ADDIS ABABA UNIVERSITY
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ENGINEERING GEOLOGICAL MAPPING AND LAND SLIDE ASSESSMENT OF DESSIE TOWN

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ENGINEERING GEOLOGICAL MAPPING AND LANDSLIDE ASSESSMENT OF DESSIE TOWN

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ABSTRACT

In order to understand the geotechnical properties of soils and rocks and the slope stability in Dessie, field traverses, digging of test pits, drilling of bore hole, vertical electrical sounding test, standard penetration test, point load test, Schmidt hammer test and various type of laboratory tests have been carried out.

The purpose of this work is to ensure those geological factors affecting planning, design, construction of engineering structures related to soils and rocks and to assesses the landslides to give a mitigation and control methods related to slope gradient classification map, Geomorphological map, Engineering geological map, landslide hazard classification map, land use and land cover map have been performed.

Dessie is situated in a graben formed by successive parallel faults that run in the north south direction. The geomorphology of Desire is governed by, the geology, the regional tectonic activity, erosion and depositional process.

The study area is covered with alternate layers of basalt and quaternary deposits of colluvial, alluviall and residual soils.

Alternate layers of stratoid and degreaded basalt separated by thin palleosoil are typical layers along the escarpments of Tosse and Azewa Gedel. The centeral part of the town is characterised by scattered hills of vesicular basalt.

The thickness of colluvial and alluvial deposits vary according to the palemorphology of the garben. Three borehole were drilled during the field work in selected areas and show that the thickness of these colluvial – alluvial soils reaches about 40m.

Landslides, especially induced by gully erosion and rockfalls down the slope is now a days a common phenomena in Desire Town. About 20 landslides including rock fall prone areas have been recognised. Most of them are resulted from the lack of proper surface drainage system on the thick colluvial – alluvial sediment and rockfalls toppleing from the steep cliffs. The landslides are aggravated by natural and man made activities, such as rainfall, change in the slope gradient, human intervention, gullies and streambed erosion.

CHAPTER ONE-INTRODUCTION

1.1 BACKGROUND

A good understanding of Engineering Geology is the base for all construction activities. It leads towards the safe and economic construction practices. Inadequate knowledge about this field of study may cause a great damage to infrastructures development. In the near past many construction activities, dams, buildings, roads and other engineering works, lost many lives, damage many properties in the world.

Following the beginning of modern construction works, in Ethiopia foreign experts came to the country and start introducing engineering geological works. This includes the construction of minor hydroelectric dams, small-scale buildings, roads and other water work activities.

Engineering geological study consider the prediction of natural and man made hazards, such as earthquakes, floods slope instabilities (landslide) etc,. Large volume slope movements in mountainous terrain, with a special type of geological formation and structure and climatic factor are a persistent threat to human activity throughout the world. Very steep slope, unconsolidated weak material or sediment, heavy rainfall and gully erosion are the most generating factor for the movement of materials from unstable areas.

Landslides or mass movements involve the down slope movement of rock and / or surfical material in mass under the influence of gravity. These days, landslide problems are becoming a common phenomena in the highlands of Ethiopia causing lose of life damaging farmlands and infrastructures. A few of the affected areas are Dessie town, East Gojjam North Wollo, Damot Mountain near Wolyta Town, Goffa slide near Arba Minch , Abay Gorge and Gilgel Gibe Slides (Kebede Tsehayu *et al.*, 1995).

The Dessie landslide has got a special attention in that it occurs with in the town in which more than 200,000 people reside. Due to favorable geomorphologic settings, geologic structures and other human induced factors, a number of landslides have occurred in the town and it's surrounding. The landslide that occurred at different time becomes more pronounced. Consequently, it has a great impact not only on the socio economic conditions but also retarded the development of the city particularly from the civil construction point of view. The landslide damaged the road sections, bridges, dwelling houses, and communication facilities. (Lulseged Ayalew, 1999). Due to the adverse landslide hazards in Dessie town, this thesis work is armed at studying engineering geological properties of the soils and rocks so as to prepare an engineering geological map giving more emphasis to landslide hazard assessment on both existing and potential slope failure areas.

1.2 LOCATION AND PHYSIOGRAPHY

Dessie is located in the Amhara Regional State; South Wollo zone, at about 400 km north of Addis Ababa. The city is bounded between 39^0 37'E to $39^0$39'E longitudes and 11^0 06'N to 11^0 11'N latitudes (Fig1.1). The town serves as a main link between the Red Sea port of Assab and Djibouti and the other Northern Ethiopian towns.

The capital of Southern Wollo Administrative zone, Dessie, covers an area of about 16km^2. The 1994 census shows that out of 123,558 people residing in the town, 62, 602 were males and 60,956 were females. The population density of Dessi is 819.5 persons per square kilometer (CSA, 1999). At present it is estimated that more than 200,000 people resides in the town. Regarding education and health facility, the data collected recently by the ministry shows that the educational facilities include eleven kindergartens, ten elementary schools, three junior high schools, two senior high schools and one teachers training institute. In addition to governmental schools, there are also few privately owned ones. The data collected recently by the ministry of health shows that there is one hospital with 175 beds one-health center three clinics and seven pharmacies (MWUD, 1995)

The foundation of Dessie was laid down in the late nineteen century (1893). Since then the town grew from sparse settlement in to highly populated town. Consequently there is a built up and expansion of residential houses, industries, governmental and non-governmental institution. Physiographically, it is situated on the western highlands of Ethiopia at the western margin (escapement) of the Ethiopian Rift Valley. The town is located in a graben confined by structurally controlled Tosa Ridge and Azwa Gedel to the west and east respectively. The altitude varies from 2450 meters to 3000 meters above sea level including the Tossa tip. The area experiences a temperate climate with humid to moderate humid with a mean annual rainfall of 1185 mm and a mean daily temperature of 14 ^{0}c in rainy season and 25^{0}c in dry season (Lulseged Ayalew, 1999).

1.3 LAND COVER

The steep slope topography of Dessie is not favorable for construction of large buildings with in the limits of the town. Due to this, many houses has been concentrated at the center of the town (Figure 1.2) in relatively flat to gentle slope areas. However the steep slope areas have also scattered residential houses.

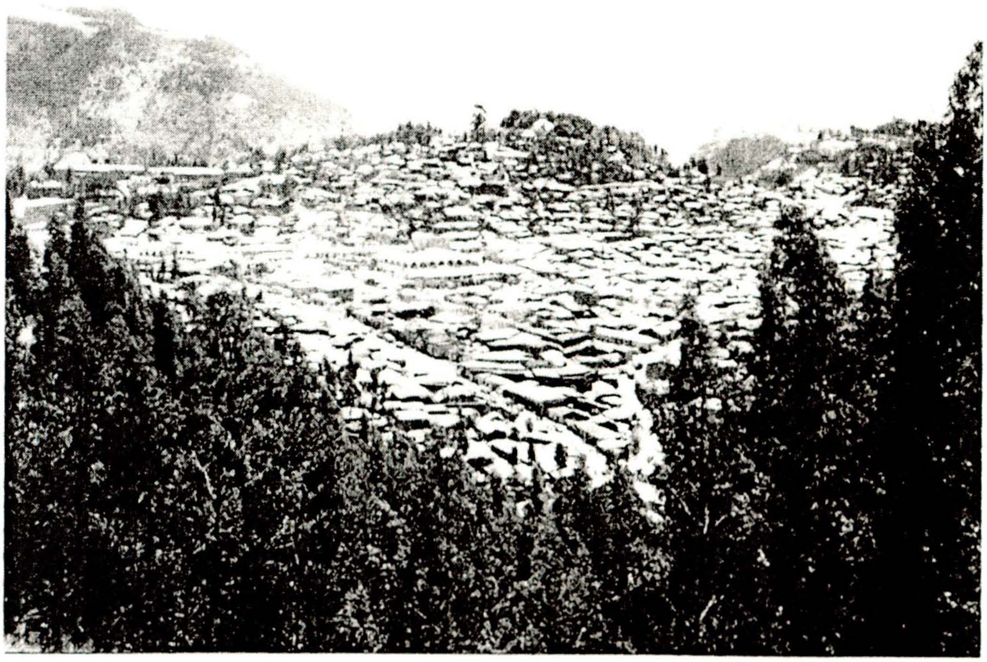


Figure 1.2 Dense settlement of Dessie Town in more flat stable area.

Almost about sixty percent of Dessie have been covered with woodland vegetation. People reside in Dessie have a good understanding about the vegetation and its use in preventing the landslide hazards. Except the central part of the town, scattered tree with in the settlement and dense tree along the foot of the escarpment are very common (Figure 1.3).
The Tossa Mountain is covered with bushes and short grasses except the steep slope (cliffs) and active land slide areas.

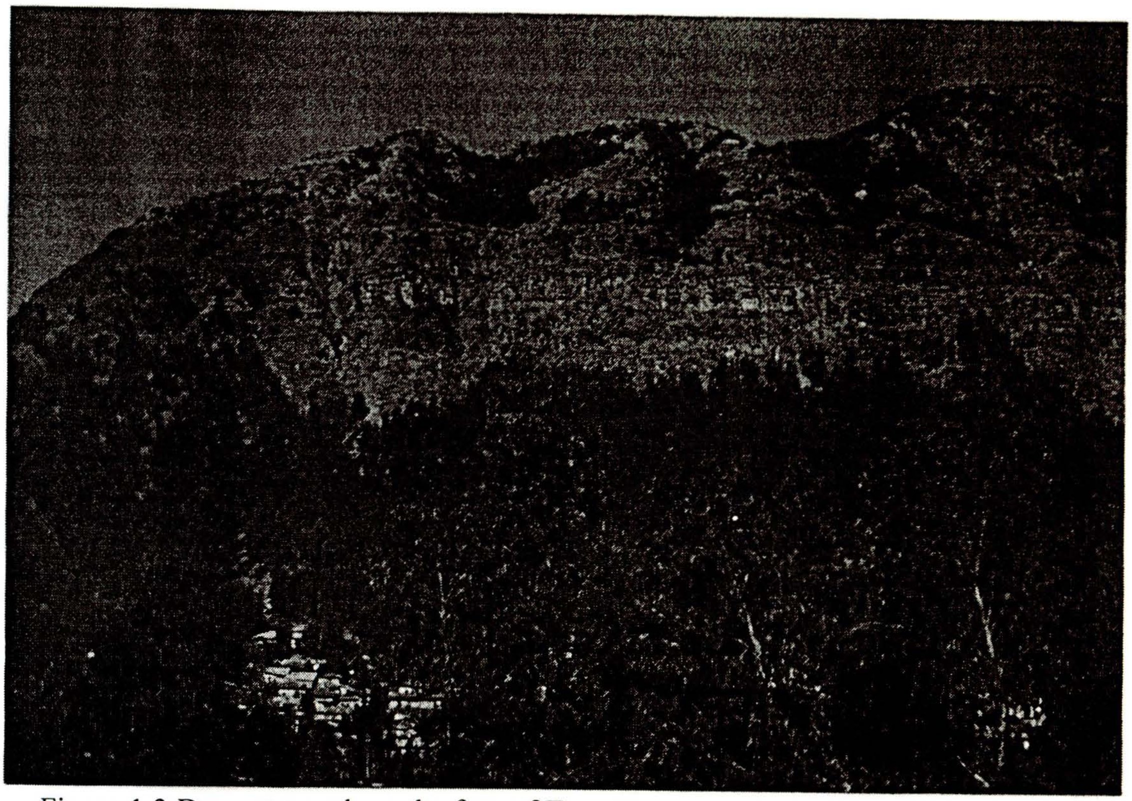


Figure 1.3 Dense trees along the foot of Tossa escarpment.

During the fieldwork, the sparsely scattered trees in the low lying areas of Kerra have been destroyed by the local Kebele residents and became totally a bare land.

1.4 PREVIOUS WORKS

Different researchers described the geology and volcanic sequence of Dessie area. Abate etal. (1968), Gregnann, *e t al.*, (1973), Justin- Visentin and B.Zanettin (1974).

A synthetic review of the stratigraphic succession of Dessie and its surroundings was given by Abate *et al.*, (1968) cited in Gregnain *et al.* (1973). Kazmin (1979) described the occurrence of successive volcanism during Miocene and basalts that covered hills and mountains around Dessie are of this age.

The landslide that occurred at different time becomes more pronounced and consequently, it attracts the attention of many engineering geological studies. Gebretsadik Eshetie (1982), identified and located 9 landslide areas. The hydrogeology of the area was studied by Ketema Tadesse, 1980 and Kebede Tsehau and Almaz Gezahegn (1995). Tadesse Dessie and Tadesse Hailmariam, (1991) Lulseged Ayalew (1999have also studied the general landslide process. According to the works of Kebede Tsehau and Almaz Gezahgn (1995) four major types of landforms characterize the study area. Lulseged Ayalew (1999) analyzed the cause and mechanism of slope instabilities in different sectors of the town.

The present work covers the engineering geological properties of soil and rocks mapping and assessment of landslide including classification, extent of landslide remedial activities land slide hazard mapping and other related works.

1.5 OBJECTIVE OF THE WORK

The impacts of landslide on various infrastructures and buildings in Dessie town and its surroundings have become more severe from time to time. The main objective of this research is to provide basic information to city planners and decision-makers about the geotechnical and engineering properties of geological materials constituting the area. The landslide hazards have become critical for the future town development. Hence, one of the objectives of this work is to identify potential landslide areas for future sustainable development of the city and also to prepare landslide hazard map.

The specific objectives of the project are:

1. To identify and classify the soils and rocks of the area by their geotechnical properties and to prepare engineering geological and geomorphologic map of Dessie town at the scale of 1:20,000.

2. To study the natural and man induced factors that facilitate instability (landslide) and to produce landslide hazard map at the scale of 1:20,000.
3. To study the general hydrogeology from landslide hazard perspective (runoff ground water occurrence, etc.)
4. To analyze the occurrence and temporal and spatial variability of earthquake in relation to landslide.
5. To recommend remedial measures of land slides.

1.6 METHODOLOGY

The study includes field, office and laboratory works. The following methods have been employed for successful completion of the research.

- Review of relevant maps and literature
- Arial photo interpretation (1:50,000 and 1: 10,000 scales)

Field survey

- Drilling of 3 bore holes for inclinometric tube installation, SPT test during drilling.
- Electrical resistivety survey
- Digging of Test pits
- Schimidt hammer test
- Point load testing
- Conventional engineering geological mapping
- Classification of rocks and soils from geotechnical perspective

Laboratory tests

- Atterburg limit
- Shear strength
- Consolidation
- Unconfined compressive strength
- Grain size analysis

Compilation and correlation of combined literature, photo interpretation geophysical and site exploration data.

CHAPTER TWO - GEOMORPHOLOGY

2.1 GENERAL

Its geology, the regional tectonic activities and erosional and depositional processes determine general geomorphology of a given area. The difference in strength among the types and varieties of rocks and the varying degree of jointing among the units of the bed rock impart changes in erodability from formation to formation (Goodman, 1993)

In accordance with the rock structure, the work of weathering and erosion is concentrated along certain zones and layers, wearing down the weakest and leaving the strongest to stand out in relief. The erosion of landscape thus produces patterns and trends in the topography that provide information about the nature of the rock and soil. The construction of depositional landscapes yields this information by providing different clues. The deposition of levees along rivers rocks and debris by a landslide or avalanche imparts a unique style to the landscape (Hoek,1995)

2.2 SLOPE AND LANDFORMS

Identification of a slope grade of a particular area helps to determine the type of landforms that constitute the general morphology. Dessie is situated in a graben formed by successive parallel faults that run in the north south direction. Following this general situation, the town is characterized by a flat surface at the floor to a very steep sided cliff (fault escarpment) at the two, east and west extremes.

Based on the slope degrees, the following landforms have been recognized (Figure 2.1).

2.2.1 Flat landforms

Strictly speaking no perfect flat surface or flat lying (<2% of slopgrade) plain is observed in the town of Dessie. Almost all parts of the area have a slope that gently dips towards the

Borkena River. This land form cover around Kerra,TTI, Hotemeda and some places of thick alluvial cover. The elevation varies from2450 to 2550. It is very difficult to trace the exact boundary where flat landfroms terminates and the gentle slope starts.

In the lower part around kerra, it is characterized by wide valley floor of thick alluvial deposit. Most of this landform is a settlement area, grazing land and football field. It has a general, gradually descending slope at the reaches of the riverbed (Borkena River).

2.2.2 Gently sloping landform

This covers many parts of the area that has an elevation range of 2550 to 2700m. It should be noted that step like faults buried under the colluvial and alluvial sediments are possible to exist in this landform. This covers the main part of the town in which the main asphalted road crosses. Most of the N-S oriented road of Dessie is located along the buried fault lines that makes a step like morphology. This situation is manifested by the sharp slope changes immediate to the roads (especially the two main roads starting from north of Arada). This gentle slope area has a slope grade of 5-10% according to FAO-UNESCO slope gradient classification, 1997 Table 2.1.

Table 2.1 Slope gradient classification (FAO_UNESCO,1997)

Grade	Classification
0-2%	Flat
2-5%	Gentle Undulating
5-8%	Undulating
8-15%	Rolling
15-30%	Moderately Steep
30-60%	Steep
>60%	Vary Steep

2.2.3 Steep slope landform

Since the town is well defined in its structurally controlled morphology, the general direction of the slope is more or less defined. This landform type exists between gentle slopes and very steep slope areas Fig 2.1 that have a general slope grade of 30-60% and elevation difference of 2700 to 2800.

Below the foot of the Tossa and Azewa Gedel cliffs, it is very difficult in most parts to traverse. It has a sharp change of slope on its boundaries both in the lower and upper part. Most of the erosional gullies are started from this part and also have the maximum depth. The most typical gully that induces a mass movement and also very risky condition for a flood hazard (landslide 4) exists with in this slope division. Most of the gully erosion landslides are associated with thick talus deposits that at times fall down the slope.

2.2.4 Very steep landforms

This covers the escarpment of the ridges in which most of the contact springs start at the base. It has almost vertical basalt cliffs with different degree of weathering. It is from this part of the landform that the erosion activities start and form incisions that makes a small channel for series of surface runoff. It has elevation difference of about 200m ranges from 2800 to 3000 it covers all the way from Segno Gebya to Boru Meda including all the highest elevation and along Azewa Gedel ridge.

2.3 GEOMORPHOLOGICAL UNITS

Geomorphological unit is a part of a landscape or the appearance of the land that resulted from geological processes and together constitutes a geomorphology of the area. Past tectonic disturbances and subsequent denudation, processes have had a significant effect on the morphology of the Ethiopian highlands. Major faults running parallels to the East African Rift system give rise to vertical scarps in many places. Isolated hills left after intensive weathering and subsequent erosion have slopes of more than 30^0 (Lulseged Ayalew, 1999)

The major geomorphological units of Dessie are therefore a result of geological, geological structures, weathering, erosion and depositional and mass movement processes.

2.3.1 Landforms related to lithological variations

With in the valley of Dessie graben, here and there scattered basaltic hills are one of the elevated feature Fig 2.2 Most of these hills are stable relative to the other slide hillsides such as Tossa and Azewa Gedel.

These basaltic hills are covered with thin residual soil cover in which the eucalyptus trees are planted on. This geomorphic unit includes hills of St Medhanialm Church, St. Silassie Church and around Robit Gebeya.

2.3.2 Structurally Controlled landforms

A distinctive feature of the Dessie graben is its morphology. It has $16km^2$ size with elongated depression following Borkena river at the floor 7km long and 3km wide with irregular topography and it is almost enclosed by large escarpment ranges in elevation from the floor from2450 to 3000 that reach a difference in height of up to 550m.

This includes the escarpments of the fault along Tossa cliffs and Azew Gedel and that extends to northeast of the area. The fault escarpments are modified and reactivated by slope process and erosion. The fault escarpment along the Tossa ridge has a very steep sided that has many erosion rills and incisions formed by the weathered surface of the basalt.

Structural joints across this escarpment are the cause for the rock fall that gives irregular appearance of the side of the cliffs.

2.3.3 Landforms associated with gravitate movement

Gravitational movement includes landslide bodies, rock fall and toppling landslide crown and deep-seated gravitational deformation steps.
Gravitative movement is a common phenomenon in all sloppy terrain that includes hillsides, gully erosion and riverbanks. Typical landform of this type is observed at Kerra in which the movement is reactivated several times and makes a clearly observed landslide crown at its upper boundary. It forms a local ridge of thick alluvial cover at the center and its eastern, southern and northern parts are slide more than one by reactivating the pre existing slide mass.

Rock falls along the foot of Tossa ridge especially north of sire spring that gives a relief above the relatively flat area. The landslide bodies with their longitudinal and transversal cracks are also a typical morphological subunits.

In some places along a deep-seated gullies a step like mass movements are occurred due to a non-uniform deposition that has different shear strength. Some part of it along the side of the valley has high horizontal permeability hence, reduces its shear strength and slips easily, where as the strong and impervious layer stand for long forming the above type of land form.

2.3.4 Landforms associated with fluvial and slope processes

The residual soil is eventually eroded by processes such as rain splash, sheet wash, gulling, and land sliding, which carry the loosened particles in to rivers. The transporting agencies may be intermittent, and the eroded material may be deposited temporally on hill slopes in channels or floodplains of rivers.

It is by the erosion, transport and deposition of weathered material that assemblages of landforms are produced. Soils and landscape then are products of weathering and the movement of sediment through the hydrologic cycle.

In erosion forms most of the stream and erosion that from a deep gully are started from the high-elevated Tossa ridge and drain down slope to the Borkena River. Along their ways on the thick colluvial and alluvial sediments, they form a narrow deep valley. The material from the landslide also transported through these narrow valleys and deposited as an alluvial plain. Borkena river, that along its way through the town makes a deep gorge on highly weathered and dissected basalt bed and locally gives a water fall. In its low-lying and flat position the river eroded the sides of the thick soil cover and give a wide river channel filled with basalt gravels. The highly weathered degraded basalt is highly affected by storm flood and eroded easily to form rills and incisions east of Borken river.

Due to the sloppy nature of the area and moist characteristic of the soil, the flood intensity or erosion capacity in Dessie is very high forming denudation land forms that are formed by erosion on the top of the hills that reduce the thickness of residual soils. In some parts, a relatively thick soil of this type is cultivated on the top of the mountainous areas.

Weak surfaces under cut by stream, river or storm water are subjected to erosion by running water or materials are transported by gravity down the slope. This material after transported by respective agents is placed in a deposition area and gives a special type of form for the landscape.

Alluvial cones are materials formed by alluvial in a flood plain that are accumulated and give a cone shaped deposit.

Talus, colluvial deposits are formed at the foot of the cliffs in the studied area. Creep or fall of the material by the landslide process down the slope accumulates the depositional form. The preexisting morphology of Dessie graben is almost filled with thick colluvial- alluvial sediments that constitute gravel, silt and clays. This morphological unit as a landform exists starting from the foot of Tossa ridge up to the Borkena river. It is characterized by flat to gentle slope topography.

Colluvio- alluvial deposit has an average thickness of about 30m as observed from borehole sections (Annex 2). In bore hole three (BH3) the first top 10m consists of gravels, sand and clay that the grain size decreases down the hole. The colluvial deposits disappear at about 20m depth.

CHAPTER THREE – GEOLOGY

3.1 REGIONAL GEOLOGY

3.1.1 Introduction

Contemporaneous with and immediately following the major uplift of the Horn of Africa, extrusion results from fissures and centers of immense quantities of flood lavas. These lavas especially in northern and central Ethiopia covered the greater part of Mesozoic rocks (Mohr, 1971). Early volcanic events, which gave Ashange basalts and initial opening of the southern Red sea from east -west trending extensional fractures (Kazmin, 1976). The second cycle gave Aiba basalts, about 34 Myr, and Oligocecne Alaji basalts being the third volcanic activity, which are related to rifting in the Red Sea and the Gulf of Aden.

The Ethiopian continental flood basalt province is one of the youngest (30 Myr) and it is large igneous province covering an area of at least 600,000 km^2 (Mohr & Zenettion, 1988) cited in Dereje Ayalew *et al.,* (1999).

Volcanic activity date back to 45Myr in the southwest and started around 30 myr in the north during the pre rift tectonic stage, and continues until now (Pik *et al.*, 1997). The lava is mainly basalt with subordinate rhyolite, forming bimodal suite. Rapid major uplift occurred with eruption of the Trap series the upraised and up arched land fissuring under tension and permitting the ascension of magma to form the Trap series.

The pre Trapian land surface had been subject to deep laterization and later to denudation, which removed some or all of the Upper sandstone. Indeed, it is the Trap series lavas, which have provided a protectative covering and preserved the evidence for the earlier laterization and denudation (Mohr, 1971)

The Trap Series consists of very thick lave flows, chiefly flood basalts locally, in the north, form a pile up to 3000 m thick which is directly overlain by rhyolites up to 500 m thick (Dereje Ayalew, 1999).

3.2.1 Stratigraphy

According to Zanettin (1977), the Tertiary Ethiopian volcanism occurred in three stages separated by periods of quiescence. During the absence of volcanism important tectonic uplift (formation of escarpments by block tilting and /or block faulting) and concomitant erosion occurred. Each stage can be subdivided in to one or more volcanic formation.

The three stages are:

a. The pre Oligocene stage (Ashange Formation). The existing belt block in an E-W or NW -SE direction tilted to the S or SW shows the existence of escarpment and when the volcanism ended, the region was uplifted and deeply eroded.

b. The Oligo -Miocene stage divided in to two sub stages.

The Oligocene sub stage (Aiba + Alaje Sirro + Termaber Guessa Formations)

The renewal of volcanism (34 -28 Myr ago) was connected with strong extensive crustal movements. The Ashanige peneplain were fractured and flooded by huge quantity of basalts (Aiba Formation).

At the end of the Oligocene the western escarpment of the Afar was clearly defined at least as far south as 10^0 30'N. In the upper Oligocene-Lower Miocene (26-20Myr) north of 10 30' the type and composition of the volcanism changed radically (Termaber Guassa Formation) from fissural to central and occurred both along the escarpment and within the plateau.

The Miocene sub-stage (Alaji Molale + Termaber Meghezez formation).

