andesite, tuff and limestone gravels of around 10-30mm in diameter. Coarse sand among gravels is mixed. 2.50-4.70m: It is dominantly composed of basalt, tuff and limestone gravels of around 10-40mm (max 100 mm) in diameter, sub-angular sandy gravels mixed with clay. Coarse sand and a bit of clay among gravels is mixed.		50								
3.0														50							
4.0														40							
5.0														50							
6.0							white grey	high	hard			4.70-5.80m: slightly weathered limestone in white grey in color. It is composed of rock fragment - short columnar core. The hardness extent of C <sub>1</sub> -C <sub>4</sub> class (hard core)		100					6.20		
7.0												5.80-13.60m: relatively weathered andsite in black grey in color.		70					labo 1		
8.0												5.80-6.40m: It is composed of short columnar core. The hardness extent of C <sub>4</sub> class is hard. 6.40-7.35m: It is composed of rock fragment - angular-shaped core. The hardness extent of C <sub>1</sub> class, slightly hard. 7.35-7.90m: It is composed of short columnar core. The hardness extent of C <sub>1</sub> class is hard.		90							
9.0							black grey	slightly high	slightly hard			7.90-9.00m: It is dominantly composed of rock fragment core and a bit of coarse sand. The hardness extent of C <sub>1</sub> class. 9.00-9.70m: It is dominantly composed of rock fragment - short columnar core. The rock in core hardness is the extent of C <sub>4</sub> class. 9.70-11.05m: sandy gravels mixed with clay, greyish black - dark grey in color. The matrix core is dominantly andesitic sub-angular - angular gravel. Sand and clay among rock fragments are found. The hardness extent of C <sub>1</sub> class in entire. It is slightly hard.		100							
10.0														100							
11.0														100							
12.0														100							
13.0														100							
14.0	1748.1	13.55	13.95			sliding soil mass (mainly silt and shale)	white grey - greenish grey	slightly high	slightly hard	moderately	24 cm			100							
15.0		1.05	15.00									13.95-25.00m: moderately and highly weathered sliding soil mass (mainly silt and shale) in greenish grey - reddish brown grey in color. 13.95-15.00m: moderately weathered shale in white grey - greenish grey in color. The hardness extent of CL class (the upper part □ class: like loose surface soil)		100	24	34					
16.0							green grey - reddish brown grey	very low	very soft	high weathering	20-22 cm			100	20	20					
17.0												15.10-18.00m: high weathered siltstone (to sand) in greenish grey - reddish brown grey in color. The hardness extent of DM-DH class. It is very soft. It can check rock structure slightly remained, argillation by force of high weathering is partly found. Rock fragment-shaped core is partly found.		100							
18.0		2.6	17.6									17.60-25.00m: moderately weathered siltstone in mainly reddish grey in color. It indicates the hardness extent of C <sub>1</sub> class. It can entirely check rock structure remained. In particular, 21.25-21.95m, 22.30-22.70m, and 23.20-24.35m depth: the matrix core become brown in color by force of high weathering, and argillation of the cores is found. At 24.35-25.00m depth, the porous cracks with weathering is distinguished. It indicates the hardness extent of C <sub>1</sub> class.		100						18.50	
19.0														100	22	57			labo 2		
20.0							green grey - reddish brown grey	slightly high	slightly hard	moderately	22-26 cm			100					18.65		
21.0												About colors of the core. 15.10-15.70m: reddish brown grey 15.70-16.30m: greenish grey 16.30-17.50m: reddish brown grey 17.50-21.25m: greenish grey 21.25-22.60m: reddish brown grey 22.60-22.95m: greenish grey 22.95-24.60m: reddish brown grey 24.60-25.00m: greenish grey		100	26	46					
22.0														100							
23.0														100							
24.0														100							
25.0	1737.0	7.4	25.0										100					Anchor of Borehole inclinometer			

Name of Study : THE PROJECT FOR DEVELOPING COUNTERMEASURES AGAINST LANDSLIDES IN THE ABAY RIVER GORGE																				
Borehole name		BH27-12		Location		Around 1km from Goha Tsion, Abay Gorge area, National road 3				Latitude		10.06.249								
Organization		Geological Survey of Ethiopia, JICA Study Team		Duration		作業日報確認				Longitude		38.09.364								
Surveyer		Shoji Tsuchiyama		Core appraiser		Shoji Tsuchiyama				Drilling operators		作業日報確認								
Elevation (m)		1709.0m		Depth (m)		25.0				Drilling rig, Engine, Pump		作業日報確認								
Angle		Vertical		Direction		Gradient		Remarks				Installation of borehole extensometer								
Scale (m)	Elevation (m)	Thickness (m)	Depth (m)	Column	Geology/ Soil	Colour	Relative density	Hardness	Weathering	Size	Geological logs		Groundwater level (m)	Core recovery (%)	Maximum length (cm)	Rock Quality Designation	SPT N value	In-site test	Laboratory test	
1.0	1708.1	0.9	0.9		Top soil						Top soil (replaced by cement for drilling)			40						
2.0					colluvial deposit						0.90-13.40m: colluvial deposit. the core characterized by basaltic boulder in black grey - brown grey in color.			60						
3.0						0.90-3.95m: It is dominantly composed of basaltic gravel. The gravels in size are around 20-60mm in diameter. It is composed of sub-rounded - sub-angular gravels. The hardness of gravels are hard.						0.90-3.95m: It is dominantly composed of basaltic gravel. The gravels in size are around 20-60mm in diameter. It is composed of sub-rounded - sub-angular gravels. The hardness of gravels are hard.			80					
4.0			3.95			3.95-7.60m: sandy basaltic gravels, which is mixed with clay. blackish brown - brownish grey. The gravels are around 20-60 mm in diameter. Clay among gravels is partly found. It is dominantly composed of sub-rounded - sub-angular gravels.						3.95-7.60m: sandy basaltic gravels, which is mixed with clay. blackish brown - brownish grey. The gravels are around 20-60 mm in diameter. Clay among gravels is partly found. It is dominantly composed of sub-rounded - sub-angular gravels.			90					
5.0						7.60-13.40m: hard basaltic gravels in blackish grey in color. The gravels are around 30-60 mm in diameter. Some basaltic gravels among tuffaceous ones is partly found. It is dominantly composed of sub-rounded - sub-angular gravels.						7.60-13.40m: hard basaltic gravels in blackish grey in color. The gravels are around 30-60 mm in diameter. Some basaltic gravels among tuffaceous ones is partly found. It is dominantly composed of sub-rounded - sub-angular gravels.			90					
6.0						13.40-15.70m: high weathered silt(tuffaceous) in greish white in color. It is composed of sandy - rock fragment by force of high weathering. The hardness extent of D <sub>u</sub> -D <sub>s</sub> class in entire. It is possible to break up the rock fragments by finger. It is very soft, however, can check rock structure slightly-remaining.					13 cm	13.40-15.70m: high weathered silt(tuffaceous) in greish white in color. It is composed of sandy - rock fragment by force of high weathering. The hardness extent of D <sub>u</sub> -D <sub>s</sub> class in entire. It is possible to break up the rock fragments by finger. It is very soft, however, can check rock structure slightly-remaining.			100					
7.0			7.6			15.70-17.30m: relatively fresh massive siltstone in greish white in color. It is composed of rock fragment - short columnar core. The rocks in core are hard. The hardness extent of C <sub>u</sub> -C <sub>s</sub> class. It sounds poor fozy when hammered lightly-blow to core.					10-13 cm	15.70-17.30m: relatively fresh massive siltstone in greish white in color. It is composed of rock fragment - short columnar core. The rocks in core are hard. The hardness extent of C <sub>u</sub> -C <sub>s</sub> class. It sounds poor fozy when hammered lightly-blow to core.			100	13	23			
8.0						17.30-18.70m: high weathered silt and shale in slightly brownish gray - brownish gray in color. It is composed of sandy - rock fragment by force of high weathering. The hardness extent of DM-DH class. It is slightly soft.					10 cm	17.30-18.70m: high weathered silt and shale in slightly brownish gray - brownish gray in color. It is composed of sandy - rock fragment by force of high weathering. The hardness extent of DM-DH class. It is slightly soft.			100					