From the end of the Oligocene until the upper Middle Miocene (25-15 myr ago) the fissural volcanism was followed by a central volcanism with alkaline affinities (Termaber Meghezez Formation 15-13 myr ago) closely similar to that of Termaber Gussa formation. This stage too was followed by up lift and erosion.

b) The Mio-Pliocene stage (Fursa + Balchi + Bishoftu formation)

After the formation of the escarpment of southwestern Afar fissural volcanism, become confined to the rifts. Distribution of the volcanic in central Ethiopia shown on Fig 3.1 and the age of the rocks decrease from north to south, and from west to east. (Zenatin *et al.*, 1977)

The distribution of the volcanics in central Ethiopia shown in Figure 3.1 and schematic stratigraphic section in Figure 3.2.

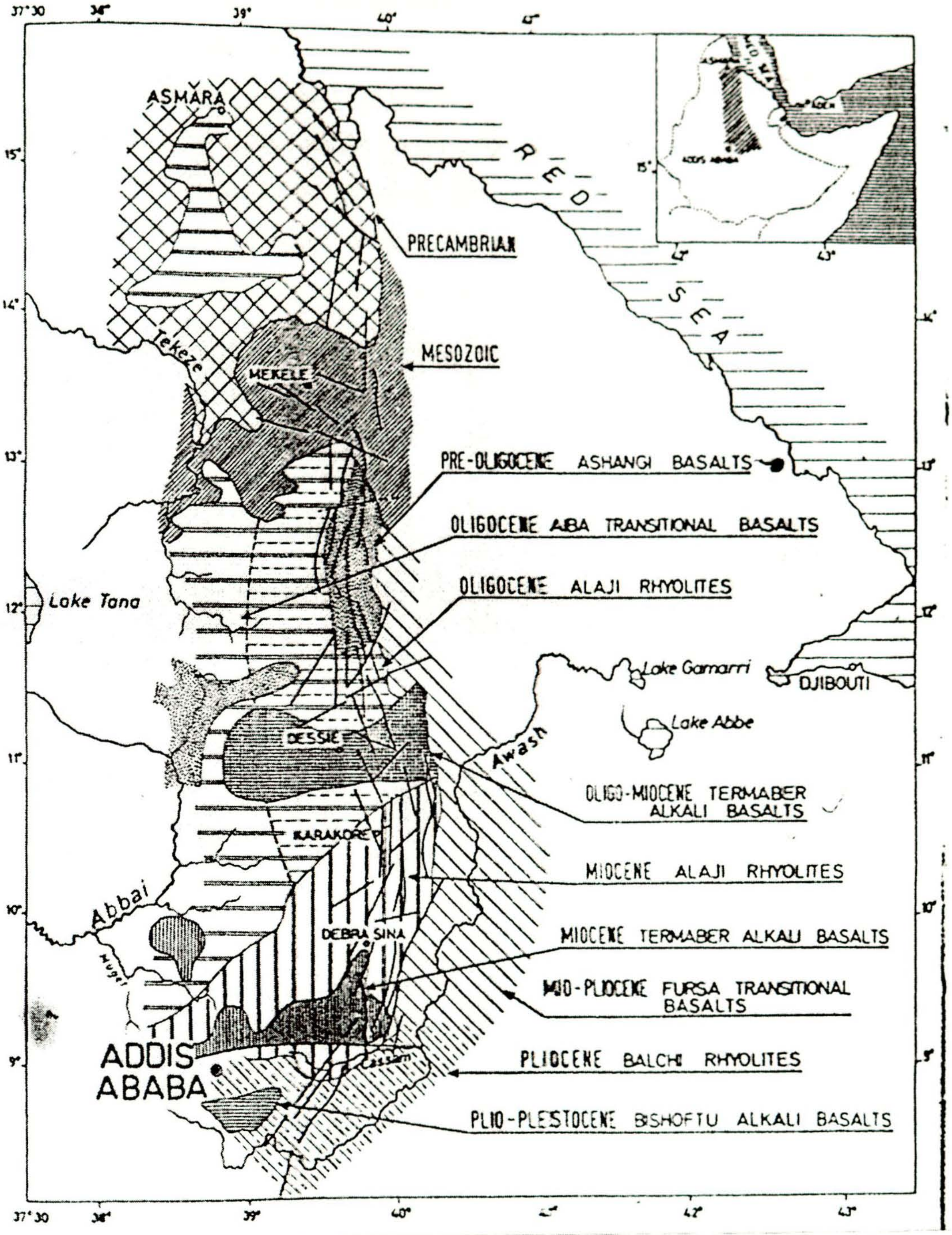


Figure 3.1 Distribution of the volcanics in central Ethiopia . The age of the Rocks decreases from N to S and from W to E.

Source : Zanettin (1977)

Abate *et al (*1968) cited in Gregnanin et al (1973) have proposed a different stratigraphic succession as follows:

- Upper unit (acidic volcanics predominantly basalts)
- Intermediate unit (predominately basaltic tuffs, rich in red and violet paleosoils, with subordinate rhyolites and some sedimentary intercalations).
- Lower Unit (mostly olivine basalts, alternating with scarce basaltic tuffs, sometimes tilted with recpect to the overlying volcanic)

According to the above authors, the distinctive features of the intermediate unit have been deduced from the volcanic out cropping in the Dessie area.

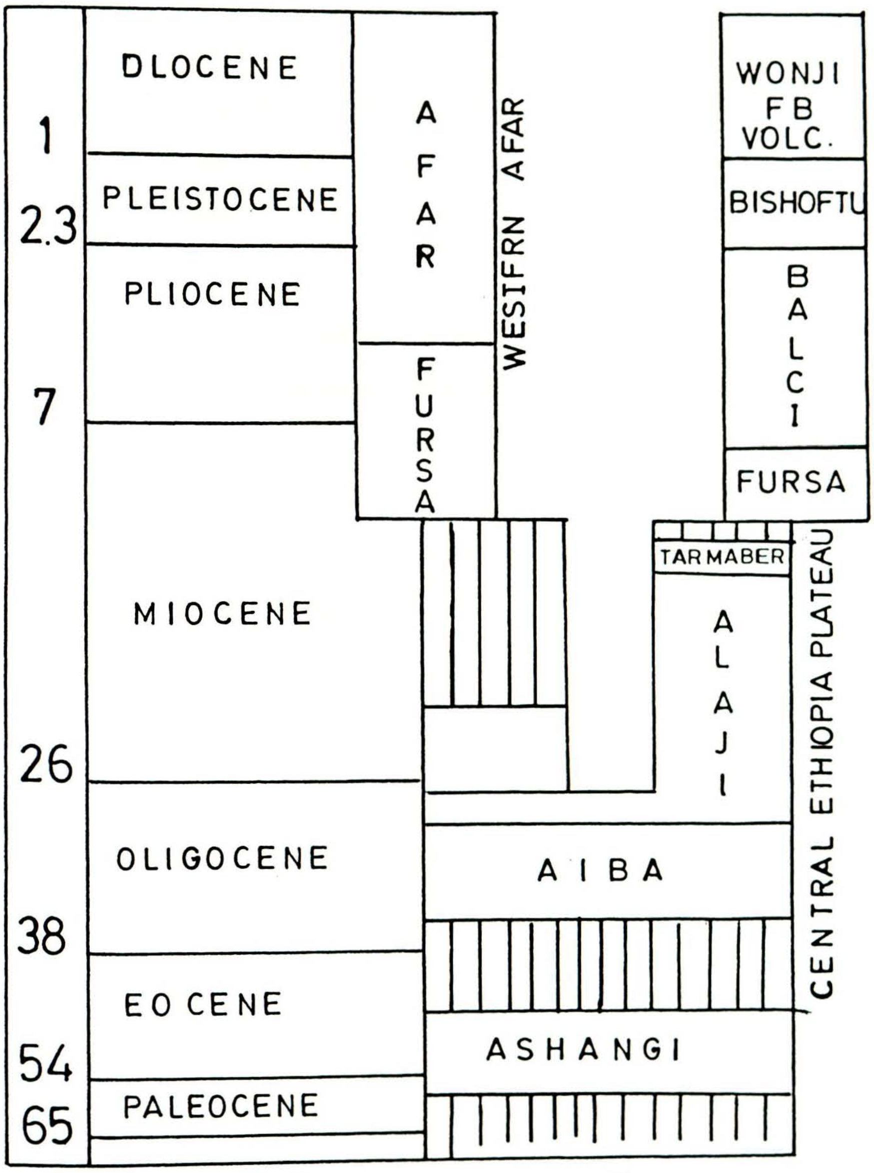


Figure 3.2 schematic Stratigraphy section of the Tertiary volcanics in Ethiopia.

Source Zanittin ,(1977)

Kazmin (1979), described the big mountains and hills which are found in the region (like Tossa, and Yegot Terara) were formed as result of successive volcanism that occurred during Miocene time. Generally; other than the variation in classification and description of some of the rock units, the geological study conducted by different scholars shows the presence of acidic, intermediates and basic volcanic rock that belongs to the Tarmaber group and it is also confirmed in the new geological map of Ethiopia.

3.1.3 Tectonics

The most important of the volcanic and tectonic stages noted in the Ethiopian plateau have been tentatively correlated with the main episodes of the evolution of the Red Sea and the Gulf of Aden (Zanettin and Jusin-Visentin, 1975)

The margins of the escarpment of the Ethiopian Rift Valley correspond to the belt, characterized by strong tectonic dislocations lying between the plateau and the rift floors in which Dessie town is situated in the western margin of this escarpment (Figure 3.3)

The recognition of the escarpment volcanic succession and its correlation with formation of the plateau succession is further rendered problematic by the complexity of the tectonics (Zanettin, 1974).

According to Zanettin *et al.*,1974, the stratigraphic reconstruction of the plateau basalts in the absence of unconformities have been possible in that the older Ashange and the younger Aiba ones is based on the fact that the former are generally more intensely crushed and weathered, while the latter can be found in clearly fresh, compact, continuous and unbroken flows. Such a distinction is generally no longer possible in the escarpment, where the Aiba basalts too were subjected to intense crushing. So the state of preservation of the basalts is not so much a function of their age, but as of the intensity of the tectonic crushing.

The older margin (western Afar margin) shows rocks of the Oligo-Miocene plateau succession that structurally characterized by tilted blocks (Zenattin, 1974). According to this author, the upper (outer) tectonic boundary of the Afar margin is almost every where clearly defined by the high fault walls which cut the stratoid formations of the Plateau. From Dessie, this limit rus

NNW-SSE from Amba Tossa to beyound Abuya Mieda (Karakore Zone) where the trend changes abruptly to NNW-SSW(Figure 3.3).

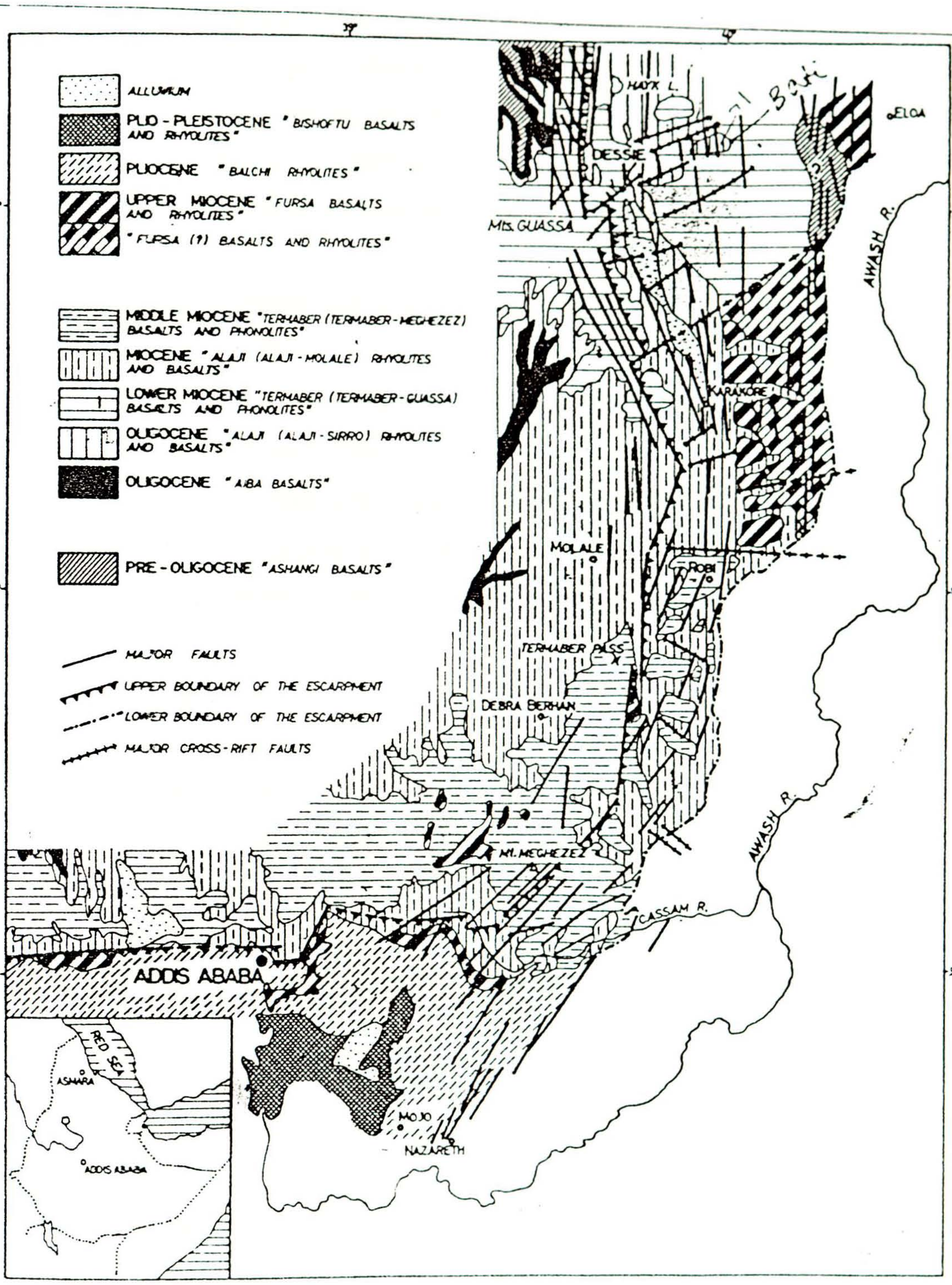


Figure 3.3 Simplfied Geological map of the Escarpments of the central Eastern Ethiopian plateau.

Source Zanittin ,(1977)

In the trend of the western Afar escarpment, north of 10^0 30' it runs NNW parallel to the system of fractures existing in northern Afar and towards the south, the escarpment describes an arc until finally in the Addis Ababa area (Piccirillo, 1977). The curved plan of the escarpment is due to the interference of the two above-mentioned trends. The lower prevailed in the southern sector, affecting an area as far north as Dessie faults crossing the escarpment with a tilting of the terrain towards the south (Mohr, 1971)

3.2 LOCAL GEOLOGY OF THE STUDY AREA

The study area, Dessie town and its surrounding is covered by Tertiary volcanics and recent alluvial and colluvial sediments (Figure 3.4).

During the geologic and petrography research in the Dessie -Kombolcha area A. Gregnanin *et al.,* (1973) were able to distinguish a characteristic strategraphic series that exposed in the Cas-cas valley - Kutaber - Ambasirro area. This series from top to bottom is composed of:

1. Upper stratoid basaltic flows
2. Distinct levels of ignimbrite with discontinuous intercalations of basalts
3. Flood basalts in thick flows
4. Degraded basic volcanites, often with short and ill defined flows, low in agglomertic levels and high in silicic deposits

The above Territory volcanics with some exceptions (no exposure of distinct levels of ignimbrite intercalations) and the Quaternary sediments are explained as follows.

3.2.1 Lithology

3.2.1.1 The Upper stratoid basalt

This rock unit is clearly exposed in the western side of the town along Tossa ridge that has a steep cliff of about 300m high and in the eastern side of the town in Azewa Gedele escarpment. This basalt layer is often separated by thin paleosoil horizons, red in color, which do not usually exceed a thickness of one or two meter.

This unit is characterized by porphyritic texture with plagioclase phnocrysts that mostly give a light color for the total mass. In the center of the town, along the road cuttings and hillsides, it is overlain by thick vesicular basalt that locally filled with some white secondary minerals.

3.2.1.2 The vesicular basalt

It is the most dominant rock type in the central part of the town exposed along the road cuttings, hillsides, and low-lying parts. This light aphanitic volcanic rock is highly porous at the top and locally this extremely porous basalt becomes scoriaceous in texture. Frequently, the vesicles are filled with precipitated secondary minerals that give amygdaloidal basalt. Along discontinuity surfaces, this porous basalt becomes more weathered and disintegrate in to small fragments and decomposed mass due to differential weathering.
In a small gully around Kerra , the vesicular basalt exist in association with agglomerate, a poorly sorted mixture of large boulders to fine silt and clay.

3.2.1.3 Degraded basalt

It is the most thickest and massive rock unit in Tossa and Azewa Gedel. It is characterized by brownish color that resulted from intensive weathering. It is also exposed in most parts of the town. In Tossa and Azew Gedel ridge a series of degraded basalt layer is separated by inter trappean soils (backed soil).

This highly weathered and decomposed rock is susceptible for sliding and it is also the most typical source for the colluvial and alluvial soils that originate from the elevated areas and deposited down slope according to their size and their depositional agent (gravity and flood). Along Tossa and Azewa Gedel ridges, this rock unit develop horizontal major joints that follow the main fault orientation of north - south direction.

3.2.1.4 Quaternary deposits

These are a superficial sediment of a deposit that are unconsolidated sediments either transported to their present place by transporting agent or the residual soils that are formed by physical and chemical weathering from the pre-existing rocks. The different transporting agents have different sedimentation characteristics and affect the properties of their soils in different ways. Therefore; soils must be recognized in terms of the means of their transportation as well as mode of deposition.

Different types of deposits that are recognized in Dessie and its surrounding includes:

- Alluvial deposits
- Alteration (residual) deposits
- Colluvial /talus deposits
- Pockets of lacustrine deposits

3.2.1.4.1 Alluvial deposits

Alluvial deposits were transported by running water and settled out when the speed of water flow was no longer sufficient to carry them. This type of deposits in the studied area are restricted to river terraces and beds. Most of the rivers that are crossing the studied area are flowing in a narrow channel that the arial coverage of alluvial deposits are very limited (Figure 3.4)

The deposits are generally of relatively narrow particle size ranging regardless of whether they consist of cobbles and gravel, from rushing rivers and creeks that are mostly below the foot of Tossa ridge, and sands from moderate rivers and streams across the gentle slope areas (Figure 2.1) and clays from sluggish rivers or from water moving in sheets down the gentle to flat area.

Since river flow and location vary considerably over time based on the hydrography of the area, multiple zones of varying grain size are frequently encountered with in one deposit along the river channels around Kerra, Dosso river and at the banks of Borkena river in the flat areas. These soils do not exhibit distinct horizontal strata and are usually unconsolidated and exposed to erosion. It makes a wide channel from time to time because of high permeability along the side of the valley. These characteristics being eroded by the river cuttings provide a favorable situation for landslides.

Along the Borkena river course, the alluvial deposit has size range from boulder in its upper part to fine clay at Kerra depending up on the speed of the river and carrying capacity.

3.2.1.4.2 Residual Deposits

Residual deposits are formed in places by mechanical and chemical weathering of their parental bedrocks. This has a typical form of mechanically weathered by plant roots (eucalyptus trees) along slided area, in hills and road cuttings. The top of humus (top soil) followed by completely weathered basalt with some fragments, which becomes moderately weathered weak basalt at the bottom. This soil is found over much of the northern, northeastern parts of the area at the top of the ridges and hills.

A residual soil along a stream cutting at the center of Kerra depression that is mainly of a landslide area is derived from pyroclastic deposits. It consists of consolidated pyroclastic sediment mainly of ash and silt size material. Along the side of this stream, a slip section of about 20m thick, consists of an alternative bed of white consolidated tuff, "marker bed" and unconsolidated ash mainly of clay material is clearly observed. A clay layer along this profile is thick and highly plastic forming shrinkage cracks and fall a part as a blocks in dry condition. When wet, due to their high capacity to absorb water they expand(Figure 7.6).

3.2.1.4. 3 Colluvial /Talus/ Deposits ·

Colluvial/talus/ deposits are formed from materials, that moved down slope by gravity on steep slopes. These materials are easily identified on air photos as bare slopes in mountainous areas but they are not obvious on vegetated lower slopes.

The Talus material is mainly found in the studied area along the foot of Tossa ridge typically west of the Dessie Teachers Training Institute and at the foot of Azwa Gedel. It is formed by big block that fall from the overhanging basaltic cliffs. The walls are highly jointed and weakened by weathering along the sides of fractures and start to fall down along the steep slopes.

Colluvial /Talus/ deposits are often loose and unconsolidated that unstable condition exist due to they rest on slopes and further slope movements are likely in such instances. Slope movements before total failure, range from the barely perceptible movements of creep at the feet of the ridges to the more discernable movements of several meters down the slope.

The colluvial deposits are characterized by coarser materials (gravel and sand) poorly cemented by matrix of silt and clay soil. Due to this poorly cemented and uncompacted nature, they are highly dissected by rapid runoff from the mountainous areas. Most of the natural causes of these movements are weathering, rainfall and floods. Cuts made in colluvial slopes are expected to become less stable with time and usually lead to failure along gullies (landslide 11,12, 4)(Figure 2.2) In the low-lying areas, these colluvial deposits are coverd by thin layers of clay soils.

3.2.1.4.4 Pockets of lacustrine deposits.

Lacustrine deposits are finegrained materials deposited in stagnant water bodies of lake bottoms, ponds, marshes etc.

Previous studies shows that deposits of this type are available at Borumeda, Kurkur Wonz and in some marshy areas. The present study also recognize the presence of pockets of Lacustraine deposits at relatively flat lying areas in the central part of the town (Arada) area and to north up to Ghion Hotel (Figure 3.4).

This extremely black clay that contain appreciable amounts of organic matter, is observed in test pits 1, 2,and 6). Previously these areas were mapped by Tadesse Dessie1991, as colluvial deposits by referring only the thin over lain granular soils.

3.2.2 Geologic structures of the study area

Understanding of the geologic structures of a site enhances the ability to predict details of site geology and their stratigraphic sequences. The geologic structure influences not only the distribution of different rock types but also their properties (Goodman, 1993).

The behavior of any engineering material is conditional by its deformability and strength, its mode of failure and the stresses and strains to which it is subjected. In the case of rocks, all these attributes are conditioned by the geologic structures.

Geologic structure is expressed by observably deformed and ruptured formations. Out of geological structures that determine the morphology of the study area, faults and joints hold the first position.

A fault is a surface along which shearing displacement has occurred and an offset can be recognized. From a mechanical perspective faults are ruptures that reduce the shear stress along them to a smaller acceptable value (Goodman, 1993).

Major faults in Dessie have a north-south direction, in which they are recognized by the discontinuity they cause in the outcrop patterns occasional springs, landslides and a topographic ridge, that from a very steep erosion resistant basalt formation facing each other across the fault plane.

East-west treading faults are also common specially along the Tossa ridge, they form many springs at the intersection with the main north south faults. These types of faults across Tossa ridge form an erosion gullies that extend throughout the town. Almost all erosional gullies are starting from the Tossa ridge and drain down with steep slope initially and deposit the load at flat to gentle slope areas (Figure 3.4) that form a thick colluvial and alluvial deposit. As revealed from the drilled geotechnical boreholes this thick erosional and gravitational deposit from Tossa ridge attain a maximum thickness of about 30m (BH3) form a narrow deep valley upon dissecting by heavy flood from the mountainous areas. However, there are indications from water wells, that this deposit may reach as much as 60m.

During a high rainy season as of 1994 in Dessie these gullies are activated by gully erosion and the wall and starts to collapse results in a mass movement and slope instability.

CHAPTER FOUR - HYDROMETEROLOGY

4.1 GENERAL

In many localities the temperature, pressure and relative humidity are susceptible to a fairly rapid change. This totality of the atmospheric phenomena is refereed to by a general designation of weather. It is the state of atmospheric phenomena existing in a given locality and at a given moment (Shiffer, 1977).

The average weather over a period of many years gives an idea of climate. The climate of a given locality is a regular succession of meteorological process, determined by geographic conditions and finding their expression in weather regime over many years. Hence, the climate is the result of various climate forming physical processes which include the balance or account of the radiant energy on the earth's surface and in the atmosphere, atmospheric circulation i.e. the system of air currents carrying different amount of heat and moisture, vertical heat and water exchange in the atmosphere in the under layer and between them. (Shiffer, 1977)

The climate is of tremendous importance in all the geological processes of external dynamics. It determines the orientation and intensity of these processes, atmospheric agents quite often appear to be a decisive factor in destruction of rocks, in transforming the relief of the land surface in complex process of sedimentation (Shiffer, 1977). Out of physical processes that determine the climate, atmospheric circulation i.e. the system of air currents carrying different amount of heat and moisture, vertical heat and water exchange in the atmosphere play a great role for the determination of the given area.

Hydrology of a given region depends primarily on climate, topography and geology. Hydrological studies are employed in different engineering practices like land use planning, site selection for engineering purpose in assessing and even the safety of engineering structure (Wilson, 1990).

In the study of engineering geology both surface and subsurface waters are very important since it affects the geomorphology, the strength of soil and rocks and determines slope stability.

4.2 TEMPERATURE

The data obtained from unpublished report of the Ministry of Works and Urban Development in 1995 show that the annual average temperature of Dessie varies from 18° to 12°c December is the coldest month and June is the hottest month of the year . The mean monthly temperature varies slightly throughout the year, although the difference in minimum and maximum temperature is high outside the rainy period.

4.3 PRECIPITATION

4.3.1 Introduction

Precipitation is the major factor controlling the hydrologic cycle of a region. Much of the geography and land usė of a region depends up on the functions of the hydrologic cycle, and therefore precipitation provides both constraints and opportunities in land and water management (Leopold, 1978).

Precipitation has many characteristics that affect planning. The relative amounts of rain and snow, their seasonal timing, and the sizes and intensities of individual storms.

Information on the intensity of individual storms is used in calculations of storm runoff, which in turn is used for design purposes in the planning of storm drains, flood control structures, culverts and river bridges. Geomorphologists require information on storm intensity because most land forming work is done during a few intense storms each year.