9.0						18.70-21.10m: moderate weathered tuff in brownish yellow - greenish grey(reseda) in color. It is composed of rock fragment - short columnar core by force of high weathering. The rock hardness condition is slightly soft. It can check rock structure remaining. It's fractured when hammered blow to core.					10-12 cm	18.70-21.10m: moderate weathered tuff in brownish yellow - greenish grey(reseda) in color. It is composed of rock fragment - short columnar core by force of high weathering. The rock hardness condition is slightly soft. It can check rock structure remaining. It's fractured when hammered blow to core.			100	10	10			
10.0						21.10-25.00m: moderate-weathered silt and shale in brownish grey - greenish grey(reseda) in color. It is composed of sandy - rock fragment core in entire. It indicates the hardness extent of C <sub>u</sub> class. It is slightly soft. It checks rock structure remaining. In particular, 22.40-22.85m: reddish brown in color by weathering. 23.30-24.70m: high weathered siltstone. It is composed of sandy - angular gravel core. It break up in relatively fracture when hammered poorly-blow to core.						21.10-25.00m: moderate-weathered silt and shale in brownish grey - greenish grey(reseda) in color. It is composed of sandy - rock fragment core in entire. It indicates the hardness extent of C <sub>u</sub> class. It is slightly soft. It checks rock structure remaining. In particular, 22.40-22.85m: reddish brown in color by weathering. 23.30-24.70m: high weathered siltstone. It is composed of sandy - angular gravel core. It break up in relatively fracture when hammered poorly-blow to core.			100	10	10			
11.0						sliding soil mass (mainly silt and shale)									100					
12.0						reddish brown - brownish yellow - greenish grey		slightly low	slightly soft	moderate - high weathering.					100					
13.0															100					
14.0	1723.4	12.5	13.4												100					
15.0			15.7		greyish white		very low	slightly-soft	high-weathering					100						
16.0					greyish white		slightly high	hard	relatively-fresh					100	13	23				
17.0			17.3		brownish gray		slightly low	slightly-soft	high-weathering					100	10	20				
18.0			18.7		reddish brown - brownish yellow - greenish grey		slightly low	slightly soft	moderate - high weathering.					100						
19.0														100	10	10				
20.0														100					20.45	
21.0														100	12	12			labo 1	
22.0														100					20.55	
23.0														100						
24.0														100						
25.0	1735.0	11.6	25.0											100					Anchor of borehole extensometer	

Name of Study : THE PROJECT FOR DEVELOPING COUNTERMEASURES AGAINST LANDSLIDES IN THE ABAY RIVER GORGE																																										
Borehole name		BH27-21		Location		Around 1km from Goha Tsion, Abay Gorge area, National road 3				Latitude		10.06.241																														
Organization		Geological Survey of Ethiopia, JICA Study Team			Duration		作業日報確認				Longitude		38.09.303																													
Surveyer		Shoji Tsuchiyama			Core appraiser		Shoji Tsuchiyama			Drilling operators		作業日報確認																														
Elevation (m)		1734.0m			Depth (m)		25.0		Drilling rig, Engine, Pump			作業日報確認																														
Angle		Vertical		Direction		Gradient		Remarks			Installation of Automatic water level meter (depth ◯m)																															
Scale (m)	Elevation (m)	Thickness (m)	Depth (m)	Column	Geology/ Soil	Colour	Relative density	Hardness	Weathering	Size	Geological logs	Groundwater level (m)	Core recovery (%)	Maximum length (cm)	Rock Quality Designation	SPT N value	In-site test	Laboratory test																								
	1733.7	0.3	0.3		top soil						Top soil (replaced by cement for drilling)																															
1.0					colluvial deposit	blackish brown	low	soft			0.30-4.50m: colluvial deposit is mainly clay in blackish brown in color. In particular, 0.30-0.50m: Some plant roots as organic matter are found. The gravels are dominantly composed of basalt. A few of limestone are partly found. The gravels in size are around 30-50mm in diameter.		80																													
2.0																			80																							
3.0																			80																							
4.0																			100																							
5.0			4.5																80																							
6.0																			90																							