Good measurement of precipitation is very important for any type of analysis required for different purposes such as flood hazard assessment.

A hydrologic record is a sample of events at the measuring station. This sample is used to make estimates of the population of all potential events at that point, and in particular of the events that may occur in the future.

Error of precipitation measurements at a point are usually of the order of several percent for a single storm and range up to 30 percent of poorly exposed gauges in large storms with strong winds (Leopold, 1978). Error in the long-term average values is generally less. Generally the precision with which the rainfall of an area can be estimated depends upon the density of the gauge network and the size and type of storm event. Sparse gauge networks tend to underestimate maximum amounts and intensities and if the record is short can grossly underestimate rainfall characteristics required for planning culverts, bridges and the structures.

Different Characteristics of rainfall are important to specialists in various fields, and therefore the number of ways of analyzing rainfall data is virtually unlimited.

The methods chosen depend up on the nature of the available data and the purpose of the investigation. For the study of geomorphological processes and civil engineer works, such as landslides, soil erosion problems flooding require data on the frequency of severe, erosive rainfalls, intensity, duration and arial extent of the large, infrequent storms.

4.3.2 Analysis of rainfall in Dessie

In Dessie town, only a meteorological station of class 4 is available which has only daily totals of precipitation. These totals may refer to several storms during a day or to a part of one storm, that bridges two measuring periods. According to Leopold(1978), these records are somewhat artificial and inaccurate description of precipitation. Therefore, the only characteristics of rainfall that can be inferred from such data are those pertaining to specified intervals of time such as days, months, seasons or years.

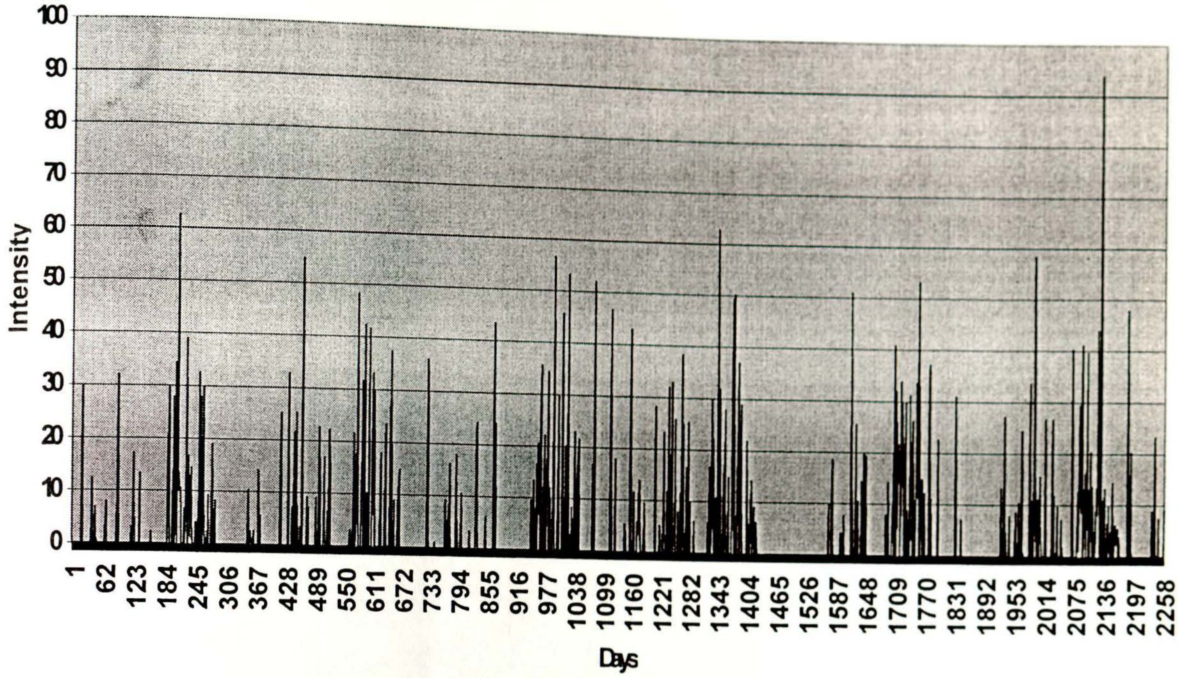


Figure 4.1 Daily rainfall intensity of dessie from 1990-1996

For the town such as Dessie, that are more affected by storm water, a rainfall-measuring station equipped with continuously recording gauges, which yield date on the characteristics of individual storms such as timing and intensity as well as total amount is required.Annual rainfall totals are more independent, though they also tend to occur in runs of wet and dry years that may not have persistence.

This tendency increases the variability of rainfall totals and reduces the precision of statistical results so that the longer periods of 30-year measurements for Dessie are analyzed (Figure 4.2).

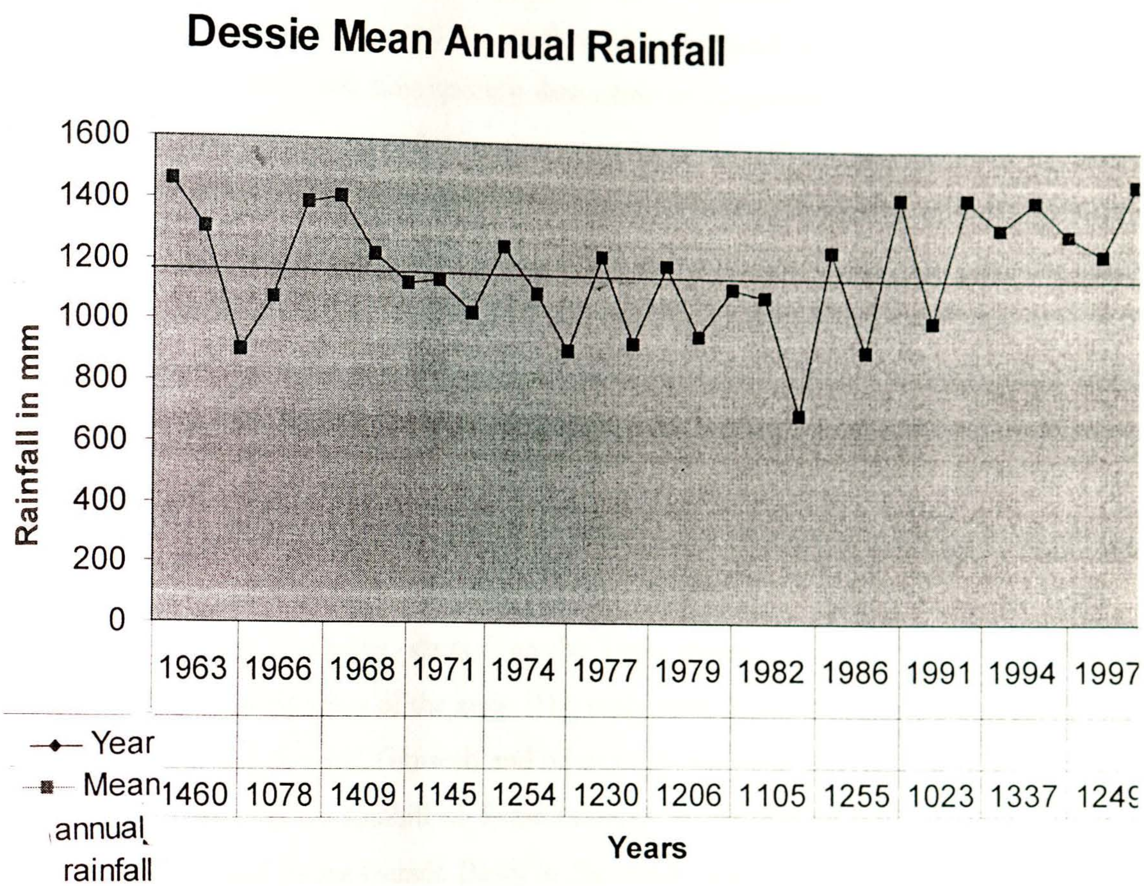


Figure 4.2 Mean annual rainfall of Dessie

The observed frequency distribution of the data recorded can be used to estimate the population of all conceivable values of the hydrologic variables. According to the rainfall data obtained from Ethiopian Meteorological Service, high amount of rain fall in Dessie town is usually observed in July, August and September with the exception of April, when there is most of the time sufficient rain, and the other months are known as periods of little rain fall. The mean annual rainfall of Dessie is about 1185 mm. It has high deviation from the mean as shown on Figure 4.2.

CHAPTER FIVE - HYDROLOGY

5.1 SURFACE HYDROLOGY

Upon reaching the ground surface, a portion of the rain is absorbed by the soil. Rain water that is not absorbed remains on the surface of the ground, fills small depressions, and eventually spills over and runs quickly downslide in to streams as overland flow, which generates floods. The absorbed rainwater seeps in to the soil by the process of infiltration and is held there as soil moisture. If the soil moisture content is raised sufficiently, infiltrating water will displace older water, which may percolate laterally through the topsoil in to streams as subsurface storm runoff or vertically to the groundwater zone where the pores of the soil or rock are completely filled with water. From this zone water moves slowly in to streams swamps or lakes providing surface runoff during dry weather (Leopold, 1978).

Runoff is water that drains on the surface in to the stream channel as overland flow and from the groundwater contribution to the stream as base flow.

Most of the runoff in Dessie, starts from the Tossa mountain range west of the town and flows to the low-lying parts of the area. The study area is highly dissected by Borkena and Dosso Rivers. Derekwnze, Gimwuh and other many seasonal intermittent streams that are feed by springs from the foothill of Tossa escarpment. Gimwuha starts from the center of the town and drains to the Gerado Basin to the south west of the town near Segno Gebeya Figure 4.4.

Most of the streams in the town are highly polluted by urban wastes that are supplied from a poor drainage of the toilets. Borkena River is therefore highly polluted by the tributary streams that cross the town. The toilet wastes are also transported by the municipality trucks up to the bank of the river and drains down to the river Borkena at Dessie out scrits to Kombolcha town, in the near distance down stream. Borkena River crosses not only Kombolcha town but also other urban and rural villages up to its confluence to Awash River. Most of the peoples in its way use the River. So, the municipality of Dessie town and the water and sewerage branch office should take immediate action for this serious problem.

The Borkena and Desso River flows from the north and drains to the south east of the town after their confluences with in the town near the main road to Woldya.

In Dessie town numerous gullies and small streams join Borkena River and during the rainy season runoff from the Tossa Mountain is channeld by a number of gullies, through the town finally drains to the River. This has exposed the area for rill and gully erosion especially in the lower slopes, which are mainly formed by loose sediments and residual soil

Borkena and Desso Rivers are gauged in to two stations with in the town. Desso gaged before its confluence to Borkena and the Borkena station is near the Dessie Hospital after the two rivers join. The recorded data from 1976 to 1997 with some years of missing data (not recorded) , shows that the least yearly mean discharge is 5.36 m^3/sec in 1984 and the highest

mean discharge is 158 m^3/sec in 1980 for Borkena River.

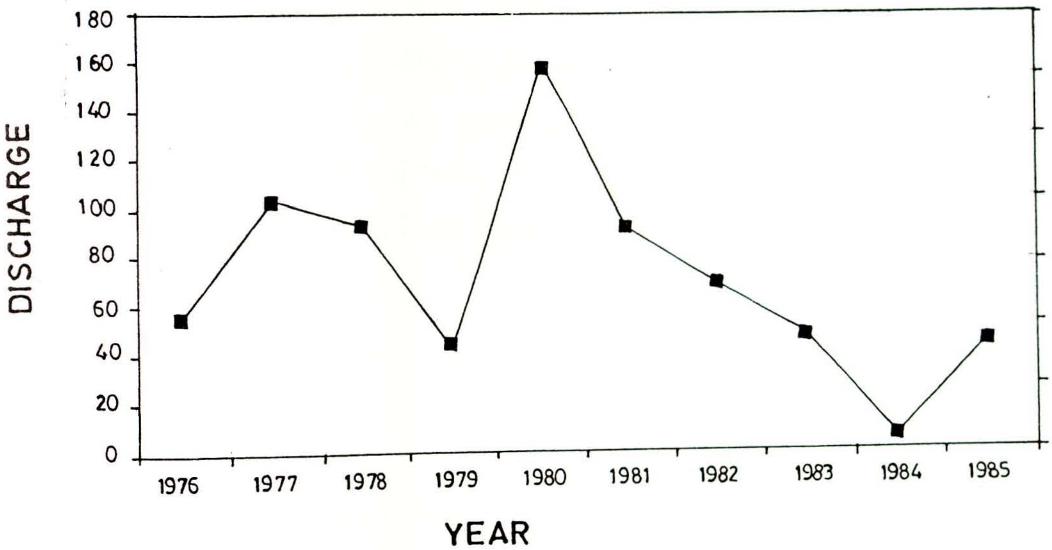


Fig 5.1 Discharge measurement of Borkena River

As it is expected, the highest mean discharge is observed during the year of high precipitation (Figure 5.1)

Precipitation and landslides in Dessie has a linear relationship,since most of the slopes failed during or shortly after a rainy season Figure 8.2.

5.2 GROUND WATER HYDROLOGY

Knowledge of groundwater condition is essential for various engeneering works. Water is the most important factor in most slope stability problems. The way ground water flows, its pressure and gradient at any point with in a slope depend on the local geology (Abramson, 1996).

Dessie area is found in a sub-humid climatic zone where there is a surplus of rainfall for recharge of ground water. This surplus of water for recharge of ground water mainly occurs in the months of July, august and September as most of the rainfall occurs with in these month.

Jointed, fractured and weathered basaltic rock constitutes most part of the study area. These fracturing and weathering of the basalt and agglomerate underlying the area possess secondary porosity, and allows ready infiltration in to the basalt aquifer and infiltration is also high in to the alluvial- colluvial deposits in the low-lying areas. Infiltration from precipitation replaces all the water withdrawn from the aquiffer through the year (Ketema Tadesse, 1978). The water that entered in to the ground is mainly discharged through the springs that are found at the foot of Tossa escarpment and boreholes that were drilled for water supply of the town

5.2.1 Ground Water Flow

The configuration of the groundwater regime in the study area is a direct product of the structural and the geomorphologic shape. The fault springs face the down thrown blocks. It is assumed that the intensive fracturing favors a higher amount of water to percolate downwards, higher than the undisturbed volcanic terrain. It is also assumed that the floor of the graben acts as hydrogeological base levels fed both by a direct recharge and mainly by lateral subsurface flow from up thrown blocks. This process may smooth the seasonal fluctuations and support a rather constant supply to these lowlands, to the alluvial - colluvial as well as the underlying volcanic aquifers.

Since Dessie town is a structurally affected zone, many fractures may be developed that may most likely favor the subsurface flow of water. In the Dessie Graben, continuous subsurface flow from the Tossa mountain block recharges, all through the year, the large volume of colluvial body.

A shallow hand-dug well that never dries up, with only minor seasonal fluctuations (from the local people) in the Hote Meda area indicates the existence of shallow ground water horizon. Below the prison compound, water is observed at ground level above the Borkena channel. At this location, the colluvium may feed the Borkena River.

5.2.2 Boreholes

The hydrogeological properties of the rock sequences can be inferred from its geological and structural point of view and from pump test data.

Most basalts due to their origin and mineralogy have usually minor to negligible effective porosity. The ground water is therefore stored and flows through a network of fractures and fissures. It also depends up on the vertical heterogeneity, the hydraulic connection and association of the different fractured layers. Within the study area, however it is more than likely that due to the intensive tectonic impacts and the structural shape, more developed fracturing, fault belts, fault breccias, etc. facilitate hydraulic connection between the different layers and adjoining blocks and may also create preferred conduits for the easier movement of groundwater.

It is suggested that in the Dessie area the hydrologic properties of the volcanic aquifer are superior in comparison to other areas of the Ethiopian plateau (WSSA, 1996).

The average 6 -7 l/s (20 -25 m^3/hr) yield is significantly higher than all Ethiopian plateau boreholes, with a few exceptional ones, as displayed in Tesfaye Chernet's (1988), Hydro geological Map of Ethiopia.

Table 5.1 Pretest well data in Dessie Town in Dec 29/1991

Well Data	Bore wells				
	Rob	Kurkur	Gabrel	Hote	Dawdo
Measuring point	Natural ground	Natural ground	Natural ground	Natural ground	Natural ground
Total depth of Borehole	78m	70m	55.5m	65m	83m
Position of the pump	72m	52.45m	45m	51m	65.0m
Power of the pump (H.P)	12	12.5	25	12	25
Discharge capacity of the pump	--			8 l/sec at 150head	15 l/s at 180 head
Actual discharge	4 liter/see	2-3lite/sec	5.8 l/sec	2-3 l/s	7.3 l/s

Source:- Dessie WSSA Branch Offfice

l/s = litre/second

Table 5.2 Pumping Test Data

Well Data	Bore wells				
	Robit	Kurkur	Gabrel	Hotel	Dawdo
Static Water Level	25.55m	14.59m	25m	21m	32m
Dynamic water level	73.33m	63m	27.45m	33.5m	52m
Position of the pump	73.52m	64.4m	51m	56m	75.8m
Power of the pump (H.P)	25	25	25	25	25
Pipe diameter (inch)	2½	2½	2½	2½	2½
Discharge capacity of pump	15 l/s at 180m head	15 l/s at 180m head	15l/s at 180m head	15l/s at 180m head	15l/s at 180m head
Actual discharge	7.34l/s	3.5 l/s	14 l/s	14 l/s	11 l/s
Date of pumping test performed	Dec 3, 1991	Dec 6, 1991	Dec 11, 1991	Dec 12, 1991	Dec 17, 1991

Source: - Dessie WSSA Branch Office

l/s = litre/second

According to the test data report, there might be a possibility that at least in some of the boreholes the real capacity is higher than the observed. The Gebreal Well is reported that its pumping - tested yield was 14 l/s (54m^3/h).

The effective porosity of a granular un-consolidated aquifer is usually high. A shallow well in coarse alluvium may therefore yield a much higher capacity than a deeper well in volcanic. According to WSSA report, some of the Kombolcha valley wells discharge above 20 l/s from an aquifer of very coarse alluvium and other wells in similar aquifers, in different parts of Ethiopia, are known to discharge 10 - 20 l/s.

5.2.3 Springs

The population of Dessie is at present supplied in part by six springs, of which KurKur and Shola are the most important, yielding 6 to 8 litters per second and 2 to 3 liter per second respectively. The others Ras Abate, Huluko sire and a spring on the Megdalle road 1.5 km

from the junction with the Addis Ababa Woldya road together yield 4 to 5 litter per second (Ketema Tadesse, 1978).

Kurkur spring located in the northern part of the town emmantes from fractured basalt. Shola spring, a fault - controlled spring very close to the north - south fault line on the western boundary of the town, supplies the southern part of the town. There are two further springs at Bededo, 17 kilometers north of the town on the Woldia Highway, whose yields are 1.5 and 1.3 liters per second (Ketema Taddese).

Table 5.3 Summery of most important springs in Dessie Town

Spring	Location	Discharge
KurKur (1)	East face of the KurKur block (NNW SSE trend)	3 - 4.2 l/s
Shola (2)	South face of the Tossa Mountain (NW -SE aligned fault)	0.8 - 3 l/s
Bededo Springs (3)	NE face of fault scarp (NW - SE aligned fault)	50 - 60 l/s (both springs)
Ras Abate (4)	East face, Tossa Mountain fault Scarp (NNW – SSE trend)	Very small, seasonal
Dawdo (5)	East face, Tossa Mountain fault scarp (NNW – SSE)	Very small, seasonal

All are fault springs

For the location of springs see Figure 4.4

CHAPTER SIX - GEOTECHNICS AND ENGINEERING GEOLOGICAL MAPPING

6.1 GEOTECHNICS

6.1.1 Introduction

The terms geotechnology and ground engineering are often used to describe the study of geotechnical processes and practical issues including techniques for which the only available methods of assessment are either qualitative or empirical (Powrie, 1997).

Geotechnics more generally is defined as the application of different methods on the subsurface material to know the engineering properties of soil and rocks. This is more concerned with soil mechanics, the study of the engineering behavior of soils, with reference to the design of civil engineering structures made from or in the earth such as embankments and cuttings, dams, earth retaining walls, tunnels, basements and the foundation of buildings and bridges. Problems in soil mechanics had begun to be identified and addressed analytically by the beginning of the eighteenth century Heyman, 1972 cited in Powrie, 1997. The expansion of the subject during this time has been very rapid, and the term geotechnical engineering has been introduced to describe the application of soil mechanics principles to the analysis, design and construction of civil engineering structures, which are in some way related to the earth.

Practically in geotechnics, geophysical methods, continuous core samples from drilling operations with various type of tests, such as, standard penetration test, permeability test, etc. Collecting undisturbed samples for laboratory tests, logging using different procedures and description and evaluation of the strength and deformability of rocks properties of soils and their bearing capacity upon loading are presented, interpreted and used by engineering geologists.

6.1.2. Geotechincal investigation in the study area

In order to understand the geotechnical properties of soils and rocks and their stability in Dessie, the following works have been executed and summarized in table 5.1

Table 6.1 Summary of geotechnical works for the study area

Item	Work executed	Work done
1	Geological exploratio	Preparation of geological engineering geology geomorphologic, slope & drainage land land cover, hazard zonation, land slide map description of each map with the scale of 20,000.
2	Core drilling	Three boreholes with a depth of 31, 41 and 42m each
3	Digging of test pits	15 test pits at selected places
4	Standard penetration test	Selected 10 points in 3 bore holes
5	Undisturbed sampling	10 samples from bore holes 10 samples from test pits
6	Geophysical survey	Vertical Electrical Sounding test at seven selected sites.
7	Rock joint measureme	20 selected site with a total of 200 measuring points
8	Laboratory tests	7 consolidation test 3 direct shear test 10 Atterbeing limits 3 Uunconfined compressive strength 15 Granisize analysis
9	Point load test	15 selected samples from different areas
10	Schmidt hammer test	200 tests
11	Inclinometer installati	In three boreholes at a depth of 29, 41, 18m

6.1.2.1 Drilling

A comprehensive landslide study has been started by mutual effort of Caglari University from Italy and Geology and Geophysics Department of Addis Ababa University
This study includes installation of inclinometer tubes for the continuos record of landslides magnitude and rate of movements.
Accordingly, the above institutions made an agreement with Building Design Enterprise (BDE) for drilling of three bore holes on selected landslide areas. The drilling work and installation of inclinometer tubes were performed from February 22, 2001 to March 16, 2001. During the progress of drilling work, standard penetration test (SPT) collecting of undisturbed samples and the total core have been carried out. Finally, the Inclinometer tubes have been installed by using full grouting techniques and the initial reading of the inclinometer orientation was taken.

Table6.2 Bore hole depth and type of tests.

BH No	Location	Depth(m)	N° SPT	N° USS	Depth of Inclinometer
1	Dawdo (landslide 5)	31.6	4	3	29m
2	Kerra (landslide 9)	41.6	5	3	41m
3	Near Administra Bldg. (Landslide 3)	41.5	4	5	18m

SPT = Standard Penetration Test
USS = Undisturbed Soil Sample
Log sheet of boreholes showing soil section and test results of borehole 1, 2, 3 is given in Annex 2

6.1.2.2 Test pits

Test pits are the most direct methods checking the shallow soil stratification and recognizing the visual inspection. It helps for determination of the field consistency and estimating the compactness of the cohesive and granular materials respectively.
A total of fifteen test pits have been dug on selected points up to a maximum depth of 4m. Most of the layers are on colluvio-alluvial materials situated relatively on the flat topography.

A reasonably accurate description of soil deposits including the physical properties of the soil involved needed before the conclusion of the study and the design of a foundation can be made in an intelligent and satisfactory manner. The physical properties of the soil deposits must be determined by boring and testing and an idealized soil profile consisting of a few homogeneous soil units with simple boundary must be prepared for the more complex soil profile. In much case the real soil profile is reasonably approximated by the idealized profile, so theory combined with the results of soil testing makes possible a predication of the soil type, strength and possibly the origin of the material.

Explanation of soil deposits usually involves a reconnaissance of the site, borings, pits made to permit sampling of subsoil for laboratory testing and field tests. Depending on the type importance and nature to the project, the program of soil exploration may range from penetration tests at a number of boreholes to a careful collection of undisturbed soil specimens for laboratory tests. The location of test pits and test points and interval for sampling depend on the type of soils and physical properties to be measured (Al-Khafaji and Andesland, 1992).

6.1.2.3 Laboratory Tests

Table 6.3 Type of Laboratory tests conducted

Type Test	Bore hole / TP No	Depth (m)	Location
Consolidation	Tp_1	2	Arada
	Tp_2	2	Zonal education Bureau
	Tp_6	2.5m	Inforont of Fikreselam Hotel
	BH_1	10	Dawdo (landslide 5)
	BH_2	10	Kerra
	BH_3	3	Landslide 3
Shear	Tp_2	4m	Zonal Education Bureau
	BH_1	24m	Landslide 5
	BH_3	16m	Landslide 3
Uncontinued comprmsive strength (UCS)	BH_2	3	Kerra
	BH_2	12	Kerra
	BH_3	25	Landslide 3
Atterberg limits	Tp_2	2	Arada
	Tp_6	2.5	Zonal Education Burea
	BH_1	8	Landslide 5
	BH_1	12	Landslide 5
	BH_1	24	Landslide 5
	BH_2	2.5	Kerra
	BH_2	4	Kerra
	BH_2	6	Kerra
	BH_2	12	Kerra
	BH_3	3	Landslide 3
	BH_3	16	Landslide 3
			Segno Gebeya
			Dessie TTI
Grain size analysis (GS)	BH_1	6, 8, 12, 24	Landslide 5
	TP_2	2,4	Zonal Educaion Buereau
	BH_2	2.5,6,10, 12	Kerra
	BH_3	16	Landslide 3
			Segno Gebeya
			Dessie TTI

6.1.2.4 Geo electrical Survey in the study area

The geoelectrical method used was vertical electrical sounding (VES). The instrument used was Terrameter SAS 300C with all its accessories. A 12 volt battery was used as a source of electrical power. The Suchlumberger electrode configuration was employed for the electrode spacing.

The Schlumberger array employs four linearly arranged electrodes two of them as current electrodes and the other two as potential electrodes. The electrodes are arranged symmetrically about the mid-point "O" as shown below.

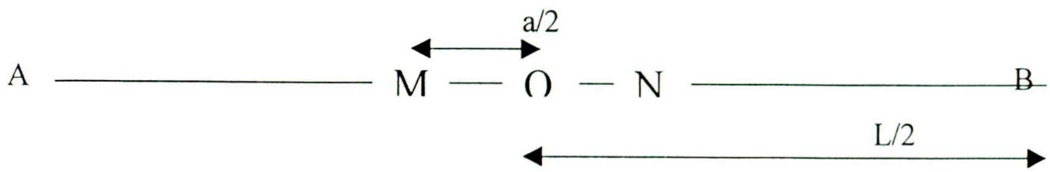


Figure 6.1 Schlumberger configration

"A" and "B" are current electrodes and "M" and "N" are potential electrodes "O" is the mid point about which the electrodes are configured "a" is the distance between the potential electrodes, and L is the distance between the current electrodes. The higher the length of L, the deeper is the information we have.

Such type of electrode configuration is usually used for sounding i.e. for exploration to depth. By varying the spacing of the outer electrodes (A&B) and keeping M&N constant and increase, about the center, i.e. symmetrically increase. As the distance L/2 increases, more information is obtained from more deeper layers.

Geoelectrical sites were selected on the basis of borehole locations around unstable areas (landslide areas). Totally 7 soundings were conducted at Kerra (around BH2), around BH1, Hote Meda. at Nigus Micheal School, around Landslide1 (TTI area) Dawdo, and the eastern margin of the site east of Arera.

The location of the geoelectrical soundings are shown in figure 4.4 and the apparent resistiveity versus electrode spacing, quantative and qualitative interpretations in Annex 1

6.2 ENGINEERING GEOLOGICAL CLASSIFICATIONS OF SOILS, ROCKS AND MAPPING

6.2.1 General

Engineering geology exists solely to serve the art and science of engineering through description of the structure and attributes of the rocks connected with engineering works. It is also part of engineering geology to identify and evaluate natural hazards like landslide, and earthquakes that may affect the success of an engineering project. It is also concerned with the storage and movement of water through the void spaces with in rocks and soils and the associated consequences for an engineering project and for the natural region (Goodman, 1993)

Engineering failures may cost lives and certainly cost money. To prevent such failures, the influence of the geology of the site on the design and construction of the engineering work must be understood and clearly explained.

Engineering Geology as defined by the International Association of Engineering Geology (IAEG), includes the discipline of applying geologic data, techniques and principles to the study of naturally occurring rock and soil materials or subsurface fluids. The purpose is to ensure those geological factors affecting the planning, design, construction operation and maintenance of engineering structure and development of groundwater resources.

6.2.2 Engineering geological classification of soils and rocks

In engineering geological mapping soils/rocks of the same genetic type can be grouped in different way or different genetic type can be classified in the same group. The classification involves grouping of different soil and rock types in to categories, which possess similar properties, so as to provide a systematic method of descriptions. Most of the time the classification takes in to consideration both the field and laboratory results that leads towards the possible identification and interpretation of rock and soils.

Why do we classify soil in general and from engineering point of view in particular?

Out of many reasons the most important once are:-

- To identify soil in a systematic manner and to determine their suitability for use in specific applications based on past experience
- In communicating soils information to other geographic area and to build database from the experience of the others. This experience exchange is very important since all soils have a common origin from rock decomposition.
- For simplification and easy understanding.

Classification of soils and rocks for engineering geological mapping should be based on the principle of their physical or engineering geological properties in its present state which are dependent on the combined effects of age, mode of origin, subsequent diagentic, and many post genetic processes including weathering. This principle enables us to not only reason out the lithological and physical character of soils and rocks but also their spatial distribution.

6.2.2.1 Engineering geological classification of soils

The word soil is derived from the Latin word solium which, according to Webster's dictionary, means the upper layer of the earth that may be dug or plowed; specifically the loose surface material of the earth in which plants grow. This definition works in the field of Agronomy where its main concern is in the use of soil for raising crop (Arora, 1997). In geology soil is the thin outer layer of loose sediments with in which plant roots are present. A geologist refers to the rest of the earth's crust a rock, irrespective of how strong or weak the bonding forces of the sediments (Gopal and Rao, 1991). The material, which is, called soil by the agronomist or the geologist is known as topsoil in geotechnical engineering or soil engineering.

The term 'soils' in soil engineering is defined as an unconsolidated material composed of solid particles formed by weathering and disintegration from solid rocks and differ depending on the parent material and the weathering process involved (Al-Khafajc and Andersland, 1992).

The domain of the engineering geologists is in most cases with in the top few meters of the surface of the earth. Therefore, surficial deposits are of critical importance in an engineering geological map. Soil is mapped only when its thickness one meter, when it is less thick, the underlying rock is mapped (Soeters and Rengers, 1980).

The different soil classification adopted by pedologists, geologist, agriculturists etc are not suitable for engineering requirements, hence the need to have engineering soil classifications arises. Eventhough several soil classification systems are in use the unified soil classification system (USCS) proposed by the U.S Bureau of Reclanmation and Corps of Engineers modified by IAEG (1981) is employed for classification of soils of the study area. The classification method used is based on greading of the constituent particles and plasticity of the fraction of the material consisting of particles finer than 0.425mm. But soil classification system does not substitute for detailed studies of soils or for testing their engineering properties. For example, the unit weight, performance under saturated conditions; compaction characteristics, strength, susceptibility to frost action etc, are not directly included in any of the classification systems.

Different soils in the study area have been classified by selecting samples and analyzed in the Building Design Enterprise Central laboratory.

6.2.2.2 Laboratory Test Results and Interpretation of Soils

Field investigation of the study area was carried out on the basis of bore holes, test pits, and taking many traverse along hillsides, gully sides, road cuttings and along the foot of escarpments.

In order to appraise engineering geological proporties of soil field test (standard penetration test) and collecting of undisturbed and disturbed samples for laboratory testes were carried out in the field and laboratory tests were conducted in the Building Design Enterprise Central Laboratory.

Samples were collected from representative bore holes and test pits that are more relevant to the study area. This includes around Kerra, Dessie TTI, Segno Gebeya, Arada, Dawdo, and other places. Accordingly, the following strength, classification and other laboratory tests have been performed.

Classification Test.

Common classification test include the determination of moisture content (w), Atterberg limits (liquid limit and plastic limit), specific gravity, and particle size distribution. The tests required for determination of engineering properties (permeability, compressibility and shear strength) are generally times consuming (Lambe,1969).

Sometimes rough assessments of the engineering properties are made with out conducting elaborate tests. The properties of soil of which are not primary interest, but an indicative of the engineering properties are index properties. Simple tests, which are carried to determine the index properties, are known as classification test. The soils are classified and identified based on the index properties. The main index properties of coarse-grained soils are particle size and relative density. For fine-grained soils, the main index properties are Atterberg limits and consistency indexes (Arora, 1997).

Grain size analysis

A grain size analysis or particle size analysis is also known by mechanical analysis, is a method of separation soils into different fractions based on the particle size. It expresses quantitatively the proportions by means of various size of particle present in a soil. It is shown graphically on a particle size distribution curve.

The mechanical analysis is done in two stages

i) Sieve analysis,

ii) Sedimentation analysis

The first analysis is for coarse-grained soils (particle size greater than 75 microns), which can easily pass through a set of sieves. The second analysis is used for fine-grained soils (size smaller than 75 microns). As a soil mass may contain the particles both types of soils, a combined analysis comprising both sieve analysis and sedimentation analysis is required. After complete size analysis, the relative proportion of different size groups in each soil sample is given in Table 6.4 The range of each group was adopted from ASTM, 4.75 mm gravel, 4.75 -0.075mm - sand, 0.075mm - 0.002 mm, silt and < 0.002 clay.

Table 6.4-Grain size analysis

No	Location	Depth m	Soil traction				Description
			Gravelly >4.75mm%	Sandy 4.75 - 0.075mm%	Silt 0.075-.002mm%	Clay <0.002mm%	
	Kerra						
1	BH_2	2.5	---	10	50	40	Clay silt
2	BH_2	6	----	5	53	42	Clay silt
3	BH_2	10	18	22	38	22	Sandy,claysilt
4	BH_2	12	---	5	52	43	Claysilt
5	Kerra	----	---	20	30	50	Silty clay
6	Kerra	----	---	5	45	50	Silty clay
	Dodo						Silty clay
7	BH1	2	---	7	35	58	Silty clay
8	BH_1	4	---	8	37	55	Silty clay
9	BH_1	6.05	38	17	30	15	Sandy,silty gravel
10	BH_1	8	5	8	47	40	Clay silt
11	BH_1	12	---	15	44	41	Clay silt
12	BH_1	24	---	8	60	32	Clay silt
13	BH_3	16	---	15	37	52	Silty clay
14	Tp_2	2	---	5	55	40	Clayey silt
15	Tp_2	4	---	8	37	55	Silty clay
16	TTI		--	74	21	5	Silty sand
17	TTI		---	28	62	10	Sandy silt
18	TTI		---	8	50	42	Clay silt
19	Segno Gebeya		---	28	40	32	Clayey silt
20	Segno Gebeya		---	35	25	40	Clayey silt

In soil classification of colluvial materials, it consists of fine material in small amount to coarse gravels and boulders to a large proportion. Coarse grained soils, more than half of material, is larger than N° 200-sieve size. In most cases the materials are well graded (have all sizes) gravels sand mixture with a little fines. In the upper elevated surfaces, steep slope areas covered with boulders cobbles and big blocks.

The laboratory soil classification gives the value of Cu (uniformity coefficient) grater than 4 and Cc coefficient of curvature between 1 and 3.

Where $$CU = \frac{D_{60}}{D_{10}}$$

$$Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

D_{60} = Particle size at 60%

D_{30} = Particle size at 30%

D_{10} = Particle size at 10%

In same places at medium or gentle slope areas Cu value become less than 4 with a little higher fine material and in plasticity chart is falls with in an area of CL (low plasticity gravelly clays, sandy clays or silty clays).

Generally, the coarser colluvial materials consist of more than 60% of coarse gravels 30% sand and less than 10% fine materials (Silt and clay). However, in some low lying areas around TTI, Kerra, Segno Gobay and Dawdo consist of 30-60% silt, 20 - 55% clay, 5 -35% sand and about 5% gravel and the soil is mostly classified as silt and clay.

Atterberg limit tests:- are routine laboratory tests for arbitrary moisture contents to determine when the soil is on the verge of being a viscous fluid (liquid limits W_L or LL) or non plastic (plastic limit Wp or P_L) The plasticity index, Ip is the range of water contents for which the soil is plastic.

$$Ip = w_L - w_P$$

A plastic soil has a large value of Ip in general, the higher the Ip, the greater the amount of clay particles present and the more plastic the soil. The more plastic a soil (1) the more compressible it will be (2) the higher shrinkage swell potential will have, and (3) the lower its permeability will be.

The shrinkage limit Ws is the water content beyond which no further reduction of mass volume takes place with further drying (Bowles, 1982).

The liquid and plastic limit are widely used for soil classification. The plasticity index is commonly used as a correlation factor to estimate the angle of internal friction and settlement parameters.

Correlated angle of internal friction is given by (Bowles, 1982)

$$K_0 = 0.95 - \sin ø$$

Where $K_0 = 0.19 + 0.233 \text{ Log } Ip$

$$\sin^{-1} ø = 0.95 - (0.19 + 0.233 \log Ip)$$

$$\frac{Ko}{\delta_v} = \delta_h \quad \text{The steady state condition}$$

Ko < 1 for normally consolidation and

K = 1 or large for over consolidated.

The liquidity index is defined as:

$$I_L = \frac{W_N - Wp}{W_l - Wp} = \frac{Wn - Wp}{Ip}$$

It can be used to estimate the insitu state. If $I_L > 1$ the soil may liquefy under a shock (the natural water content is above the liquid limit). A sudden shock may be the result of pile driving or even heavily equipment operating in the vicinity or naturally it can be induced by earthquakes.

Soil Classification based on Limit and Index Value Bulletin of IAEG, No 24, 1981

Table 6.5 classification based on liquid limit

Term	Range of liquid limit
Low plasticity	Under 35
Intermediate plasticity	35 - 50
high plasticity	50 - 70
Very high plasticity	70 - 90
Externally high Plasticity	Over 90

Table 6.6 Classification based on Ip

Term	plasticity Index
Non - plastic	Under 1
Slightly plastic	1-7
Moderately plastic	7 - 17
Highly plastic	17 - 35
Extremely plastic	Over 35

Table 6.7 classification based on liquid Index I_L

Consistency	Liquidity Index
Semisolid or solid	Negative
Very stiff state (Wn = Wp)	0
Very soft state ($Wn = W_l$)	1
liquid state	>1

Table 6.8 Classification based on Shrinakage limit Sr

Quality of soil	Sr %
<5	Good
5 - 10	Medium good
10 - 15	Poor
>15	Very Poor

Table 6.9 Classification of fine soils in terms of consistency index

Term	Consistency Index	Unconfined compressive strength KPa	Standard penetration (SPT) blows/ft
Very soft	< 0.05	<25	< 2
Soft	0.05 - 0.25	25 - 50	2 - 4
Firm	0.25 - 0.75	50 - 100	4 - 8
Stiff	0.75 – 1	100 - 200	8 - 15
Very stiff	> 1	200 - 400	15 - 30
Hard	-	> 400	> 30

The Atterberg limit tests done for soils of the study area show the following values for samples selected from Kerra, TTI, Segno Gebey, Arada & Dawdo area.

Table 6.10 – Summery of Atterberg Limits and Index values.

No	Location	Moisture content %w	Liquid limit %LL	Plastic Limit %PL	Plastic Index PI	Consistency Index CI	Liquidity Index %LI
1	Kerra Black clay	55.02	86.47	47.18	39.28	0.8	0.199
2	Black clay	54.18	96.26	46.95	49.31	0.85	0.14
3	Black clay	53.2	97.78	48.5	49.28	0.90	0.10
4	Brown clay	33.47	91.44	46.75	44.69	1.29	-0.29
5	Brown clay	33.58	97.65	46.72	50.93	1.25	-0.25
	TTI						
6	Black clay	45.04	97.65	50.54	47.11	1.11	-0.04
7	Black clay	45.33	98.11	49.96	48.15	1.09	-0.09

No	Location	Moisture content %w	Liquid limit %L	Plastic Limit %PL	Plastic Index PI	Consistency Index CI	Liquidity Index LI%
8	Brown clay	49.01	86.5	41.9	44.6	0.84	0.15
9	Brown clay	42.10	88.2	41.03	46.9	0.98	0.028
	Sengo Gebey						
10	Black clay	40.09	54.92	38.68	20.63	0.92	0.07
11	Black clay	40.20	59.31	30.55	30.3	0.75	0.24
12	BH1 (8m)	38	60.85	38.86	61.14	0.89	0.10
13	BH1 (2m)	45	100	30.23	20.17	1.5	-0.25
14	BH1 (24m)	25	50.40	38.25	57.15	0.72	0.27
15	Tp2 (2m)	54	95.4	38.25	57.15	0.32	0.67
16	BH2 (2.50m)	55	67.75	30	44.5	0.95	0.04
17	Tp2 (4m)	32	74.5	24.48	44.52	0.87	0.12
18	BH2 (6m)	30	69	21.5	42	0.91	0.08
19	BH2 (12m)	25	63.5	32.95	50.35	1.1	-0.13
20	BH3 (3m)	26	83.3	45.9	41.7	1.4	-0.42
21	BH3 (16m)	28	87.7	34.23	49.7	0.84	0.15
22	Tp6 (2.5m)	42	84	38	46		

The liquid limit and plastic limit of soil samples analyzed in the laboratory is summarized in table 6.10. Comparison of the plastic limit with the moisture content of the soils indicates that the silty clay soils were below their plastic state when they were sampled.

Soils from Kerra have relatively high liquid limit from 91.44% to 97.6% and that of TTI soils liquid limit ranges from 88.2% to 97.7%.

Description of plasticity of fine soils in terms of their range of liquid limits given in plasticity chart. Comparison of the liquid limit of soils of the study area with their respective plastic index plotted on the plasticity chart enables to describe the soils as being of very high to extremely high clay for Kerra soils and high to very high plastic silty clay for other area clays.

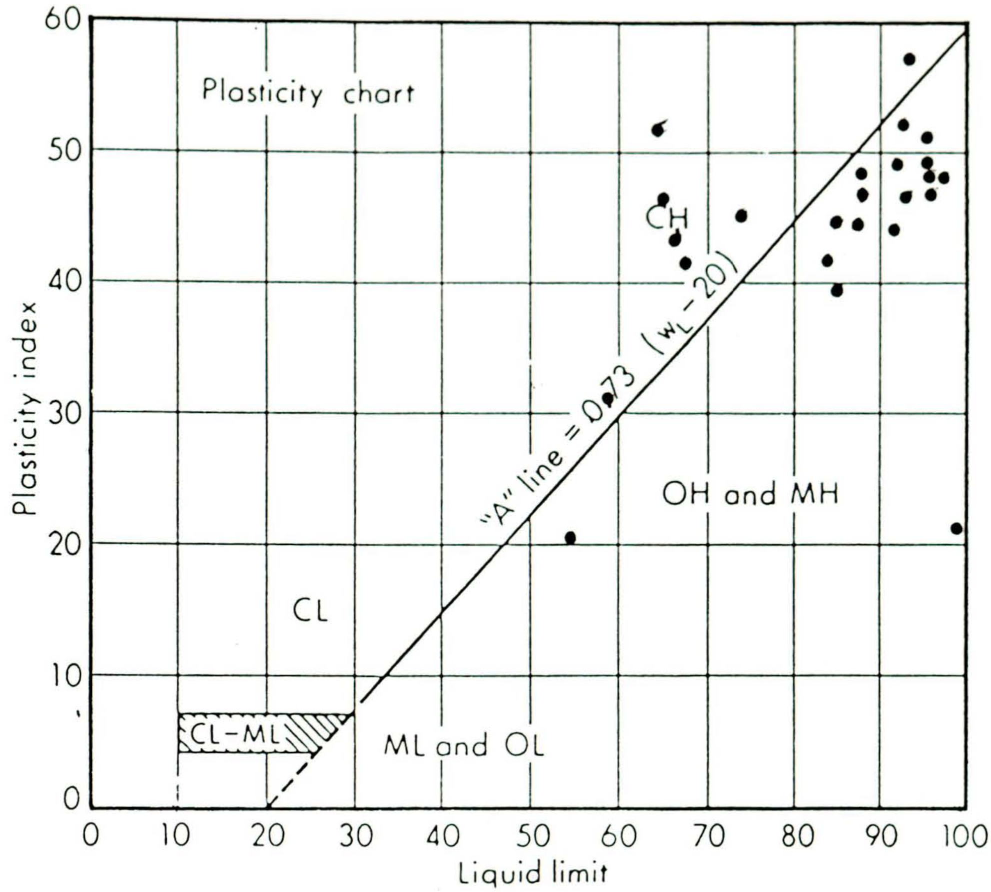


Figure 6.2 plasticity chart

CH=Inorganic clays high plasticity

CL=Inorganic clays of low to medium plasticity (gravelly clay, sandy clay)

OH=Organic clay of medium to high placticity

MH=Inorganic silt or sandy silt

ML= Inorganic silt with slight placticity

OL=Organic silt and organic silty clays of low placticity

Comparison made for plasticity index of the study area and that of the standards classification given in Table 6.6. Most of the soils are in the range of highly plastic and above, specially Kerra & TTI clays have plasticity index of greater than 45 and is extremely plastic.

Consistency index of Kerra and TTI silty clay ranges from 0.8 to 1.29 and that of Sengno Gebeya soils with similar range from 0.92 to 0.97. According to the classification table 6.9, almost all soils except the lacustrine soil of the study area are grouped under stiff soils. The liquidity index value for Kerra and TTI soils range from 0.14 to negative 0.29 and their negative value shows that the plastic limit of the soils is greater than the natural moisture content. Hence, here the soils are in the very stiff to semi -solid state.

Strength tests

Soil failure is a combination of particle rolling and sliding. This mobilizes the shear strength of the soil as opposed to the compressive or tensile strength (Bowles, 1982). The shear strength involves the soil strength parameters of cohesion (C) and angle of internal friction (ø).

Shear strength in terms of total stress is given by:

$$S = C + \sigma \tan \phi$$

Strength tests have significance on saturated cohesive soils in, particular the unconsolidated undrianed tests represent "worst case" condition. These tests serve the purpose of giving a strength indication of these soils at that water content. If the water table does not fluctuate and rainfall is moderate, these tests produce suitable values for design. If the soil can saturate, the strength determination should be made on saturated samples.

For the determination of strength of the soils in the study area standard penetration test in the field, direct shear and unconfined compressive strength in the laboratory was conducted and summarized in Table 6.11.

Unconfined compression strength (qu) is the triaxal test with out the confining (Cell) pressure at zero gage pressure. In practice, devices are available to perform this test directly after trimming the sample ends L/d ratio is 2. Su = qu/2 =C.

Table 6.11 Strength test values

No	Location	SPT	Direct Shear	Unconfined	Description
1	BH1(6m)	10	C=35Kpa $\phi=15^{o}$		firm
2	BH1(12m)	19	-	-	stiff
3	BH1(16.70m	18	-	-	stiff
4	BH1(22m)	22	C=25kpa $\phi=25^{0}$	q=99kpa	stiff
5	BH2(8)	17		qu=106 kpa	Stiff
6	BH2(13.5m)	19			Stiff
7	BH2(17.80)	15			firm to stiff
8	BH2 (23m)	18			stiff
9	BH3(35)	20			stiff
10	BH3(5.40	10	C=38Kpa $\phi=18^{o}$	qu=78kpa	firm
11	BH3(13)	15			firm to stiff
12	BH3(16.8m)	15	C=51kpa $\phi=23^{0}$		firm to stiff
13	BH3(23.m)	18		q=1.82 kg/cm^2	stiff
14	BH3(36m)	15			stiff
15	BH3(4)		C=83kpa $\phi=21^{0}$	182kpa	stiff
16	BH2(3m)		C=45Kpa $\phi=18^{o}$		firm

According to the above strength tests the soils of the investigated area is classified as firm to stiff in consistency.

For SPT and strength laboratory test (See annex 2).

6.2.2.3 Soil description for mapping

Based on field study and laboratory tests, the following engineering geological units of soils have been recognized.

Dense to medium dense granular deposits: this includes colluvial deposits constitutes of fine clayey silt, sand, gravels and big bolder. Locally, with in the colluvial deposits at relatively flat areas thick alluvial deposits are common. These are firm to stiff inconsistency. Based on strength values the coarser materials are classified as dense to medium dense clayey sandy gravels.

Firm to Stiff Sandy, Silty Clays: These soils dominate relatively at lowlying areas where alluvial materials exisit. The different classification, strength, and compressibility test for this unit gives the value of firm to stiff silty clay. In some parts Kerra and Hote Meda the soil has more moisture content and liquid limit showing the characteristics of firm soil.

The moisture content and liquid limit of Kerra soils have relatively high value from 33- 55 % and 91.4 to 97% respectively. The TTI alluvial soils liquid limit ranges 88.2--97.6% and has average moisture content of 40%. The soils from Segno Gebiya have relatively high proportion of silt and sand and low value of plasticity index. Hence, the soils around this area are stiff, sandy and silty clay. So generally, the fine alluvial clays classified for mapping purpose as firm to stiff sandy silty clay.

Residual Soils: These soil are found on the top and sides of hills and are not well developed specially on steep slope areas. An appreciable thickness of these soils is found in the north and northeast part of the study area. For engineering geological mapping these soils are classified as brown, stiff, friable silty clays.

Soft organic clay: This soil is found at the center of the town where most of the large building is concentrated. It is highly compressible with coefficient of compressibility 0.4, which is bad for foundation of structures.

6.2.3. Engineering Geological Classification of Rocks

From engineering point of view, rocks are natural aggregate of minerals by strong and permanent cohesive forces. But according to geologists rocks are natural aggregate of minerals including both consolidates and unconsolidated sediments. Hence, what Geologist call rock may be an engineering soil.

Natural ground materials, rocks and soils, cover a great range of strengths. E.g., granite is 4000 times stronger than peat soil.

Table 6.12 Comparison of weak and strong rocks (Duncan, 1999).

Strong Rocks	Weak Rocks
UCS > 100Mpa	UCS<10MPa
Little fracturing	Fractured and bedded
Minimal weathering	Deep weathering
Stable foundation	Settlement problems
Stand in steep faces	Fail on low slopes
Aggregate Resource	Require engineering care

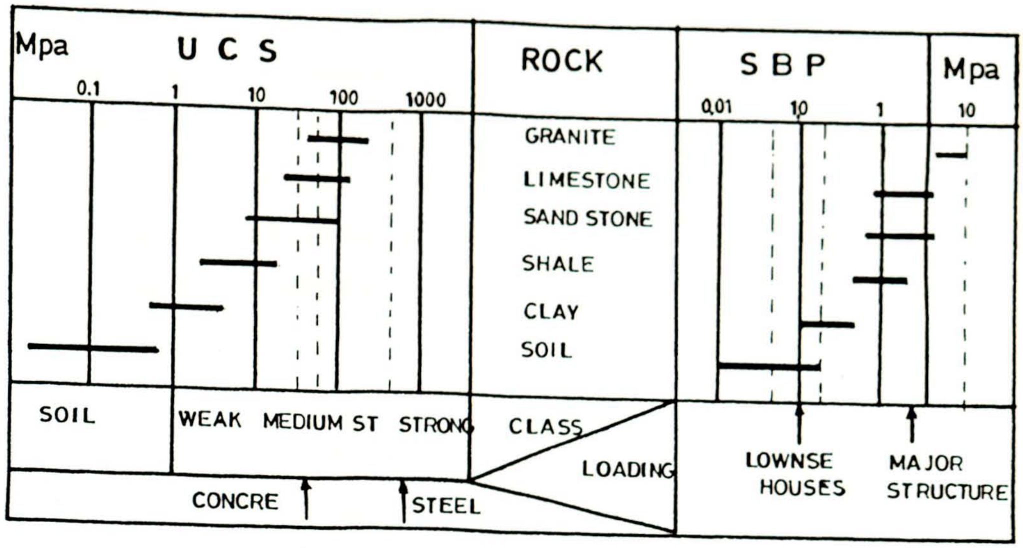
UCS unconfined (or uniaxial) compressive strength load to cause failure of a cube of the material crushed between two flat plates with no lateral restraint.