7.0																			100																							
8.0													blackish grey	low	soft			4.50-12.40m: It is dominantly composed of basaltic gravels. The gravels are hard in hardness and around 30-60mm in diameter in size. Sand among gravels is found.		100																						
9.0																									100																	
10.0																									100																	
11.0																									70																	
12.0																									60																	
13.0	1721.6	12.1	12.4		sliding soil mass (mainly silt and shale)	brownish grey	very low	relatively soft	high	17 cm	12.40-14.05m: highly weathered siltstone (to sand) in brownish grey in color. The matrix core become brownish grey in color by force of high weathering. The gravels are like sandy sediment, and it is possible to break them up by finger.								100																							
14.0			1.65	14.05																					100	17	39			15.05												
15.0																			greenish grey	very low	relatively soft	high	13 - 18 cm	14.05-17.60m: highly weathered tuffaceous silt (to shale) in greenish grey in color. It can check rock fragment structure remaining in core. Rock fragment is found in core. The hardness extent of D <sub>u</sub> -C <sub>u</sub> class, namely, it is relatively soft. Core in a high weathering partly become sandy sedimental.		100	13	24			labo 1											
16.0																															100	18	29			15.20						
17.0			3.55	17.6																											100											
18.0			0.8	18.4																					white grey	slightly low	slightly soft	slightly	10 - 17 cm	17.60-18.40m: limestone in white grey in color. The hardness extent of C <sub>1</sub> -C <sub>u</sub> class. It is composed of rock fragment - short columnar cores in entire. 17.60-17.90m: short columnar core. And 17.90-18.40m: rock fragment getting.		100	17	27								
19.0				19.5																																	100	10	10			
20.0				20.5									brownish grey	relatively low	relatively soft	moderately weathering	10 - 20 cm	18.40-25.00m: moderately weathered siltstone and shale (tuffaceous) in greenish grey - brownish grey in color. 18.40-19.50m: It is composed of rock fragment - short columnar core. The hardness extent of C <sub>1</sub> -C <sub>u</sub> class. It is relatively hard. 19.50-20.50m: Rock fragment getting. The hardness extent of D <sub>u</sub> -C <sub>u</sub> class. 20.50-21.25m: rock fragment - short columnar condition in core. The hardness extent of C <sub>1</sub> class. 21.25-21.90m: gravel - rock fragment condition in core. The core become moderately weathered. The core is brownish grey in color. 21.90-25.00m: slightly weathered tuff in brownish grey - greenish grey in color. It is composed of rock fragment - short columnar core in entire. The hardness extent of CL class. At 21.90-23.30m depth, core is brownish grey in color. At 23.30-25.00m: core is greenish grey in color.														100										
21.0				21.25																																	100					
22.0				21.9																																	21.75m	100				Automatic water level meter
23.0			4.9	23.3																																	24.Sep	100				
24.0																															greenish grey	relatively high	relatively hard	slightly weathering				100	20	44		
25.0	1709.0	1.7	25.0									100																									18	28				

Name of Study : THE PROJECT FOR DEVELOPING COUNTERMEASURES AGAINST LANDSLIDES IN THE ABAY RIVER GORGE																		
Borehole name		BH27-22		Location		Around 1km from Goha Tsion, Abay Gorge area, National road 3				Latitude		10.06.238						
Organization		Geological Survey of Ethiopia, JICA Study Team			Duration		作業日報確認				Longitude		38.09.315					
Surveyer		Shoji Tsuchiyama			Core appraiser		Shoji Tsuchiyama			Drilling operators		作業日報確認						
Elevation (m)		1733.0m			Depth (m)		27.0			Drilling rig, Engine, Pump		作業日報確認						
Angle		Vertical		Direction		Gradient		Remarks				Installation of borehole inclinometer						
Scale (m)	Elevation (m)	Thickness (m)	Depth (m)	Column	Geology/Soil	Colour	Relative density	Hardness	Weathering	Size	Geological logs	Groundwater level (m)	Core recovery (%)	Maximum length (cm)	Rock Quality Designation	SPT N value	In-site test	Laboratory test
1.0	1734	1.7	1.7		top soil	black brownish grey					0.00-1.70m: sandy soil in black grey - brown grey in color, which is mixed with some gravels		80					
2.0													100					
3.0													80					
4.0													40					
5.0													50					
6.0													70					
7.0													90					
8.0													90					
9.0													100					
10.0													100					
11.0													100					
12.0													100					
13.0													100					
14.0													90					
15.0	1747	13.7	15.4										100					
16.0													100					
17.0													100					
18.0													100	12	12			
19.0			19.35										100					19.65
20.0													100	14	34			labo 1
21.0			21										100	15	15			19.80
22.0													100					
23.0			23.4										100					
24.0													100					
25.0													100	10	10			
26.0													100	28	59			
27.0	1753.0	27.0	27.0										100	22	32			Anchor of Borehole inclinometer

Name of Study : THE PROJECT FOR DEVELOPING COUNTERMEASURES AGAINST LANDSLIDES IN THE ABAY RIVER GORGE																									
Borehole name		BH27-23		Location		Around 1km from Goha Tsion, Abay Gorge area, National road 3				Latitude		10/06/22.9													
Organization		Geological Survey of Ethiopia, JICA Study Team		Duration		作業日報確認				Longitude		38/09/32.0													
Surveyer		Shoji Tsuchiyama		Core appraiser		Makito Noda		Drilling operators		作業日報確認															
Elevation (m)		1723.9m		Depth (m)		25.0		Drilling rig, Engine, Pump		作業日報確認															
Angle		Vertical		Direction		Gradient		Remarks		Installation of borehole inclinometer															
Scale (m)	Elevation (m)	Thickness (m)	Depth (m)	Column	Geology/ Soil	Colour	Relative density	Hardness	Weathering	Size	Geological logs	Groundwater level (m)	Core recovery (%)	Maximum length (cm)	Rock Quality Designation	SPT N value	In-site test	Laboratory test							
1.0					colluvial deposit	black grey	relatively-low	soft			0.00-6.10m: colluvial deposit in black grey in color.  It is dominantly composed of basaltic gravel. In the surface layer, some tuffaceous gravels is found. The gravels are around 20-60mm in diameter in size, hard in hardness and sub-angular - angular in shape. (possibility of natural ground)		60												
2.0																			80						
3.0																				80					
4.0																				90					
5.0																				90					
6.0			6.1																	40					
7.0					sliding soil mass (mainly silt and shale)	yellowish grey		soft			6.10-8.00m: colluvial deposit in yellowish grey in color.  The sandy gravels mixed with clayey soil. The gravels in geological property are dominantly basalt, and silty - clayey soil partly found. It is dominantly composed of sub-angular - angular, dominantly basalt, and silty - clayey soil partly found. It is		60												
8.0																				80					
9.0	1714.3	9.0	9.0																	40					
10.0													greenish grey				sand size -12 cm	3.00-12.50m: weathered silt(tuffaceous). It is composed of rock fragment - short columnar core. The hardness extent of CL class. It's fractured when hammered.		85					10.10
11.0																				80	12	12			10.20
12.0																				65					
13.0			12.5																	90					
14.0													greenish grey to brownish grey	low	soft	high weathering		12.50-18.45m: high whetered siltstone and shale which greenish grey to brownish grey in color.		90					
15.0																	sand to gravel size			90					
16.0																				90					
17.0													90												
18.0			18.45										90												
19.0													90	10	10										
20.0													90												
21.0						reddish grey	relatively-high	slightly-hard	moderately weathering	10-13 cm	18.50-25.00m: moderate whetered silt in reddish grey in color.  18.45-18.75m, 19.90-20.35m: boulder of sandstone which white in color. 22.00-25.00m: silt in reddish grey in color. It is composed of rock fragment - short columnar core. The hardness extent of C <sub>u</sub> -C <sub>u</sub> class. The cracks in a horizontal direction are dominantly distinguished.		75												
22.0													85	11	11			22.10							
23.0													100	12	23			labo 2							
24.0													100	13	25			22.20							
25.0	1636.3	16.0	25.0										100												