Assessment of ground conditions must distinguish

Intact rock - strength of an unfractured rock

Rock mass- Properties of a large mass of fractured rock in the ground.

Figure 6.3 UCS and SBP of different materials (Duncan, 1999)



SBP safe (or acceptable) bearing pressure load that may safely be imposed upon rock in the ground: the estimated (or measured) ultimate bearing pressure to fail the rock (allowing for fractures and local zones of weakness) divided by a safety factor between 3 and 5.

Rock properties broadly depend on:

- Strength and stability of constituent minerals
- interlocking or weakness of mineral structure
- fractures, bedding and large rock structure
- weathering.

  Rock weathering

It is physical and chemical break down of rocks at or near the surface. Subsequent removal causes surface lowering, i.e. weathering + transport = erosion.

Weathering processes depend on contact with air and/or water, so are strongly influenced by climate.

Forest shattering is important in cooler latitudes and higher altitudes; salt crystallization is only significant in deserts with high evaporation. All chemical process accelerate in hot wet climates, and are further increased by organic acids from dense plant cover. The most important chemical process is the production of clay minerals from other silicates. Laterite (red soil, high iron and aluminum, low silica) formed in tropics. Saprolite are totally decomposed rock retaining ghosts of original structure. Spheroidal weathering forms rounded boulders or core stones from angular joint blocks weathered more at edges and corners.

The physical or mechanical properties of rocks is affected by weathering, it is vital to describe the degree of weathering of rocks. The description can be achieved in terms of discoloration, chemical decomposition or physical disintegration. A description of weathering grades on the basin of mechanics and chemical changes and engineering classification are possible.

Table 6.**13** Weathering grades of rock materials

Term	Description
Fresh	No visible sign of weathering of rock material
Discolored	Color of original fresh rock material changed and is evidence of weathering
Decomposed	Rock weathered to condition of a soil in which original material fabric still intact. But some of all mineral grain decomposed
Disintegrated	Rock weathered to condition of a soil in which original material fabric still intact. Rock friable, but mineral grai not decomposed.

As in case of the engineering classification of weathered rock, it is possible to use some qualifying terms in order to describe the extent or the degree of weathering. For example, highly decomposed, extremely discolored, slightly disintegrated. The quantification of such descriptive qualifying terms is also possible by estimation from drill core sample or from natural exposure.

Table 6.14 Engineering classification of weathered rock

Grade	Description	Lithlogy	Degree of change %	Exavation	Foundation
VI	Soil	Some organic content, no original structure	100%	May need to save and reuse	Unsuitable
V	Completely weathered	Decomposed soil, some remnant structure	>75	Scrape	Assess by soil testing
IV	Highly weathered	Partly changed to soil soil > rock	35-75	Scrape corestones	Variable and un reliable
III	Moderately weathered	Partly changed to soil soil > rock	10-35	Rip	Good for most small structures
II	Slightly weathered	Increased fractures, mineral staining	0-10	Blast	Good for anything except large dams
I	Fresh rock	Clean rock	0	Blast	sound

6.2.3.1 Strength of rock

The strength of rock material can be tested either in laboratory by using Uniaxial compression test that gives un confined compression strength (UCS) or in the field by using point load test giving point load strength (PLS). They are related by UCS = 14 PLS.

Table 6. 15 Scale of rock strength (Duncan, 1999)

Description	Compressive strength (MPa)
Weak	1.5 - 15
Moderately Strong	15 - 50
Strong	50 - 120
Very strong	120 - 230
Extremely strong	>230

Rocks with strength under 1.5 Mpa are as a rule hard soil and should be tested accordingly 50 Mpa is the boundary between soft and strong rocks (While, 1999)

The dominant rock, basalt exposed in Dessie town and its surrounding is classified for engineering geological mapping depending on rock mass classification. Assessment of rock mass strength recognize cumulative effect of different geological features strength of a rock mass largely depends on the density, nature and extent of the fractures with in it. It also relates to rock strength, weathering and water conditions.

For strength testing of rocks of the study area, point load test, Schmidt Hammer test and their equivalent of unconfined compressive strength (UCS) by changing using the relation were used in the field.

Rocks of the western part of Dessie, along Tossa escarpment are classified according to RMR and the other part of the study area were determined and classified using the above filed equipments and visual observation of their degree of weathering fractures and other weakness surfaces.

Geomechnic system of Rock Mass Rating of Tossa escarpment basalts is described below.

I. Intact rock UCS (MPa) after collecting rock samples in all parts of Tossa ridge, point load test was conducted in the filed following the standard procedure and a conversion of the point load test value I_s to unconfined compressive strength (UCS) using the relation:

$$UCS = (14 + 0.175D)\ I_s50$$

Where UCS = unconfined compressive strength

D = platen separation

$I_s(50)$ = computed points load strength

Accordingly, the following results were obtained

Table 6.16 Strength value of Tossa basalt

No	Location	Average $I_S(50)$ Values in MPa	Average compression strenght
1*	South of Tossa	3.897	87.38
2	Above king Micheal School	10.02	231.5
3	Near Gabriel spring (Tossa)	10.52	240
4*	Middle of Tossa	4.51	101.15
5*	North of Gabriel spring(Tossa)	3.61	79.22
6*	Tip of Tossa	4.71	104.91
7*	North of Tossa	4.07	94.84

* Source Tadesse Dessie, 1991

From the above table the mean average UCS is about 134 MPa. According to Rock Mass Rating (RMR) the rating value is 12

II Rock quality designation (RQD) indicated degree of fracturing.

$$RQD = \sum \frac{\text{Core length} > 10\text{cm}}{\text{Total Core length}} \times 100$$

or Interms of volumetric joint count

RQD= 115-3.3 Jv, where Jv= □ 1/Si

Where Si is the average spacing for the i^{th} joint set

Joint spacing measurments along the cliff of Tossa escarpmet gives the following averge Joint sets (si)

area 1 S1 = 20, 35, 60, 70, 40, 80, 50cm

average = 46cm

area $_2$ S_2= 30, 40, 20, 60, 100, 90, 70cm

average = 58cm

area3 s3 50, 60, 30, 40, 90, 150, 80

average = 65cm

area 4 S4= 100, 20, 30, 80, 50, 40, 60

average = 54cm

area 5 S5 = 30, 10, 40, 20, 60, 50, 70

average = 40cm

Then, RQD=115 - 3.3Jv

where Jv= 1/Si

$$Jv = \frac{1}{0.46} + \frac{1}{0.58} + \frac{1}{0.65} + \frac{1}{0.542} + \frac{1}{0.4} = 9.78$$

RQD = 115 - 3.3 X 9.78

= 115 - 32.27

= 82.73%

According to RMR rating it gives the value of 17

III Mean fractures spacing according to the above data is between 60cm to 1.50m then the RMR value is 15

IV Fracture condition open less than 1mm to weathered and the RMR value is 20

V Ground water state is dry in the present condition (February to March). Therefore the value of dry ground water condition in the RMR table is 15

VI Fracture orientation: The orientation of fracture along the Tossa cliff is almost vertical hence, it facilitates rock fall and toppling. Therefore, the condition is unfavorable which attains the value of (-15) in the RMR value.

Therfore Rock mass Rating (RMR) is the sum of the above six ratings

RMR = I + II + III + IV + V + VI

RMR = 12 + 17 + 15 + 20 + 15 + (-15)= 64

According to the Guideline properties of Rock Mass classes in table below the rock is in class

II and is good rock

Table 6.17 Guideline properties of Rock Mass Classes (Duncan, 1999)

Class	I	II	III	IV	V
Description	V.good rock	Good rock	Fair rock	Poor rock	V.poor rock
RMR	80-100	60 – 80	40 - 60	20 - 40	< 20
Qvalue	> 40	10 – 40	4 - 10	1 - 4	< 1
Friction angle (0)	> 45	35 – 45	25 - 35	15 - 25	< 15
Cohesion (KPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
SBP	10	4-6	1 - 2	0.5	< 0.2
Safe cut slope (0)	> 70	65	55	45	< 40
Tunnel Support	None	spot bolts	Pattern bolts	bolts shotcrete	steel ribs
Stand up time For span	20yr for 15m	1yr for 10m	1 week for 5m	12hrs for 2m	30 min for 1m

The other parts of Dessie town and its surrounding basalt exposures are classified based on degree of weathering, point load test and Schmidt hammer test (where sample is available). The point load and Schmidt hammer test result is attached in the Annex 4 and summarized below.

Table 6.18 Average values of compressive and point load strength of basalts of different localities.

No	Location	Average Isvalue MP	Average compr. strength	Qualitative strength
1	Station 1	10.02	231.5	Rvhi
2	Station 2	10.52	240	Rvhi
3	Station 4	9.35	130	Rvhi
4	Station 7	6.25	87.5	Rme
5	Station 9	10.93	152.6	Rvhi
6	Station 10	9.53	133	Rvhi
7	Station 12	9.35	130	Rvhi
8	Station 13	13.31	186.3	Rvhi
9	Station 15	9.84	137.7	Rvhi
10	Station 20	10.02	231.5	Rvhi
11*	Quarry sw ofDessie	4.451	113.12	Rvhi
12*	South of Tossa	3.897	87.38	Rvhi
13*	Middle of Tossa	4.512	101.15	Rvhi
14*	Tip of Tossa	4.713	104.91	Rvhi
15*	North of Tossa	4.0766	94.84	Rvhi
16*	Quarry north of Dessie	2.446	55.475	Rvhi
17*	Azewa Gedel	4.134	90.52	Rvhi
18	Robit Gebeya	3.59	87.546	Rvhi
19	Kurkur Wuha	4.138	99.449	Rvhi

Rvhi = rock with very high mass strength

Rme = rock with medium mass strength

* Source: Tadesse Dessie, 1991

Classification of the rock mass strength units was made based on uniaxial compressive strength according to British standards Institutions (BS 5930 : 1981).

Table 6.19 Classification of rocks based on uniaxial comprehensive strength

Compressive strength kgf/cm2	Description
50 - 125	Rock low (Rlo)
125 - 500	Rock Medium (Rme)
500 - 1000	Rock high (Rhi)
1000 – 2000	Rock very high (Rvhi)

Schmidt Hammer

The Schmidt hammer test was conducted in the field to supplement point load test results. Schmidt hammer was used widely due to its portable size and the possibility of testing on outcrops with in a short time. Rock classification diagram for the study area is a based on fifteen-rebound number readings taken for each observation points . The median value out of the fifteen readings is considered. The obtained results were converted to compressive strength using a nomogram.

Table 6.20 Results of Schmidt hammer

No	Location	Average Reboun	Average compressiv strength	Qualitative strength
1	Upsteam of K (Borkena) spring)	24	210	Rme
2	Upstream of Kerra	20	180	Rme
3	Borkena bed at Kerra	14	150	Rme
4	Sego Gebeya	38	360	Rme
5	Sego Gebeya	30	210	Rme
6	Sego Gebeya	42	425	Rme
7	SE quary site (get f Kobolcha) (station 9)	46	465	Rme

No	Location	Avera Rebou	Average compressive strength	Qualitative strength
8	Quarry site	50	590	Rhi
9	Near Ayterit palace	3	25	R10
10	Station (12)	34	325	Rme
11	Quarry Station (13)	45	500	Rhi
12	Station (15)	24	215	Rme
13	Station (14)	26	260	Rme
14	Station 18	28	300	Rme
15	Nigus Micheal School	37	380	Rme
16	Nigus Micheal School	41	410	Rme
17	Nigus Micheal School	34	400	Rme
18	Near Gabreal Spring	44	450	Rme
19	Near Gabreal Spring	23	200	Rme
20	Near Gabreal Spring	46	500	Rhi
21	Near Gabreal Spring	50	590	Rhi
22	Near Gabreal Spring	42	425	Rme
23	Near Gabreal Spring	44	450	Rme
24	S-W quarry	45	502	Rhi
25	Tossa South	46	500	Rhi
26	Tossa Middle	36	340	Rme
27	Tossa Top	46	465	Rme
28	Tossa North	49	582	Rhi
29	Azewa Gedel	58	780	Rhi
30	Robit Gebeya	32	275	Rme
31	Kurkur Wuha	33	317	Rme

6.2.3.2 Rock units for engineering geological mapping

For each test area and rock unit, a schmidt hammer test result is correlated with point load test. The results indicate that these is an agreement of results of the two tests.
Furthermore, for the engineering classification of rocks of the study area, the physical observation of the rock is taken in to consideration. The degree of fracturation, degree of weathering and erodability observed in the field. For the general mapping propose therefore, point load test, Schmidt hammer test and degree of weathering were applied.

According to the Schmidt hammer test, the rocks of the studied area have been classified in to rocks of very high mass strength, High Mass strength, intermediate and low. Since the test is conducted on selective out-crops of relatively strong, the above-mentioned physical condition of the rock is very important for classification and mapping purpose. Therefore rocks of the study area are classified as very high, high medium and low mass strength.

CHAPTER SEVEN-LANDSLIDES

7.1 GENERAL

Landslide is a movement of a mass of rock, earth or debris down a slope as the product of the rupture in the topographic surface equilibrium (Cruden,1991) as quoted in Dikau et al (1996)

Landslide can occur on any type of rock and soil and result in a movement of soil and bed rock, artificially accumulated material such as embankments, earth dams or material that was just involved in sliding processes. The size of landslides is variable from detachments of a few cubic meter to movements of hundreds of millions of cubic meter, which may affect the entire side of a mountain.

Many projects intersect ridges and valleys, and these landscape features can be prone to slope stability problems. Natural slopes that have been stable from many years may suddenly fail because of changes in topography seismically, ground water flows, loss of strength, stress changes, and weathering (Abramson, 1996). Slope stability evaluations are concerned with identifying critical geological materials, environmental and economic parameters that will affect the particular project as well as understanding the nature magnitude and frequency of potential slope problems. Where dealing with slopes in general and landslides in particular previous geological and geotechnical experience in an area is valuable.

According to Abramson *et al* (1996), the aim of slope stability and landslide study includes.

- To understand the development and form of natural slopes and the processes responsible for different natural features.

- To assess the stability of slopes in the short term

- To assess the possibility of landslides involving natural or existing engineered slopes
- To analyze landslides and to understand failure mechanisms and the influence of environmental factors.
- To enable the redesign of failed slopes and the planning and design of preventive and remedial measures, where necessary.
- To show the effect of seismic loading on slopes and embankments.

The hillside and road cuttings of most parts of the north, south and western region of the Ethiopian plateau have suffered from landslide in both the superficial materials and the bedrock. Although landslide have been observed for at least the last three decades, in more recent times the sensitivity of both the public and administrative bodies to these problems has increased as more and more people are now living in the areas affected (Lulseged Ayalew,1999).

Almost 60% of the total population of Ethiopia live in the highlands with an altitude of more than 1750. The mean annual rainfall in these regions exceeds 1200 mm and accounts for some 70% of the total precipitation the country receives each year. Landslides or landslide generated problems have claimed about 300 lives damaged over 100km of asphalt road, demolished more than 200 dwelling houses and devastated in excess of 500 hectars of land in Ethiopia in from 1992 to 1999. (Lulseged Ayalew 1999).

Large-scale landsliding in Dessie town, where more than 200,000 residents, began in the late 1980s when materials from a large mountain scarp in the west began to move dawn hill related to both natural and artificial conditions. In September 1994 part of a slope around a Soft Drinks Factory and in August 1998 a little further north were amongst the late landslides in the town (Lulseged Ayalew, 1999)

In the following sections, type of land slides, identification of existing and potential landslides their triggering factor hazard classification and slope stabilization methods (preventative and remedial measure) will be discussed.

7.2 LANDSLIDE CLASSIFICATION

Several classification methods and systems have been proposed for landslides. Soil `failures involve such a variety of processd and disturbing factors that they afford unlimited possibilities of classification. One of the most comprehensive references on land slides or slope failures and also the most consistently around the world is the one proposed by the International Association of Engineering Geologists (IAEG) commission on Landslides (HRB 1978).

Landslides are distinguished according to the rate of slope movements. Rates of movement range from less than 6 inches per year to more than 5 feet per second, according to Cruden and Varnes (1992) quoted in Abramson (1996).

Table 7.1-velocity class of landslide

Class	Description	Velocity (mm/sec)
7	Extremely rapid	5×10^{3}
6	Very rapid	50
5	Rapid	0.5
4	Moderate	5×10^{-3}
3	Slow	50×10^{-6}
2	Very Slow	0.5×10^{-6}
1	Extremely Slow	$<0.5 \times 10^{-6}$

Source: Cruden and Varnes (1992) cited in Abramson 1996

The rate of movements can be expressed in multiple of 100 as shown in table 7.1.

Based on the kinematics of landslides, how movement is characterized thorough out the displaced mass constitutes another way of classifying landslides. According to Cruden and Varnes (1992), there are five kinematically distinct types of landslide movements.

These are falling, toppling, sliding, spreading and flowing There are also a sixth group complex slope movements which includes combination of two or more of the above five types. Falling and toppling are features frequently associated with rock slopes where as the latter three are related to soil slopes. Each type of landslides has a number of common modes.
In falls, a mass of any size is detached from a steep slope or cliff, along a surface on which little or no shear displacement takes place. In topples one or more units of mass rotate forward about some pivot points under the action of gravity and forces exerted by adjacent unit or by fluids in cracks .

A slide is a down slope movement of a soil mass occurring dominantly on surface of rupture or relatively thin zones of intense shear strain (Cruden and Varnes, 1992). Movements are usually progressive from an area of local failure. The first overt signs of ground movement are usually cracks in the original ground surface along which the main scarp of the slide will form. The slide may be transnational or rotational, or combinational of both (combined slide).

Transnational slides often involve movement along marked discontinuities or planes of weakness, including previously existing failure planes. In clay soils transnational slides take place along saturated sand or silt seams, particularly where these zones of weakness dip roughly parallel to the existing slope. Rotational slides have a failure surface that is concave up wards and often occur with in an intact soil mass. Purely rotational, slope failures (slumps) most commonly occur in relatively homogeneous materials. In addition, slumps as do the transnational slides may degenerate to flows if dilated slide debris becomes saturated.

Spread is defined by Cruden and Varnes (1992) as an extension of a soil mass combined with a general subsidence of the fractured mass in to softer underlying material. The rupture surface is not a surface of intense shear. Spreads may result from liquefaction of granular deposits or failure of weak cohesive soils in a slope (Schuster and Fleming, 1982) mentioned in Abrhamson (1996). They commonly occur on shallow slopes.

Flow is a spatially continuous movement in which surfaces of shear are usually not preserved. The distribution of velocities in the displacing mass resembles that of viscous liquid. Th lower boundary of the displaced mass may be a surface along which appreciable differential movement has taken place or it may be a thick zone of distributed shear.

Slides may turn gradually in to flows with changes in water content, mobility, and evolution of movement. As the displaced material loses strength and gains water or encounters steeper slopes, debris slides may become rapid debris flows. Slope can under go creep movements that are too slow to be detected, for example, less that 1 inch per year Creep can be categorized as continuous or of a seasonal nature (Abramson et al 1996)

Slope movements could also be classified as:

- According to age as contemporary, dormant and Fossil
- According to stage (initial, advanced and exhausted.
- According to their cause (earth quake, exceptional precipitation, sever flooding accelerated erosion from wave action, liquefaction and movement without any apparent cause (Dikau, 1996).

7.3 FEATURES AND DIMESIONS OF LANDSLIDES

Typical observable features mostly identify landslide. The extent of these feature varies according to the type of the material undergoing the failed slope, the magnitude of the landslide small or sever, and also on the type and extent of triggering factors.

Landslide feature is shown schematically in Fig 7.1. The upper portion of the figure is a plan of typical landslide. The dashed line is the trace of the rupture surface on the original ground surface. In the section of the lower portion of the figure, cross hatching indicates undisturbed ground, and stippling shows the extent of the displaced material (Cruden and Varnes, 1992) cited in Abramson et al 1996.

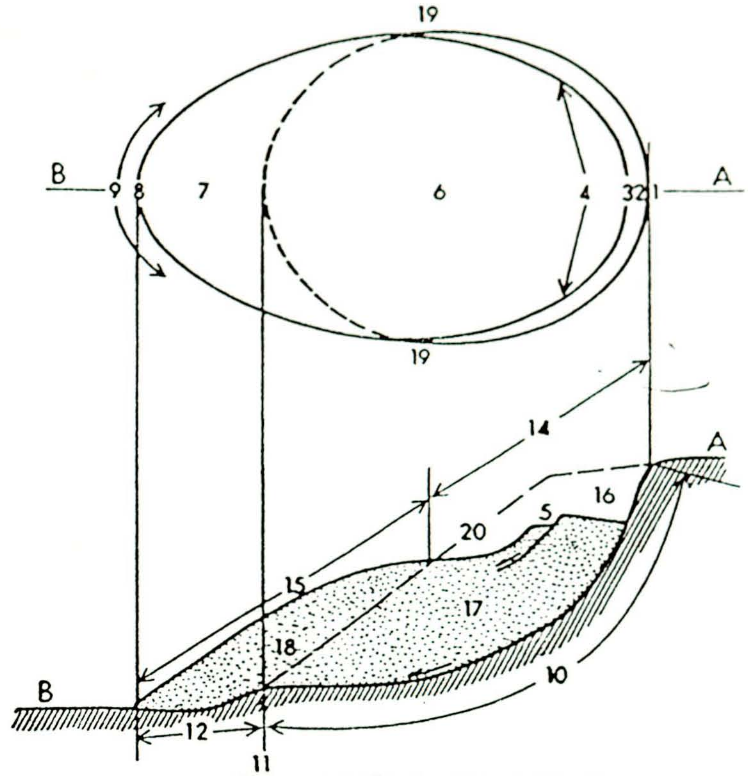


Figure 7.1 Typical landslide features.

Table 7.2 observable feature of landslide and location

OBSERVABLE FEATURES	IDENTIFICATION	LOCATION ON FIGURE 6.2
Crown	The practically undisclosed material above the main scarp	1
Main s carp	A steep surface on the undisturbed ground at the upper edge of the landslide	2
Top	The highest point of contact between the displaced material and main scarp	3
Head	The upper parts of the land slide between the displaced material and main scarp	4
Miner scarp	A steep surface on the displaced material produced by differential movements	5

OBSERVABLE FEATURES	IDENTIFICATION	LOCATION ON FIGURE 6.2
Main Body	The part of the displaced material that overlies the surface of rupture	6
Foot	The portion of the landslide that has mo beyond the toe.	7
Tip	The point on the toe farthest from the top	8
Toe	The low margin of the displaced material	9
Surface of Rupture	The surface that forms the low boundary of the displaced material	10
Toe of surface of rupture	The intersection between the lower part of the surface of rupture and original ground surface	11
Surface of separation	The iginal ground surface now overlain by the foot of the landslide	12
Displaced material	Material displaced from its original position by landslide movement	13
Zone of Deletion	The area within which the displaced material lies below the original ground surface	14
Zone of accumulation	The area with in which the displaced material lies above the original ground surface	15
Depletion	The volume bounded by the main scarp the depleted mass, and the original ground surface	16
Depleted mass	The volume of displaced material that overlies the rupture surface but underlies the original ground surface	17

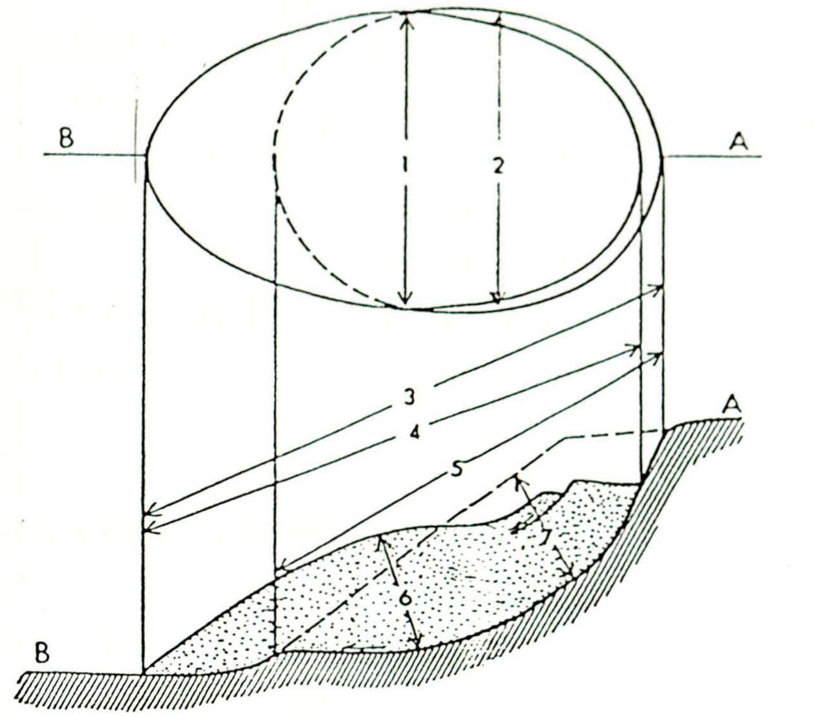


Figure 7.2 landslide Dimensions

In the section, class hatching indicates undisturbed ground and the broken line are the original ground surface. The dashed line in the plan is the trace of the rupture surface on the original ground surface (Cruden and Varnes, 1992) cited in Abramson *et al.*, 1996.

Table 7.3 IAEG proposed standardized typical dimensional variables for landslide as shown in figure 7.3.

Landslide dimension	Identification	Location on figure 5.3
Width of displaced Mass, Wd	The maximum breadth of the displaced mass perpendicular to the length ld	1
Width of the rupture surface, wr	The maximum width between the tanks of landslide, perpendicular to the length, r	2
Total length.	The minimum distance from the tip of the landslide to it crown	3
Length of Displaced	The minimum distance from tip to the top	4

mass Ld		
Length of the rupture surface. R	The minimum distance from the toe of the surface of rupture to the crown	5
Depth of the displaced mass, Dd	The maximum depth of the displaced mass, measured perpendicular to the plane containing Wd and Ld	6
Depth of the rupture surface, Dr	The maximum depth of the rupture surface measured perpendicular to the plane containing Wr and Lr.	7

7.4 EXTENT OF LANDSLIDE IN DESSIE

As previously mentioned, the location of the town is where events related to landslides are comparatively more frequent. The terrain characteristics, the dominance of soil of relatively lower shear and compressive strength and internal structure of past geologic events has appreciable contribution for the incidents. Steepness of Tossa Mountain and Azwa Gedel (with sharp N-S trending slopes), rapid runoff, thick accumulation of loose colluvial and alluvial soil on the graben (where major settlements lie) and the network of gullies and their deep incision are the accelerators of the problem. This is not, however the adverse effects of mis management of resource, quarrying, deforestation etc.

According to Lulsegd Ayalew (1999), during his study on the problem of landslides in Dessie using aerial photos taken before the expansion of the town, east of Azwa Gedel and chain - mountain along the Kombolcha - Dessie road, local breaks in slope had been recognized.

In 1982 Gebretsadik Ehete has reported a total of nine landslide cases from which five of them are in the southern parts of the town. According to the above report nine houses were destroyed in 1979 and many trees had been uprooted from a flash flood from Tossa Mountain.

The 1994 land slide that destroyed many house and the bridge along the main road had also reported as unstable area and had recommended for protecting the widening of the gully that may cause the damage of the bridge by Gebretsadik Eshsete in 1982.

Most of the landslides that have been recognized were caused by the widening of stream channels due to back cutting process of erosion.

It can be deduced from these reports that landslides in Dessie began at least 20 years ago and it has been aggravated due to lack of timely intervention. If its remedial measures were taken earlier, big damages like that of the 1994 disaster could have been avoided.

Today, about 20 different slides have been distinguished and each one suffered several general or partial movements. They follow fixed orientation, lithology and structure or external morphology because all the land slides have moved and advanced in the direction of the drainage network. Almost all the failures have on slopes of fine- grained to coarse gravels loose unconsolidated materials mainly along gully banks.
Consequently, many houses, roads, bridges, culverts, fences, drainage ditches, telephone and electric poles and pipes along those gully banks were seriously damaged people were displaced from their houses.

According to the survey made by the Bureau of Works and Urban Development in 1994 following the accelerated damage in the same year, the total number of housing units that have been affected and that are likely to be affected (Table 7.4) if protective measure are not taken amounts to 197.

Table 7.4 magnitude of damage caused by landslide in Dessie

Level of Damage	Location (Higher / Kebele)	Affected size of Residents	Affected size Housing unit
Very Risky	1/7, 1/9, 2/3, 3/3, 3/4	232	37
Moderately Risky	4/2, 1/6, 1/7, 1/9, 2/3 2/6, 3/2, 3/3, 3/4	521	78
Under Potential Risky	1/6, 1/7, 2/6, 3/3, 3/4, 3/5	510	82

Source:- Amhara Regional State Bureau of works and Urban Development (1995)

7.4.1 Classification and location of landslides in Dessie

The possibility and frequency of occurrence of landslides along any slope are dependent on the geologic characteristics of its constituent materials. It is, thus, apparent that geological studies should estimate the extent to which a natural slope is likely to be stable.

The geologic factors which govern the possibility and frequency of landslide and hence determine the safety and stability of hill-slopes and cuttings are:-

- The nature of the rocks or/and soils occurring along the slopes or cutting wall
- The geologic structure of the country rocks
- The prevailing ground water conditions along the slope or cutting wall

Based on the degree of slope, geology and structure, the type of landslide in Dessie town can be grouped in to the following categories.

7.4.1.1 Creep, Rock fall and Toppling

Large screen deposits cover the foot of the cliffs of Tossa and Azwa Gedel with an average length of 40 m and occasionally up to 100m, which constitute from fine material to coarse gravel and occasionally boulders as shown in figure 7.3

The upper basaltic cliffs in the scars have vertical joints ranges from a few centimeters to 3m in joint spacing and wide fracture aperture that produce slightly separated rock columns.

The columns become progressively detached from the bedrock by topple movement. Then, the rock columns locally crushed on to the slope, were broken in to several parts or/and also with out breakage descended bounding and rolling down slope, resulting in debris deposits of scree and big rock falls. Materials involved vary in size ranging from bedrock to gravels and boulders from the steep wall of the cliffs.

In most places along the Tossa foot starting from the northern boundary up to Segno Gebeya A number of these screes and rock falls now belong to currently active rock fall zones (Fig. 7.3)

Figure 7.3 Creep and Rock full along Tossa Foot

The most risky area related to rock fall is concentrated around Teacher Training Institute north of "Sire Spring" and around land slide 11. Rock falls generally involved small blocks from 0.5m to 3m in diameter and further small creep, occur in some steep to gentle hill sides both process are related to periods of heavy rainfall. The more severe condition occurred around a residential house and a flourmill along the foot where a big block about 3m in diameter is blocked by an eculpates tree Figure 10.1. According to rock fall classification based on a volumetric nomenclature of rock falls around Dessie are Debris fall (less than $10m^3$) boulder fall ($10\text{-}100m^3$) usually only a few large blocks, and block falls greater than $100m^3$ of a large block which is fragmented during travel in different localities. For the failure of the rocks, the form of the discontinuities are determinant. Joints along the fault scarp provide planar sheets, intersect to form wedge, yield stepped surface or boundary vertical joints. Repeated falls from the same wall, ultimately form a fan-shaped cone of fallen debris at the base of the slope. These are more pronounced in the previously quarry areas and these talus screes should be distinguished from its accumulation arising from a large fall, results in accumulation of debris of all sizes that can obstruct a valley upon erosion from the cliff. The distance covered by the rock fall along the foot of the Tossa scarp depends up on the orientation and angle of the slope facet, imparted, the size and shape of the block, the angle at which it strikes the slope, the state and deformation of the rock or ground, absorption of the shock by any covering vegetation.

Hill slopes made up of fresh basalt or/and slightly weathered are sufficiently stable so much so that even a vertical slope may continue to exist permanently along the cliffs of Tossa. However, in some areas the occurrence of closely spaced sets of joints or of shear zones and other planes of weakness in these rocks cause rock slips.

7.4.1.2 Gully erosion and rotational landslides.

This includes almost the entire areas of the town where a thick alluvial - colluvial deposits associated with a steep gully. Most of the landslides in Dessie are gully erosion and widening, landslide associated with heavy rainfall that causes a storm flood.

Unconsolidated materials of clay, sand, gravel cannot stand permanently along a steep slope greater than their angle of rest (the angle with respect to the horizon, at which loose materials can stand permanently on an inclined surface and this seldom exceeds 35^0 Mukerjee, 1995) are therefore extremely unstable and are liable to be affected by land slides in course of time.

Most of the landslides occurred with this condition are rotational landslide in which a failure surface is concave upwards and often occur with in intact soil mass. Purely rotational slope failures (slumps) most commonly occur in relatively homogenous materials of alluvial deposits. Soil falls that are composed of fine materials are very common along the steep walls of the quarries.

Figure 7.4 Rotational Slide caused by Gully erosion (Landslide 17)

The most typical landslide of this type are landslide 17 and landslide 4 with a maximum width of 100 m and about 20m depth for the latter Landslide 4 is located on steep slope part that a flood on its youth stage erodes the side of the gully each year and the size become increasing from time to time and at present it reaches beyond the capacity of the retaining structures made for the slope stabilizing purpose.

7.4.1.3 Single, Multiple and Successive Rotational Slides

Kerra landslide is a zone of active landslide that form a successive failure at least four stage of sliding. The slide surface that was initially produced by the primary movements was also used by secondary and tertiary movements. It forms its own typical morphological features of a landslide ridge. The role of progressive failures in problems associated with natural slopes has been increased more and more along the stream banks. In most cases, the landslide materials to exhibit progressive failures are clays that have been gradually derived from the pre-existing rock and those derived from alluvial deposits of fine material.

Figure 7.5 Planar Slide at Doro mezlia, Slump at Kerra and protecting vegetations

The rotational slips around Kerra area mostly have shallow depth and they are more clearly classified as a slump (Figure 7.5). It is induced by the removal of underlying material, that provide support, by rivers, weathering underground erosion due to seepage or piping near the Borkna river and the lower part of "Derek Wonze" where it meanders due to the block of the stream by the sliding mass. At this locality, the main causes for the sliding is that the loose of

strength of the underlying fine material, which is decomposed to highly expansive clay on its top part. A landslide section along Kerra depression shows that an alternating layer of ash pyraclastic deposit and decomposed material (clay size) reduce the shear strength of the material by expansion of clay layer that increase the lateral pressure.

The Kerra landslide in most places along the Borkena river and downstream end of "Derek Wonz" and west of Dosso stream in a slump landslide, longitudinal and transvers cracks are very common .

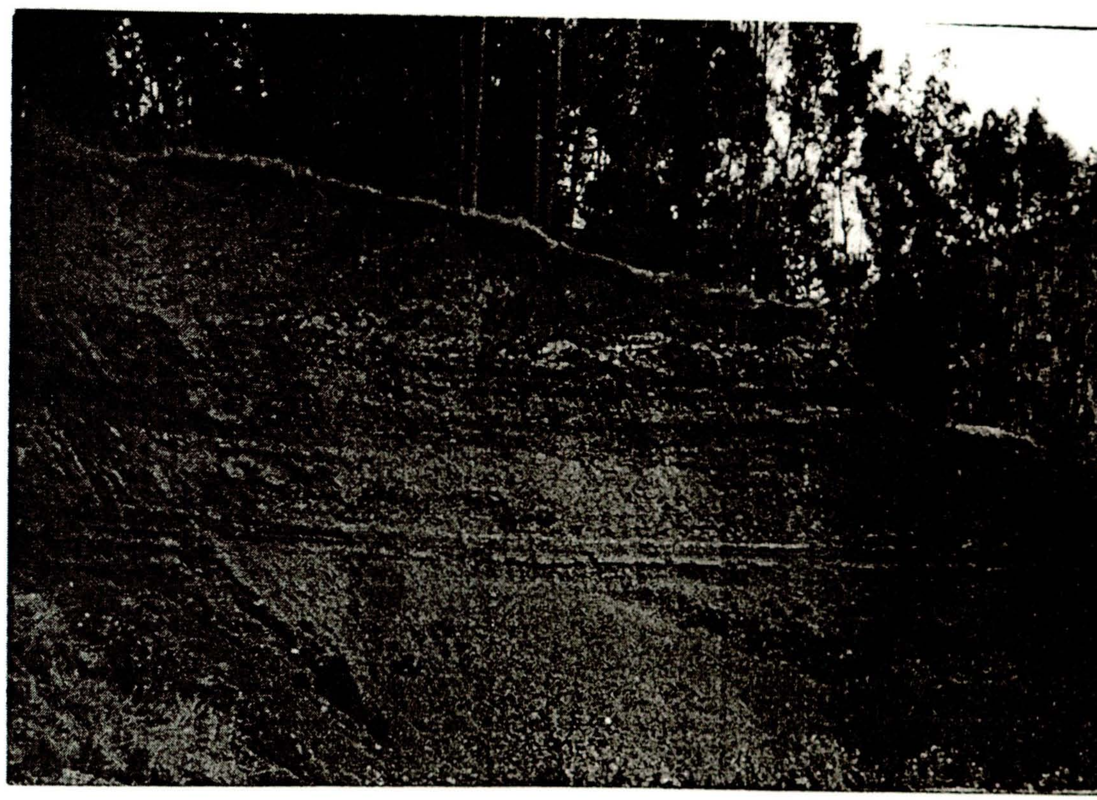


Figure 7.6 Scree,creep in alternate bedding of pyroclastic deposit in Kerra

Table 7.5 major landslide and their dimension

Landslide Nº of location	Type of landslide	Width	Length	Maximum Depth of gully	Material
17 (Amega vally)	Rotational (Slump)	50	100	10m	clay
10 (near Segogeya school)	Rotational	30m		10m	clay
20 (along Tossa and Azawa Gedel foot)	Fall planer	irregular	up to 200m	-	rock
11	gulling	20m	300	15m	
12	rotational	2050m	350	10m	Clay
Doromezelya	rock slide planer	100m	300	2m	rock
2 (near TTI)	gulling	15m	200	5m	Colluvial and Clay size
8 (near technical School)	gulling & fall	20m	250	8m	Clay
Landslide along dos	Slump	30m	150	2m	clay
4	gulling	50m	350m	25m	Collvials
5(BH_1)	Rotational	100m	150	20m	Colluvial
3(Bh_3)	gulling & fall	40m	200	25	Colluvial
Kerra	Slump translation planner	Various	large	various	Clay & ash

Generally, land slides in Dessie are various types based on slope, material and depth of gullies most of them are on steep slopes along gullies characterized by colluvial deposits consists of clay, silt, sand, gravel and boulders.

Landslides along Amega Valley, Dosso Stream and in most parts of Kerra the slope are steep to gentle and the material is mostly clay. In clay materials along the streams, a slump type of landslide is characterized by longitudinal and transverse cracks.

Slumps are characterised by an upward concave shear surface and by the fact that the sliding material maintains some compactness.

Materials near the bank of the river slide like a viscous mass landslide known as flows (earth flow or mudflows). These landslide masses are always a mixture of clay (solid particles) and water in different proportion, with the latter commonly relatively abundant. In fact, such events are typically a direct consequence of rainfalls of extreme intensity and the nearness of groundwater table to the surface that resulted from heavy rain.

The flow starts as partially unconfined mass movement but become more channellized at the base of the slope . According to Dikau, et al (1996), an additional feature of a genuine rotational slide is the small degree of internal deformation of the displaced material, which distinguished it from flow-like mass movement types, although sometimes soil slump materials liquefies and transforms into a flow at its downslope end and it is known by slump-earth flow.

CHAPTER EIGHT - SLOPE INSTABILITY CONDITIONS AND INFLUENCING FACTORS

8.1 GENERAL SLOPE STABILITY CONDITION

The stability of a slope depends on three main factors:

- The slope gradient that is the force of gravity, which tends to drag downward the rock/soil masses. It is as more effective as higher is the inclination of the slope with respect to the horizontal plane.
- The cohesion (or internal fiction) which tends to keep each other joined the earth materials making up the slope and to impede that one part is detached from the rest or deformed assuming a different equilibrium.
- Attrition, which contrasts the gravity, pushes and prevents the slope material to slide along a shear surface. With the term slope material are intended here soil, bedrock or regolith i.e that superficial layer including both the soil and the most external weathered portion of the bedrock.

  A situation of equilibrium exists when

  $Y.h\ Sin\alpha = \delta.Y.h.Cos\alpha + C/Cos\ \alpha$ as shown in the following figure.

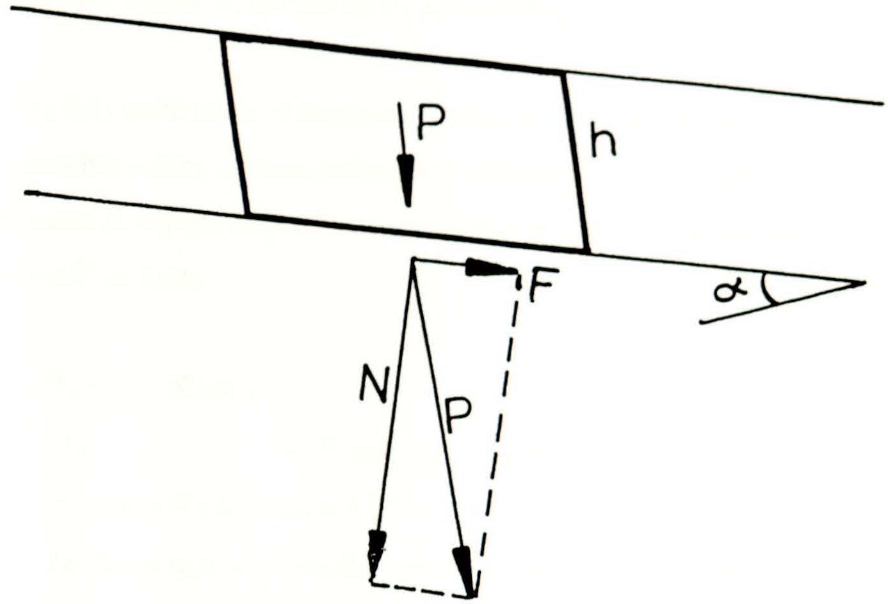


Figure 8.1 Forces acting on sliding prone mass

Where h is the thickness of the layer involved in the eventual movement, Y is the unit weight (defined as the weight per unit volume and is expressed by the ratio between the total weight and the volume) of the sliding prone material, α is the inclination angle of the slope δ is the attrition coefficient (α + tan ø, with ø the angle of internal friction) and C is the cohesion per unit area.

The angle of internal friction is an expression of the resistance offered by the single particles when they are caused to slide, roll and rotate against each other. The larger the grain the wider is the zone affected. The more angular the grains, the greater the frictional resistance to their relative movement since they interlock more thoroughly than do rounded ones.

The cohesion is a component of the material shear strength and is characteristic of each material very much influenced by its permeability.

On (Fig 8.1) earth mass of thickness h, measured along the vertical of weight P and resting on a possible sliding surface making an inclination angle α with the horizontal. The weight component along the slope (F) is contrasted by the friction on the sliding surface and the cohesion C, so that.

$P \sin \alpha = N \tan ø + C$

But $N = P \cos \alpha$, so we get

$P \sin \alpha = P \cos \alpha \tan ø + C$

To the weight substitue the vertical pressure $Yh.\cos \alpha$ then it becomes

$Yh \cos \alpha . \sin \alpha = Yh \cos \alpha . \cos \alpha \tan ø + C$

and hence $Yh \sin \alpha = Yh \cos \alpha \tan ø + C/\cos \alpha$

A variation in the values of any of the above equation parameters leads to:

- Stability conditions if the left member is less than that on the right
- Instability and a break of the equilibrium with the development of landslide occurs if the right member become is less than that on the left.

If the unit weight Y or the angle α increase maintaining constant tan ø and C, or if tanø and C decreases, with Y and α constant, the equilibrium can not longer be and the mass movement is initiated.

In incoherent rocks, cohesion is equal to zero; hence, the slope is stable only when its inclination is equal or less than the natural angle of repose of the material is made with. The angle of repose is related to the internal friction angle and the above equation becomes:

$$\frac{\sin \alpha}{\cos \alpha} = \tan \alpha$$

Table 8.1 Angle of internal friction values for cohesionless soils.

Description	ø Values (degrees)		
	Loose	Medium	Dense
Non plastic silt	26 - 30	28 - 32	30 - 34
Uniform fine to medium sand	26 - 30	30 - 34	32 - 36
Well-graded sand	30 - 40	34 - 40	38 - 46
Sand and gravel	32 - 36	36 - 42	40 - 48

Source : Hough (1909), and Lambo and Whiteman (1969) cited in Abramson 1996

When the material is saturated with water, the internal friction angles may decrease. Such reduction can be much larger if the interstice pressure increases. Since it is the grain to grain interaction that produces the internal friction, the decrease of the grain to grain friction results in a lower internal friction angle.

8.2 Factors contributing to slope instability

Slope failures are often caused by processes that increase shear stresses or/and decrease shear strengths of the soil mass.

Table 8.2 Factors contributing to slope instability

Increase in shear stress	Action	Agent	Causes
Transitory effects Increase in lateral pressure	Removal of support	Erosion	➢ by streams & rivers ➢ by glaciers ➢ by action of water ➢ by successive wetting and drying
		Natural slope movement	➢ falls ➢ slides ➢ settlements
		Human activity	➢ Cuts & excavations ➢ Removal of retaining walls ➢ draw down of bodies of water
	Over loading	by natural causes	➢ Weight of precipitation ➢ accumulation of materials because of past land slides
		By human activity	➢ Construction of fill ➢ Buildings and other over loads at the crest ➢ Water leakage in culverts, water pipes, and sewers
	Transitory effects	earth quakes	
	Increase in Lateral pressure		➢ by water in craks and fissure ➢ by freezing of the water in cracks ➢ by expansion of clays
		Factors inheren the nature of material	➢ Composition, structure, stratification
Reduce shear strength		Changes caused weathering and physiochemical activity	Wetting and drying process hydration, removal of cementing agent.
		Effect of pore pressure	
		Changes in struc	Stress release structural degradation

Source:- From highway Research Board (1978) mentioned in Ablamson (1996).

8.3 CAUSE OF SLOPE INSTABILITY

To recognize the reasons for the susceptibility of an area to sliding, and the factors which higher the movement of the rock mass is of extreme importance, because only a precise and correct diagnosis can serve as a basis for effective remedial measures. The variety of landslide types reflects the diversity of factors, which are responsible for their origin.
Slope failure in Dessie is mostly due to the following causes:

8.3.1 Changes in the water content :-

Effects of precipitation rainwater infiltrating into the soil increase the pore pressure and induces a decrease in the material Cohesion and of the internal friction. Recurrent mass movement events have been and are recorded in year characterized by particularly large amounts of rainfall as of 1994. An increase of the discharge of spring for both natural man induced causes lead to the same problem of instability associated to an excess of precipitation, overload and loss of cohesion.

During periods of drought, clayey soils dry up and mud cracks develop. This leads to a general decrease of cohesion of the rock or soil mass while, at the same time, the infiltration of water through the cracks increases, the water pressure in the interstices leading to increase in pore pressure and decrease in cohesion of the material. Water through the poorly consolidated soil and soft rock can dissolve the cement weakening the links among the grains. This results in a dimension cohesion and in a remarkable decrease of the internal friction.

8.3.2 Gullies and stream bed erosion:

Almost all landslide identified in Dessie town have been occurred following the deep gully erosion formed by successive storm water flow that converges from Tossa Mountain and Azewa Gedel towards Borkena river. Streams and gullies that start mainly from the above mountains large amount of flood runoff particularly after rainstorms. The stream and gullies are characterized by high velocity and high erosive power due to the high slope gradient.

Thus, causing toe-slope erosion of the unconsolidated materials as they cut through the superficial deposits that have occupied lower slopes.

In addition to the toe-slope erosion, as the level of the streams rise up at the time of storm floods, saturation of the slope materials may occur resulting in loss of strength of the material and this causes failure.

Lack of proper drainage system for the storm water that begins from the up slopes of Tossa Mountain inhance the deepening of the gullies and increase of its width. The most remarkable example of this type is landslide 4 in which the extent of the gully increase from time to time and reaches its maximum size that could not be prevented by check dams and gabions in that, almost all of them are destroyed.

8.3.3 Change in the slope gradient

It can be due to natural causes (e.g. riverbank erosion, river lateral shifting antecedent land sliding, accelerated erosion at the base of the slope, etc.) or induced by man's activity and engineering works, this include cut of the slope foot for the road of Dessie to Kombolca, civil buildings, river bank protection, unplanned quarrying can directly affect the slope gradient.

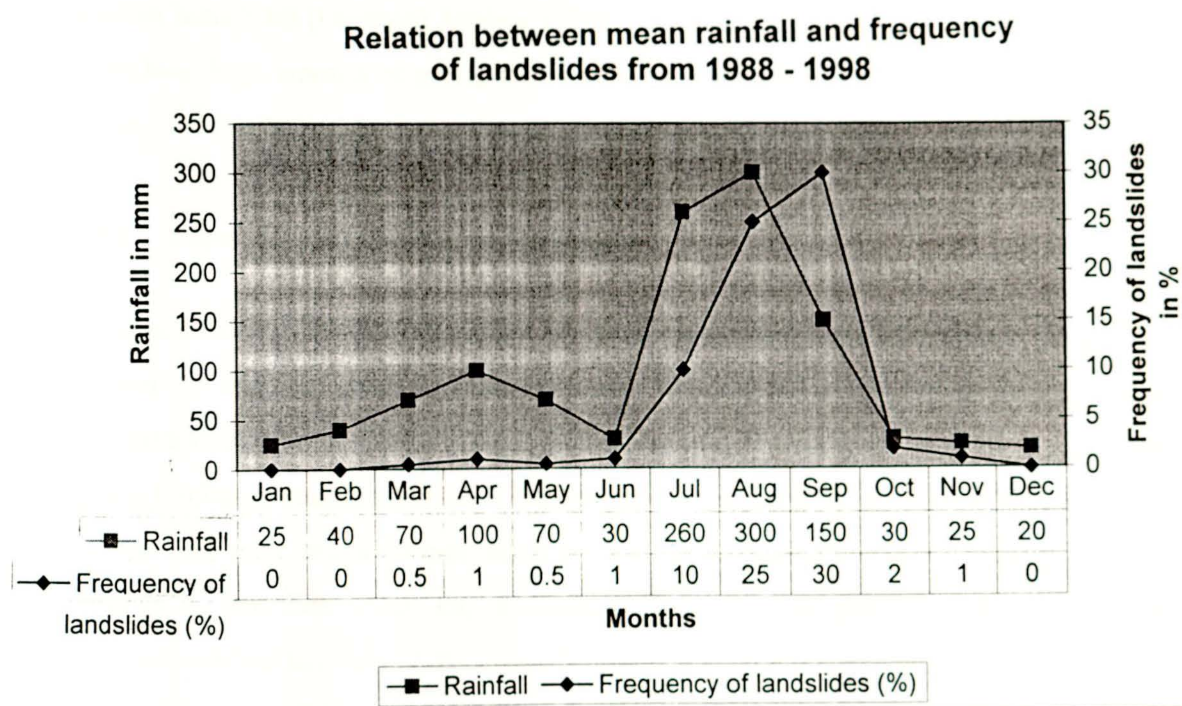
The increase in the slope gradient induces a change in the shear strength of the rock mass that disturbs the equilibrium.

8.3.4 The effect of rainfall on landslides

The climate of Dessie belongs to sub-humid to moderate humid, with mean yearly precipitation slightly higher than the mean annual total of evaporation, common properties of humid climate. According to the rainfall data obtained from Ethiopian Meteorological Service Agency, high amount of precipitation in Dessie town is usually observed in July, August and September including April. Analysis of the rainfall distribution data revealed a net change in total amount from year to year (figure .8.2)

The total average no of rainy days in Dessie are 83 and out of these, 51 rainy days are the average number of days from June to September that accounts for more than 60% of the average number of rainy days in a year based on rainfall records of 15 years and more over with in these years, the highest rainfall intensity in 24h is 83mm.

Lulseged Ayalew 1999, selected three years of unusual high amount of precipitation (1993, 1994 and 1996). The high amount of precipitation in these three years was happened following some years of dry periods. To determine the influence of rainfall in



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	25	40	70	100	70	30	260	300	150	30	25	20
Frequency of landslides (%)	0	0	0.5	1	0.5	1	10	25	30	2	1	0

Figure 8.2 Effects of rainfall on landslide

the occurrences of landslides in the study area and its surroundings, precipitation data of 10 years from 1988 - 1998 was taken and analyzed. A mean of precipitation was setup to compare it with the frequency of failure in the same span of time. The result is shown in Figure 8.2 from the result except some months, the relation of the amount of precipitation and frequency of slope failure is strongly correlated.

The amount of rainfall in the preceding year is very important to determine the moisture content of the soil. For example, three consecutive years before 1993 was relatively a dry period with their individual annual rainfall less than the mean. This high amount of rainfall in 1993 was lost in increasing the soil moisture to a field capacity. Hence, even if the rainfall in 1993 is greater than 1994 and 1996, the number of cases of slope instability recorded in the town was relatively lower

The intensity of precipitation through out the year was relatively regular compared to 1994 and 1996 that a rapid build up of pore pressure along cracks owing to anomalous high amount of rainfall was unlikely.

In 1994 the soils were relatively wet and remolded, and shrinkage cracks were already formed earlier at the end of 1993. This means that slight daily precipitin was able to produce shallow landslides (Lulseged Ayalew,1999).
Therefore, high amount of precipitation induces landslide in Dessie not only by erosion of gullies but also by increasing moisture content hence pore pressure.

8.3.5 Effect of groundwater on landslides

Because of lack of enough data about the groundwater condition of the study area, it is very difficult to map the ground water level and flow direction. However, starting from the structural condition of Dessie (a high recharging zone from the two horsts), the variation of spring discharge seasonally, that is the frequent occurrence of stoppage of discharge of old springs and their re-appearance after some time, appearance of new springs and/or wet grounds in landslide areas, the abundance of seeps, wet grounds and springs and the fluctuation in the amounts of discarge of springs, it can be inferred that fluctuation of ground water level is possible. Moreover, the direct precipitation on thick colluvial soils in filtrate to the level of groundwater and is a very important influence of rainfall in the process of landslide initiation due to its impact in the level of subsurface water.

During the rainy season, at the low-lying area such as Kerra around Borkena and lower part of "DerekWonz" the ground water is flowing on the surface and there is some indications of mudflows along the stream and riverbanks. Moreover, during the fluctuation of ground water pore pressure is developed on the steep surface result in unstability of the material. Its flow exerts pressure on soil particles, which decrease the stability of slopes and also ground water wash out soluble cement and thus weaken the intergranular bonds, consequently cohesion decreases and the coefficient of internal friction drop.

In relation to groundwater, deforestation of slope around Kerra changes the vegetation cover of the area that the roots of trees maintain the stability of slope by mechanical effects and contribute to the drying of slopes by absorbing part of the groundwater. The increase in groundwater level increases the overload and the increase the shear stress, the water pore pressure which on its turn diminishes the frictional resistance.

8.3.6 Human intervention

This includes quarrying activity, construction of civil works, excavation close to the toe of slopes and disturbance of natural drainage ways. Despite the weathering and nearly vertical joints of the rocks forming Tossa mountain, the rock and debris fall that come from the cliff side are mainly caused by the quarrying activity. However, at present conditions, most of the quarrying activities along the foot of Tossa Mountain are abounded in that the people are more concious and develop awareness about landsliding causes than before.

With out exaggeration, eucalyptus trees around Dessie save the lives of many people specially those living at the foots of Tossa escarpment. Trees block many of the big blocks of basalts. However, knowingly or unknowingly, deforestation processes, specially around Keera and near Nigus Micheal school (during the field work), is going on.

Construction of roads, bridges, houses and other engineering structure with out considering the nature of the slopes and slope materials and the settlement of people in land slide prone or risky zones mainly along stream and gully sides caused over loading of slopes consequently resulting in failures.

8.3.7 Earthquakes

The widely used yardstick of the strength of an earthquake is earthquake intensity. Intensity is the measure of damage to the work of man, to the ground surface, and of human reaction to the shaking.

The earth quake historical assessments and record becomes of utmost importance in modern estimates of seismological risk.

The first intensity scale was developed by de Rossi of Italy and Fores of Switzerland in the 1880s. Since then it revised and the present more refined scale was devised in 1902 by the Italian volcanologist and seismologist Mercalli with a twelve-degree range from I to XII. The description is given in table 8.4 and allow the damage to places affected by an earthquake to be rated numerically.

Table 8.4 Modified Mercallic (MM) intensity scale of 1931 (Bolt, et al, 1975)

Mercalli	Intensity
I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, specially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors specially on upper floor of buildings, but many people do not recognize as an earthquake. Standing motor cars may rock slightly. Vibration likes passing of truck. Duration estimated
IV	During the day felt indoors by many outdoors by few. At night, some awakened. Dishs, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking buildings standing motor cars rocked noticeably.
V	Felt by nearly everyone, many awakened some dishes, windows, etc. broken; a few instances of cracked plaster; unstable objects over turned. Disturbances of trees, poles and other tall objects sometime noticed pendulum clocks might stop.

Mercalli	Intensity
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys.
VII	Every body runs out doors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structure; some chimneys broken. Noticed by persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls through out of frame structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX	Damage Considerable in specially designed structures well designed frame structures thrown out of plumb, great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously, under ground pipes broken.
X	Some well built wooden structures destroyed; most masonry and frame structures destroyed with foundatios, ground badly cracked. Rails bent Landslides considerable from riverbanks and steep slopes, shifted sand and mud. Water splashed over banks.
XI	Few if any (masonry) structures remain standing, bridges destroyed, Broad fissures in ground, underground pipe-lines completely out of service, Earth slumps and land-slips in soft ground. rails bent greatly.
XII	Damage total practically all works of construction are damaged greatly or destroyed. Waves seen on ground surface. Lines of sight and level are distorted objects are thrown up ward in to the air.

In Ethiopia, earthquakes have been occurred and destroyed many house and lost many lives. Serdo and Karakore earthquakes are the main to be mentioned

Although Dessie town is located on the western plateau margin outside of the rift floor, which is an active zone volcanic activity and seismically, several earthquake and tremors had occurred in the area in the past. Some of these earthquake tremors were extensively felt at Dessie and damages were also reported (MWUD, 1995).

Table 8.5 earth quake history of Dessie

Year	Date		Magnitude (Mercalli)	Remark
	Month	Day		
1845	02	12	---	Wollo, felt radius reaches 650-700km
1922	01	23	---	Felt in wajja, 75km north of Dessie
1935	06	22	---	Felt in Wajja, 75km north of Dessie
1942	11	18	---	West plateau margin Woldia
1964	07	03	VI	Felt in Dessie
1965	04	14	III	Felt in Dessie
1971	11	13	IV	Felt in Dessie
1974	12	17	V	Felt in Dessie
1977	07	08	---	Dessie area (2 dead from landslide)

Sources: Extracted from Earthquake history of Ethiopa and the horn of Africa, Perre Govin 1979 and cited in MWUD in 1995.

As most of the landslides in Dessie are gully erosion-induced type the past history of the landslides are not strongly caused by earthquakes. From the Mercalli intensity description by Bolt etal, 1975 landslides occurred along steep slope when the scale is greater than X.

If the earthquake produce shocks and vibrations of high magnitude, they can be one of the causes of slope failure in the area and the following type of movements result.

- Compaction of the granular material reduces the volume hence subsidence results
- Unconsolidated gravels on the steep slope will move dawn the slope
- Unstable blocks of basalt from the Tossa cliff start toppling and falling.

- Reduction in strength in soft, cohesive soils (strain softening), which results in settlement of structures that, can continue for years and also results from a form of liquefaction.

Although these dynamic accelerations last for a short time, they can have an enormous effect in causing sliding on marginally stable slopes, with the result that feature commonly associated with earthquake is landsliding on a scale depending up on the topography in the epicentral area (Bolt, 1975). A potential landslide mass, which is stable under static condition, may fail after a number of cycles of vibration caused by an earthquake.

Although certain masses of soil or rock are brought, during an earthquake, to a condition of marginal instability such that failure may be triggered by some other event weeks to months after wards, the principal effects of an earthquake in terms of landslides are immediate. The landslides, which develop, fall into the classification of rapid to intermediate and with consequence that earthquake-generated landslide tend to be more upsetting to human activities than the isolated events which occur under static conditions

CHAPTER NINE - LANDSLIDE HAZARD MAP OF DESSIE

9.1 GENERAL

Natural forces and human activities are constantly changing the surface of the Earth. All earth and rock sloping grounds are susceptible to landsliding under severe conditions. Land slides can occur in almost any land form if the conditions are right (e.g steep slopes, high moisture level, no vegetation cover e.t.c.).

Although landslide prone areas can be identified through air photos, many of them are too small to be readily detected even in large-scale (10,000)-Arial photography. It is therefore, attempt was made to examine and to locate those areas that are conducive to landslide during the field stay for hazard mapping.

During hazard mapping, the most critical conditions considered is a landslide, which is a mass downward movement of either rock or unconsolidated material. The movement is caused by gravity acting up on materials that are in an unstable state of equilibrium. Movement is initiated by any change in conditions that up sets the temporary conditions. Three general types of landslides that are most commonly encountered in the studied area and bases for classification of hazard zones are movements involving shallow soil slump of soft clays, and movements involving rock fall and toppling.

The most favorable conditions for the movements are gully erosion, over loading during wet and structure and topography.

All types of landslides are dependent up on local geology; hence geologist and engineers are interested in the detailed geology of the areas where the slides are likely to occur and already exists. Such data can enable them to avoid location of construction sites where landslides are possible (ITC,200).

9.2 HAZARD CLASSIFICATION

Hazard mapping requires both direct hazard mapping and indirect hazard mapping using an expert based weighting method for each particular area. In order to cary out the direct hazard assessment of the area, all the geomorphologic units were considered. The most important characteristics taken in to account to determine the degree of hazard in the area were:

i) Evidence of recent activity, such as bare scarps cracks (both on the surface and existing engineered structure), fresh rock fall deposits, etc.

ii) Geomorphologic setting of the unit

iii) Type and condition of materials

iv) slope steepness

Adjacency of other units that might generate active processes reaching in to the neighboring unit.

Other criteria were also taken in to account, such as the remarks made by inhabitants of the area, historical records the presence of damaged infrastructure, the presence of stabilization work and information from the literature.

According to the above criteria, hazard map of Dessie has been classified in to four areas.

9.2.1 High-risk area

Stratified beds of successive lava flows that separated by intervocalic soil and have an appreciable dip (60^0 -85^0) daylighting any slopes along the escarpments could introduce a condition favorable to seepage and sliding on the lubricated beds. Jointing along Tossa escarpment is productive of slides during periods of heavy rainfall. Renewed movements on old fault planes are common. As gravity is the fundamental cause of landslides, topography of great relief is the most subject to slides. Even in areas of low relief, slides can be a problem.

Valley stress relief induced landslides are naturally eroded slopes created by movements of storm water often produce V- Shaped gullies, such as almost 80% of slides in Dessie The overstepped sides of such gullies become overstressed even the lateral support is gradually removed. As a result, strain energy was released following removal of large overburden soils during previous geological periods and systems of shear zones subsequently developed.

After this stress relief, the gully sides were then subjected to a slow and cumulative process of deterioration and destruction through weathering and through development of pore water pressure at the time of heavy rainfall. Eventually the wall fail and the failure often occur on well defined shear planes or relict joints that developed as a result of stress relief. These processes may continuous and become wide and wide as of land slide 4 and cover a large area due to lack of proper and enough remedial measures.

In these areas there is a high probability that destructive phenomena will occur with in the coming years. These events are expected to damage infrastructures or buildings considerably. Construction of new infrastructure or buildings is not advised in these areas, at least not until a detailed study (that include the results of inclinometers already installed in to three selected areas with in the town) has been done.

9.2.2 Moderate risk area

This area includes where Rock fall rotate and rests on relatively low slopy areas below the foot of the cliff, land slides caused by bank erosion, drainage and seepage related landslides, landslides caused by construction.

A landslide with dimension of hundreds of meters is difficult to escape even if it occurs over a period of minutes to hours and such a large event would therefore classified as rapid fall. An important component of a landslide and one related to its velocity is the distance that the slide progresses before it comes to rest. When the rocky material falls from almost vertical or very steep slopes and the material moves with out a continuous contact with the slope and then collapse, jump and rolls down and it could destroy any on its way.

Banks undercut by streams and rivers are subject to erosion by running water. Where the banks are made of soil or unconsolidated material, the weakest and the most favorable slide-prone position is often located at the point of maximum curvature of the stream or river.

Here the toe of the soil slope is under constant erosion by the running water, resulting in undermining of the toe and an ensuring failure. Bankfull erosion is a common phenomenon along Borkena River and Dereke Wonz stream that affect many houses and fences along its way.

In these areas there is a high probability that a destructive phenomena, from the rock fall and bank full flooding along Borkena river, will occur

9.2.3 Low risk area

This area covers the southern outskirts of the slopes covered with vegetation mainly of eucalyptus trees, a nearby areas of high flooding (below landslide 4) and marginal areas of landslides, the northern parts of the area with localized boulders that can be slide if disturbed and rock fall that may happen above the Kurkur spring and swampy surface below.

In the low hazard areas no destructive phenomena (landslide, sever rockfall, flooding, inundation, etc) are expected to occur with in the coming years, assuring that the land use situation remains the same. In adequate construction of infrastructure buildings along swampy places and a near by landslide areas un proper plough and deforestation of the existing trees may lead to problems, however.

9.2.4 Very low risk area

This covers almost the entire stable area all over the town. In this areas no sign of rock fall, landslide, inundation no destructive phenomena are expected to occur except failures resulted from un proper use of foundations for large buildings as it is more common in Dessie.

The hazard map is shown in Figure 9.1. The percentage of total area that is classified as very low and low hazard is fairly large where as the moderate and high hazard areas occupy mostly the steep slopes.

Table 9.1 Key to landforms and their susceptibility to landslide

Topography	Land form or geologic material	Landslide Potential
I Level terrain		
A. Not elevated	Alluvial flood plain	3
B. Elevated		
1. Uniform	River terrace	2
2. Surface irregularities, sharp cliff	Basaltic plateau	1
3. Iterbeded porous over impervious layer (paleosol).	Jointed and weathered successive basalt flows and Inter -volcanic soil.	1
II Hilly terrain		
A. Surface drainage not well integrated Disconnected drinage	Basalt	3
B. Surface drainage integrated		
Parallel ridges	Basalt in hills	1
a) parallel drainage	Basalt	2
b) Valley topography	Weak basalt	2
c) Vertical sided gully		
III Level hilly, transitional terrain		
a) steep slopes	Talus, colluvium	2
b) Moderate to flat slopes	Fun, delta	3
c) Hummocky slopes with scarp at head (Kerra)	Oldslide	1

1 = Susceptible to land slide

2 = Susceptible to landslide under certain conditions

3 = not susceptible to landslide except in Vulnerable locations.

CHAPTER TEN - LANDSLIDE HAZARD MITIGATION MEASURES

10.1 INTRODUCTION

In the preceding chapters, a treatment has been given of those geological phenomena, which pose landslide hazard in Dessie town. Growth of population, and particularly concentration of people and their work into the center of the town has heightened such threats to levels where large scale and often costly, planning to reduce the landslide hazards, has become more essential in Dessie. Overall, assessment of actions needed is complicated in many ways. Indeed, the source of a major geological hazard (landslide) mitigation may be, at the same time, a great asset to the community. In this culmination focus on geological hazards taken as a whole and consider the relative effects of landslides, flooding and other geologically related processes. This analysis requires, first, those basic questions on risk assessment be defined. In the process, as is usually the case in others, the availability or lack of it of the fundamental geological and demographic data comes to the front. Not only must planners rely generally on incomplete and uneven statistics to predict, from past occurrences, future catastrophes, but the available data must be worked in to a form that allows some quantitative comparison between various landslide hazards. Detailed topographic and geological maps at appropriate scales are usually the starting points for such analysis. Then a detailed study of the separate hazards must be made.

Many variations on the techniques for studying hazard mitigation can be found. The following points are aimed at establishing.

i) The need for interaction between those professions which deal with urban development, such as town planner, architects and engineers insurers, local government and public works officials, and

ii) A direction in which improvement can be made in presenting geological data for environmental studies so that they are comprehensible at the same time, more open to estimates of uncertainty.

Zoning to mitigate risk is approached in two main ways (Bolt, etal 1975) one is to treat the risk in a given area as a function of the cumulative severity of damage from landslides, floods and so on, irrespective of the frequency of occurrence of these events.

An alternative rating scheme is to take in to account the frequency of occurrence of the hazard. This enables the infrequent but catastrophic events to be given proper weight in comparison with those that are much more frequent but less damaging. For this purpose, recurrence curves, which rank the frequency and size of hazardous events per certain years per unit of area, must be constructed.

10.2 REMEDIAL MEASURES FOR LANDSLIDES IN DESSIE.

Failure to identify contributing causes of failure could render the stabilization work ineffective and slope instability recurrent. For this, it is enough to consider the failure of check dams and gabions constructed partialy or totally demolished in Dessie.

Slope stabilization methods generally reduce driving forces, increase resisting forces or both. Driving forces can be reduced by excavation of material from the appropriate part of the unstable ground and drainage of water to reduce the hydrostatic pressures acting on the unstable zone (Abramson et al, 1996). Resisting forces can be increased by:

1. Drainage that increases the shear strength of the ground
2. Elimination of weak strata or other potential failure zone
3. Building of retaining structures or other supports
4. Provision of in situ reinforcement of the ground
5. Chemical treatment (hardening of soils to increase shear strength of the ground).

Before the best method can be selected, the actual or potential causes of slope instability must be determined.

As an alternative to slope stabilization, the unstable slope can be avoided by adjusting the location of constriction or selecting a different site all together.

The following remedial measure has been proposed for the landslides in Dessie.

10.2.1 Drainage

Of all stabilization techniques considered for the correction or preventation of landslides, proper water drainage is the most important in Dessie. Because water is believed to be the most troublesom factor in causing the landslides and hence initial remedial measures, which do not need detail investigation and also not costy as compared to others. Drainage reduces the destabilizing hydrostatic and seepage forces on a slope as well as the risk of erosion and piping.

Carefully planned surface drainage is essential for prevention of surface water in flow in to the slide or potential slide. Every effort should be made to ensure that surface runoff is carried away from and not seeping downwards in to the slope. Such consideration should always be made and are extremely important when evaluating a failure.

During surface drainage work their should be a design mechanism which reduces the velocity of the storm or spring water coming on a steep slope from the side of Tossa mountain in many dispersed and concentrated flows. Temporary remedial measures usually considered after a landslide include:

i) Using sand bags and used tires to divert water runoff away from the failure zone (as in most of the land slide in Dessie done by the dewelers)

ii) Sealing cracks with surface coatings such as shotcrete, lean concrete, or bitumen or very fine impervious clay to reduce water infiltration up on granular colluvial materials.

iii) Covering the ground surface temporarily with plasitc sheets or the like to reduce the risk of movements during construction on already slided surface of thick soils

Surface run off usually is collected in permanent facilities such as V or U shaped concrete lined or semicircular corrugated steel pipe channels and diverted away from the slide mass. These channels should be placed strategically at the head of the slope and along the slopes. The detailing of surface water collection system should provide for minimum maintenance displacement due to future slide movements.

During the design of surface drainage the following very important catchment parameters (site specific) should be considered.

1. Area and shape of the catchment zone
2. Rain fall intensity
3. Steepness and length of the slope being drained hence estimating the speed of erosion
4. Condition of the ground surface and nature of the subsurface soils
5. Nature and extent of vegetation.

Redirection of surface runoff when it is found to be a cause of a landslide or partially unstable zone, as of many landslides in Dessie, should be carried out that ensure the stability of the slope is not further worsened. Redirection or diversion of surface run off commonly is the first response to a rainfall induced failure. The design of the remedial drainage system should consider natural drainage patterns.

Past experience from remedial measures taken in Dessie landslides revealed that retaining structures or slope stabilizing methods, along gullies without proper drainage channel is not effective. Most of the checkdams, gabions and retaining walls were destroyed by running water that washout the floor and sidewalls.

10.2.2 Afforestation practice (Vegetation)

Vegetation (grass, shrubs, and trees) is highly effective and advantageous for soil stabilization purpose. Removal of earth materials to construct cuts and embankments inevitably removes the vegetative covering (deforestation) and the surface soils are left exposed and susceptible to run off and wind attack. Vegetation stabilizes the soil surface by the inter twining of its roots, minimized seepage of runoff in to the soil by intercepting rainfall, and retards runoff velocity. Large diameter trees such as eucalyptus trees also act as a barrier during rock fall. The most remarkable example for this is occurred along the foot of Tossa ridge where a big block about 3m in diameter is blocked by eucalyptus tree that saves the nearby houses (residential and a flavor mill houses). (Figure 10.1)

Figure 10.1 Eucalyptus trees as a barrier for rock fall

In addition, vegetation may have indirect influence on deep-seated stability by depleting soil moisture attenuating depth of frost penetration, and providing a favorable habitat for the establishment of deeper rooted vegetation (shrubs and trees).

Vegetation is multifunctional, relatively inexpensive self-repairing, visually attractive, and does not require heavy or elaborate equipment for its installation. However, there are certain limitations. Vegetation is susceptible to drought. It is difficult to get established on very steep slopes.

Vegetation can affect the balance of stresses in a slope due to mechanical reinforcement from the root system of trees, slope surcharge from the weight of trees, modification of soil moisture, reduction of pore pressures by interception and transpiration from the foliage, attenuation of frost depth penetration, and lateral restraint by buttressing and soil arching action from the trunks or stems (Abramson *et al*, 1996).

Root reinforcement in soils provides apparent cohesion. The results of several root and fiber soil reinforcement studies are shown in Table 10.1 and summarized graphically in Figure 10.2 (Gray, 1978)

Table 10.1 Tensile strength of tree roots

Tree species	Root diameter (mm)	Tensile strength (Kpa)	Average tensile strength, all size classes (Kpa).
Rocky Mountain Douglas fir	2	22,630	18,280
	4	22,270	
	6	17,770	
	8	16,185	
	10	14,827	
Coastal Douglas fir	2	56,595	48,800
	4	58,592	
	6	47,168	
	8	44,660	
	10	43,014	
Sparuce-Hemlock	2	9,990	4,975
	4	9,577	
	6	9,508	
Birch	2	45,470	36,550
	2 - 7	21,840	
	>15	45,200	

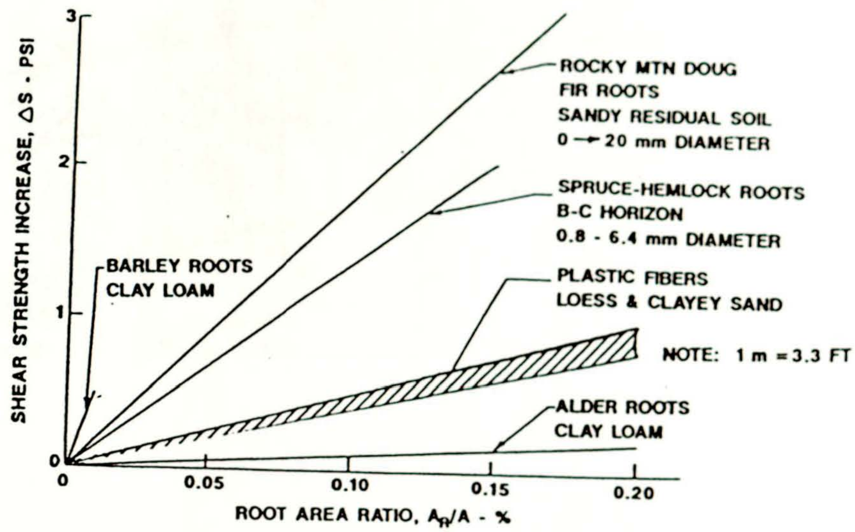


Figure 10.2 summery of the shear strength increase resulting from fiber and root reinforcement of various soils (Gray 1978)

The figure shows that for typical root area ratios (0.05 to 0.15 percent), the amount of apparent cohesion or shear increase provided by the live or fresh root is in the range of 3.445Kpa to 17.225Kpa.

During the stability analysis of slope root strength can be incorporated.

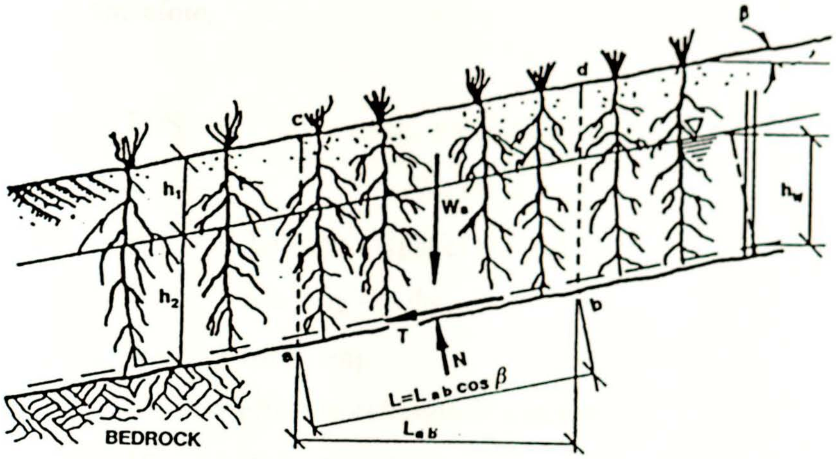


Figure 10.3 shows how root strength can be incorporated in to stability analyses

The down slope component of soil weight can be expressed as

	T	= Ws sin B
Where	Ws	= bulk unit weight of the soil
	B	= slope angle

The total shear strength, S, of the soil/ root system, reinforced by root contributing an increse in shear strength of ΔS_R, is given by the modified form of Coulomb's equation for shear strength.

$$S = (S_S + \Delta S_R) + \sigma \tan \phi'$$

Where

S_S = shear strength of the root free soil

σ = Effective normal stress

ϕ' = Effective angle of friction of the soil

Therefore,

$$FOS = \frac{(C' + \Delta S)L + W'S \cos B \tan \phi'}{Ws \sin B}$$

Where

$W's$ = buoyant weight of the soil

$= r_1h_1 + (r_2 - rw)h_2$

Ws $= r_1h_1 + r_2h_2$

C' = effective cohesion of root free soil

ΔS = shear strength increment per unit area of soil where $\Delta S_R = \Delta S_L$

r_1 = Unit weight of soil above groundwater table

r_2 = Unit weight of soil below ground water table

Since plants and grass absorb different amounts of water depending on the type of soil that they grow in, there are several different criteria for the selection of the most appropriate species.

Figure 10.4 Uprooted and tilted trees along the Tossa foot

A general rule of thumb is to use local plants and grass that are adaptable to local climate (Abramson, 1996). In general, vegetation that absorbs large amounts of water from the soil are best in clayey soil to ensure a drier and stronger soil crust. On the contrary, species that absorb less water would be ideal for sandy soils because intense drying of sandy surface soils make them more susceptible to erosion.

Coniferous trees (not local tree) along Tossa foot on a steep slope surfaces uprooted due to the above case (Fig. 10.4), where as eucalyptus trees are the best in both clay and sandy soils of Dessie.

10.2.3 Surface slope protection

The objective of surface slope protection is to provide near impermeable surface protection to slopes and maintained dry or partially dry. The surface slope protection measures include application of shot create, masonry blocks or rip-rap. Among these, masonry blocks are the most applicable. For masonry, it is essential to consider the weathering potential and durability of the blocks to be used in construction. Slope stabilization by masonry blocks has been used for centuries to prefect slope materials against the effects of erosion and weathering. In the past, old masonry walls were dry packed. Today, masonry blocks are usually bedded on a minimum 3-inch thick layer of free draining crushed stone or gravel conforming to the criteria for the design of filters. Weep holes draining the bedding material should be provided at the toe of masonry facing to facilitate discharge of groundwater flow. Weeps may also be installed in the wall above the toe.

Erosion of toes of slopes by moving water in rivers & streams, is common and often causes instability if left unattended. The general solution for this problem is to protect the toe of the slope with layers of riprap placed at the base of the slope to an elevation of about 3 to5 feet above the mean high-water level.

The selection of slope surface protection measures depends on the overall cost of the work involved. These methods are expensive to apply such as in Dessie. However, on very risky areas such as landslide three and five are more convenient.

10.2.4 Reinforcement

For specially land slide areas, that are more close to the foundation of infrastructure such as landslide 5 and 3, reinforcement is very crucial this includes soil nailing stone columns, Retaining walls, etc.

Soil nailing can be used to retain excavations and stabilize slopes by creating insitu-reinforced soil retaining structures. In soil nailed excavation the reinforcement generally consists of steel bars, metal tubes, of other metal rods that resist, tensile stresses and shear stresses. The nails can be installed in the excavation cuts by either driving or grouting in predrilled boreholes. Now days this technique is already introduced in our country and applied in many projects by Bauer a German foundation construction company and the project in Gilgel Gibe hydroelectric power tunnel supporting. Soil nailing in excavations has been used in granular and cohesive soils and in relatively heterogeneous deposits.

Stone columns can be used to stabilize or prevent landslides. This ground improvement technique increase the average shear resistance of the soil along a potential surface by replacing or displacing the in situ soil with a series of closely spaced, large diameter columns of compacted stone.

10.2.5 Catchment

Regardless of which of the rehabilitation methods are chosen, there is usually the need for catchment of falling rock. Catchment can consist of engineered benches, ditches, wide shoulders, and steel barriers nets, fences, and concert walls. The type of catchment used depends largely on site conditions specifically, the height and angle of the slope and clearance between slope and the facility are important (Abramson, 1996). This not only dictates how much space there is for catchment, but it also relates to anticipated paths of failing rocks. Obviously the catchment area must be some where along the paths of the rocks to be effective.

Key considerations in the design of such barriers are height, location and strength. These catchements are normally used in conjunction with banches, ditches and shoulders.

Ditches can be used to redirect surface runoff away from slopes. Ditches are usually lined with shotcrete or concrete. They can be V-shaped or rounded. It is important to design the ditches so that they drain in to a proper receptacle, have an allowable capacity and grade such that they do not overflow.

10.2.6 Construction of economical engineering structure

At present state, most of the gully slides have check dams, gabions and retaining walls. But most of the structures became damaged due to in proper foundation and their lateral limit. In a few places check dams and gabions have been stabilizing a slope and reduces the lateral increase of the gully slide.

For the future remedation, it should be continued to construct these structure after designing properly that takes in to consideration the depth of the gullies.

10.2.7 Avoid human intervention in high risky areas.

This includes deforestation, quarrying along the foot of the cliffs, and construction with in unstable areas.

10.2.8 Evacuation of people from risky areas and settling to other planned areas

Peoples must not settle in landslide areas, which are usually located along stream and gullies and along the bank of the Borkena River. This condition is very risky for their lives and properties and therefore the local authorities must arrange this condition as much as possible without any delay.

At present, many houses have been constructed near the foot of Tossa escarpment, which leads to a very serious problem due to rock fall. This condition must not continue and the newly constructed houses should be either evacuate or a proper prevention method such as catchments should be done.

Table 10.2 Summery of remedial measures

Landslide		Soil/rock type	Remedial Measures	
Previous	Now		existing	future
1	1	Alluvial	Check dam	Checkdam Gabions Drainage system
2	2	Alluvio- Collubial	Check dam	Check dam Proper drainage
3	3	Colluvial	Gabions Checkdam	Proper drainage Vegetation Reinforcement of the bridge Gabions Evacuation of residents

4	4	Talus deposit	Gabions check dams	More close checkdams and gabions well designed drainage system including retaining walls
5.1	5	Colluvial	Checkdams Gabions Vegetation retaining walls	Evacuation of residents Checkdams & Gabions reinforcement of the bridge
5.2	6	Alluvio-Colluvial	Checkdam Gabion	proper drainage Vegetation
7	7	Colluvials	Checkdam Open ditch	Retaining wall Proper drainage Benching the slope Vegetation
8	8	Alluvial		Checkdam retaining wall drainage
9	9	Alluvial	Vegetation but now defforestation	Trench ditches vegetation
10	10	Alluvial	Checkdam	Retaining wall drainage checkdam
11	11	Talus		Drainage (diversion Filling of the gully gabions Vegetation
12	12	Alluvio-Colluvial		Checkdam Gabion Proper drainage

				Vegetation
14	13			Retaining wall
20	14			Drainage, check dam
16	15			Drainage
-	16			Drainage, check dam
17	17	Alluvial		Proper drainage Check dam gabions
18	18			Catchement
Foot of the Tossa cliff	19	rock fall	Vegetation	Vegetation Catchment
Foot of the Tossa Cliff	20	rock fall	Vegetation	Vegetation Catchment

CHAPTER ELEVEN - CONCLUSION AND RECOMMENDATIONS

Giving special emphasis for the engineering geological work, a landslide assessment, hazard mapping, and detail investigation of extents of landslide and its possible remedial measure have been prepared after intense field work from 19th of February to 28th of March 2001.

The topography of Dessie, a town situated on a narrow graben between Tossa fault escarpment in the west and Azewe Gedel in the east, is the result of tectonism and localized volcanism with in the floor of the graben. The topography is characterized by about 2% slope gradient near the floor to more then 60% near the foot of the Tossa escarpment.

The studied are covered with basalts of different type degraded basalt, stratoid basalt, vesicular basalt flows of the trap series associated with patches of scoriacious basalt, and deposits of scree, colluvial, alluvial and some residual soils in the north and pockets of lacoustrine deposits at the center of the town.

The thickness of the colluvial alluvial deposits varies from place to place as revealed form the boreholes and vertical electrical sounding tests. It depends of course, on the paleomorphology of the graben.

Different joint sets measurements of escarpment basalts show that the master joints follow the direction of the major North South trending fault .

As other highlands of Ethiopia, Dessie receives heavy rainfall specially in July, August and September that together with the steep slope facilitate surface erosion and high amount of infiltration with in the granular soil. The disturbed volcanic terrain (intensive fracturing) flactuate a higher amount of water to percolate downwards. This condition is revealed from Tossa escapment springs that face the down thrown block and their discharge flueterate from season to season.

Engineering geological properties of basalts have been determined using point load test, schmidt hammer and by observing the weathering conditions. Accordingly, the rocks along the escarpment is classified as very high mass strength, basalts that cover the entire hills as moderate mass strength and the other areas specially along river beds high mass strength and the north basalts as low mass strength. Based on point load test, and Schmidt hammer test the value for basalt rocks ranges from 2-10.6 Mpa

The engineering poerties of soils have been determined in the laboratory and classified for engineering geological mapping.

Colluvial materials consist of from material silt size to big boulders. The grain size decrease down the slope. Most of the gullies along the buttresses of the Tessa escarpment are formed from this thick well graded colluvial deposit. In most cases the material is not cemented that, it is highly dissected by surface water, hence, forming a deep valley.

Alluvial material found in relatively lowlying areas around Kerra, TTI, Sengogebey is consists of silt and clay with a small amount to non of sand.

The moisture content and liquid limit for Kerra soils have relatively high value from 33-55% and 91.44% to 97.6% respectively. The TTI alluvial soils liquid limit ranges from 88.2% to 97.65% and has a mosture content of about 40%.

The soils from Sengo Gebey has relatively high proportion of silt and sand and low value of plasticity index.

Organic soils found at the center of the town are highly compressible with average coefficient of compressibility(Cc)equal 0.4 which is a very bad soil for foundation.

The terrain characteristics, the dominance of soil or relatively lower shear strength and compressive strength, internal structure of past geologic events has appreciable contributions for the landslides in Dessie. Steepness of Tossa mountain and Azwa Gedel, rapid runoff, thick accumulation of loose colluvial and alluvial soil where major settlement lie, and the network of gullies and their deep incisions aggravated the landslide problem.

At present, about 20 different landslides including very dangerous rock fall areas have been distinguished and each one suffered several general or partial movements. Almost all the land slides have moved and advanced in the direction of the drainage network. Most of the failures are on slopes of fine-grained to coarse gravels, loose unconsolidated materials mainly along gully banks.

Most of the landslides in Dessie are gully erosion induced type that are associated with heavy rainfall that cause a storm flood flowing on steep slope valley without and drainage system. Rock falls that are driven from the Tossa Cliff, caused by intersection of joints and descended bounding and rolling down slope as far as 300-500m.

Considering landslide erosion and flood hazard classification can be possible with landslide areas the first risky areas.

Based on the above study, the following recommendations have been given:

- Pockets of lacustrine deposits found at the center of the town should be avoided during foundation work.

- Safe bearing capacity of this layer should not be greater than 0.25-0.50 kg/cm^2 as its angle of internal friction and cohesion soil is 7^0 and 51 kPa respectively.

- Geothecnical soil investigations including slope analysis during the construction of heavy structure must be carried out and should be supervised by professionals.
- Construction of new houses below the foot of Tossa and along gullies and riverbanks should be avoided.

- Future extension of the town should be at a stable part of the town specially to the north and northeast.

- It is not advisable to construct large story buildings around the center of the town with out reaching the bed rock directly or using appropriate foundation type (e.g. pile foundation).

- During construction every cuttings should be retained.

- Of all stabilization techniques considered for the correction or presentation of landslides, proper water drainage is the most important and recommended for Dessie.

- During surface drainage work their should be a design mechanism which reduces the velocity of the storm water from the steep slope (especially along landslide 4)

- During the design of surface drainage the following very important catchment parameters (site specific) should be considered.

1. Area and shape of the catchment zone.
2. Rainfall intensity
3. Steepness and length of the slope being drained, hence estimating the speed of erosion.
4. Condition of the ground surface and nature of the subsurface soils.
5. Nature and extent of vegetation.

- Most of the gabions and check dams constructed were broken and taken away by the flood. To avoid this, proper foundation type and level of relatively stiff or hard layer should be found and protected from under flow.

- The walls of the gullies to be controlled should be protected from storm water washing by proper retaining structure.

- Depth of gullies and type of remedial measure should be designed first.

- Landslides in Dessie town are believed to involve only the loose superficial deposits of alluvial and colluvial materials. No evidence of deeper landslides, this should be verified from the installed inclinometers.

- Hydrogeological condition of the slopes, possible groundwater interference, depth to ground water level and its fluctuation, and ground flow direction should be assessed
- For the town such as Dessie,that are more affected by storm water,a rainfall measuring startion equipped with continually recording gauges, which yield date on the characteristics of individual storms such as timing and intensity as well as total amount is required.
- The toilet wastes are transported by the municipality trucks up to the bank of Borkena River and drains down to the River .So the municipality and the water and sewerage branch office should take immediate action for this serious problem.

REFERENCE

Abramson L.W., T.L., S.S., G.B., (1996): *Slope stability and stabilization methods, John Wiley & Sons, Inc, New York*

Amir wadi al-*Khafaj and orlands B. Anders land,(1992) Geotechnical Engineering and soil testing, Saunders college publisher*

Arora K. R., (1997): *Soil Mechanics and Foundation Engineering, Standard Publishers Distributions, Delhi.*

Bolt B.A., W.L. Horn, G.A. Macdonald, R.F. Scott (1975): *Geological Hazards. Springer – Verlag, New York, Heidelberg Berlin.*

Bowles J.E, (1982): *Foundation analysis and design, third edition, McGraw – Hill, International book company*

Bowles J. E., (1984): *Engineering properties of Soils and their Measurements McGraw-Hill, New York*

CSA (1999), *Central Statistics Agency Addis Ababa*

Dereje Ayalew Pik R., C.D., C.C., Gezahegn Yirgu (1997): *Journal of Volcanology and geothermal research, Elsevier, France*

Dereje Ayalew and Gezagn Yirgu (1999): *Geochemical and isotopic Characteristic of volcanic rocks from south Ethiopia, Journal of African earth science Vol. 29, No.2 ppxx-xx, Elsevioer, Great Britain*

Dikau R., Denys Brunsden, L.Schrott and M.L.Ibsen (1996): *Landslide recognition, identification, movement and causes. John Willy & Sons Ltd., England*

DMR (1987): *Dessie Municipality unpublished Report*

Duncanc, (1999): *Foundation on rock. Wyllie*

Gebretsadik Eshete (1982): *Slope Instability survey in Dessie Town. EIGS, A.A*

Goodman Richard E, (1993): *Rock in engineering construction, Jone wiley and sons, inc, U.S.A*

Gopal Ranjan and A.S.R Rao,(1991): *Basic and Applied soil mechanics, wiley, Eastern Limited, New Delhi*

Gouin P; (1979): *Earthquake History of Ethiopia and the Horn of Africa. Int. Development Research Center Ottawa, Canada*

Gray, D.H., (1978): *Role of woody vegetation in reinforcing soils and stabilizing slope. Symposium on soil reinforcing and stabilizing Techniques Sydney, Australia, pp 253-306.*

Gregnanin A., E. M. Piccirillo and Endeshaw Abebaw (1973): *The subdivision of Volcanic series in the Ethiopian Pateau: new geologic interpretation of the Dessie Kombolcha area. Roma, Italy*

Hoek, E., (1995): *Rock Slope Engineering. Journal of Gotechnical Division ASCE Vol. 106, No. GT9, pp1018 – 1030*

IAEG-HBR (1978): *High way Research Board,1978 ,Landslide and engineering practice ,special peport No.29 E.B. Eckel Ed.,Washington Dc*

ISRM (1981): *Rock and soil description for engineering geological purposes. Report by ISRM, Bull. Int. Standard of Rock Mechanics No. 75, pp224 – 257*

ITC Journal*, Eu runout project Volume 2 –issue-1-2000 Guest Editor. C.J. Van Western, Netherlands*

Justin – Visentine (1974): *Dike Swarms, Volcanism and tectonics of Western Afar margin along the Combolcha- Eloa Traverse. Francesco Grannino & Figlc Napoli, Traly*

Kazmin, V., (1975) *Explanation of the Geological Map of Ethiopia, Unpub. Report EIGS Addis Ababa*

Kebede Tsehayu and Almaz Gezahgn (1995): *A report on Landslide problems of Dessie town EIGS Addis Ababa*

Ketema Tadesse (1978): *Dessie Town Water Supply. EIGS, Addis Ababa*

Ketema Taddese (1980): *Hydrogeology of the Borkena River Basin. Addis Ababa Universtiry*

Lambe, T.W and Whitman, R.V (1969): *Soil Mechanics, John Willey and Sons, Inc, New York*

Leopold, B.L., and Dune, T., (1978): *Water in Environmental Planning. Free man and Company, San Francisco*

Lulseged Ayalew (1998): *The effect of seasonal rainfall on landslides in the highlands of Ethiopia. Technical University of Clausthal, Germany*

Lulseged Ayalew, (1999): *Slope Stability engineering. Takuo Yamagami & Jing – Caijiany, Japan*

Mohr P.A. (1964): *The geology of Ethiopia, IL, Poligratico, Asmara, Ethiopia*

Mohr, P.A. (1971): *The Geology of Ethiopia, IL, Poligratico Asmara, Ethiopia*

Mukerjee *P.K(1995) A Text book of geology ,The world press Calcata*

Murithy V.N.S, (1989): *Soil Mechanics and Foundation Engineering, Saikripa Technical Consultants, Bangalore*

MWUD (1995): *Ministry of Works and Urban Development unpublished report of Dessie Landslide problem*

Pik R., C.D., C.C., Gezahegn Yirgu and Dereje Ayalew (1997): *Journal of Volcanology and geothermal research, Elsevier, France*

Powrie William (1977): *Soil Mechanics Concepts and application. John Wiley and Sons, Inc. New York*

Robertst A., (1977): *Geotechnology . University of Nevada*

Shiffer V.V., (1977): *Physical geology. Mir publishers, Moscow*

Soeters, R., and Rengers, N., (1985): *Procedures for field description and classification of engineering geological soil and rock units. The Netherlands, ITC*

Tadesse Dessie & Tadesse H/Mariam (1991):*Engieneering geological map of Desire EIGS, Addis Ababa*

TRB –SR176 (1978): *by Schuster and Krizek (1978): Landslide analysis jand control. Special report 176, R.J.Krizek editors*

UNESCO –FAO (1997): *Guidelines for slope and soil profiles description, third edition. FAO, Rome*

UNESCO – IAEG (1976): *Rock classification for engineering geological mapping. Report by IAEG Commission on Engineering Geological mapping, Bull. Int. Assoc. Engineering geology No. 12, pp476-489*

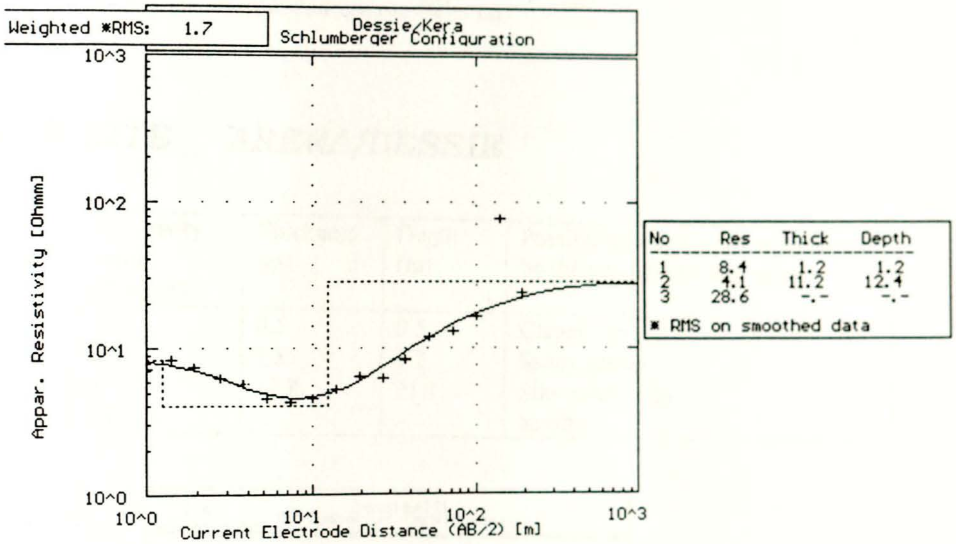
UNESCO (1984): *Growndwater. Studies and Reports in Hydroegeology V33.*

Wilson, E. M., (1990): *Engineering Hydrology, fourth edition, Macccccmillan Press Ltd. London, 348pp*

Zanettin, B., E.J., P.E (1977-78): *Volcanic succession, Tectionics and magmatology in central Ethiopia. Volume XC, part II, Universita dipadova, Italy*

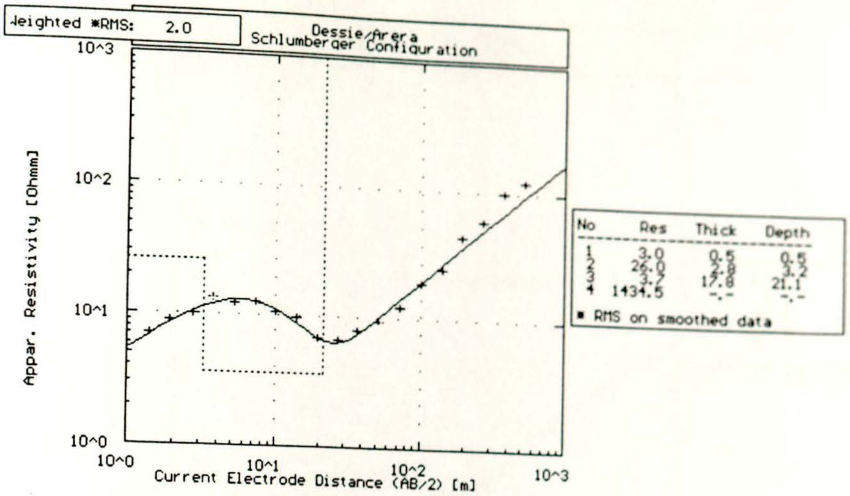
Zanettin, B., Niteoletti M., and Justine-Vesentin, E., (1974): *The volcanic succession in centeral Ethiopia. Memo 1st Geol., Miner, University, Padova*

Quantitative and Qualitative Interpretation of Vertical Electrical Soundings



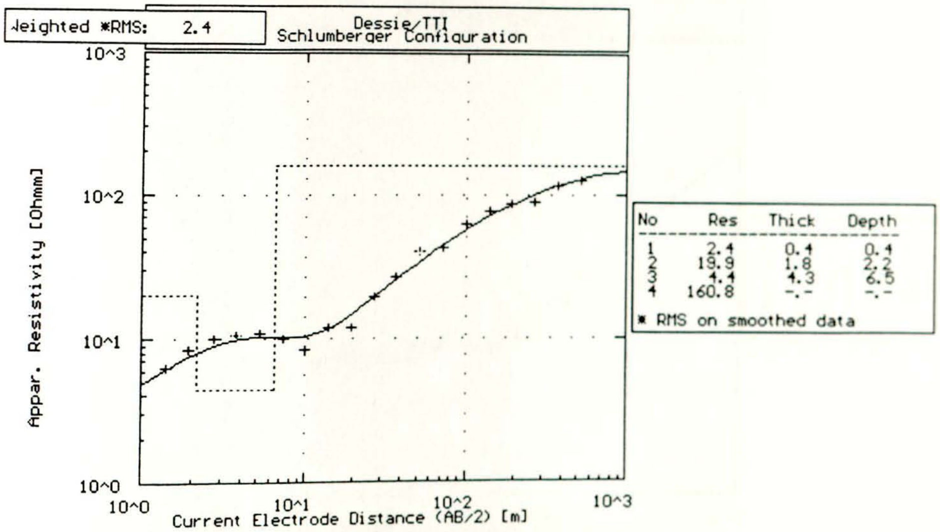
VES Site _ Kera/Dessie

Layer Number	Resistivity value (Ohm.m)	Thickness (m)	Depth (m)	Possible geologic units represented by the given resistivity value
1.	8.4	1.2	1.2	Top soil (Clayey)
2	4.1	11.2	12.4	clay
3	28.4	-	-	Gravely sandy clay



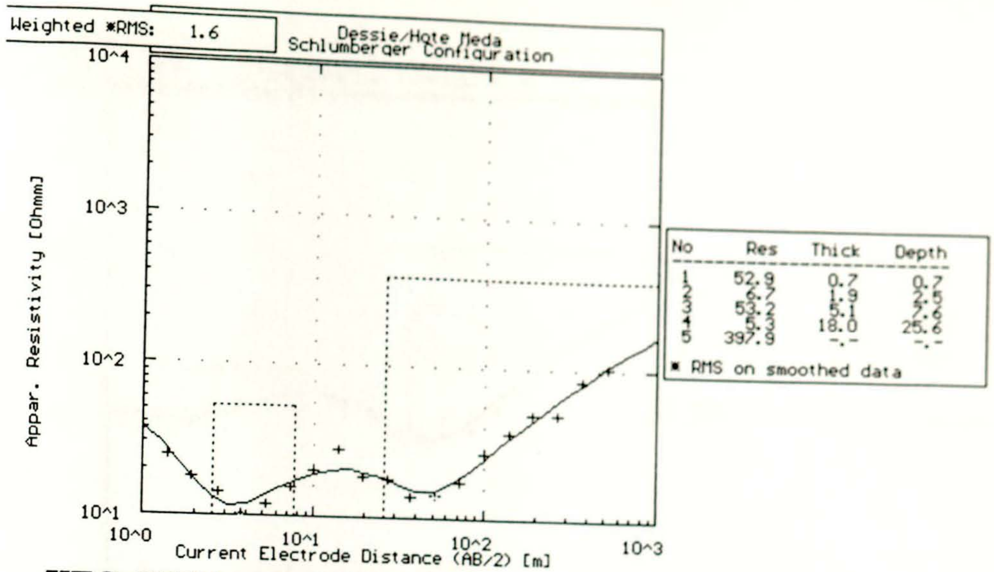
VES SITE _ ARERA/DESSIE

Layer Number	Resistivity value (Ohm.m)	Thickness (m)	Depth (m)	Possible geologic units represented by the given resistivity value
1.	3	0.5	0.5	Clayey top soil
2	26	2.8	3.2	Sandy gravel
3	3.7	17.8	21.1	Silty sandy clay
4	1434.5	-	-	basalt



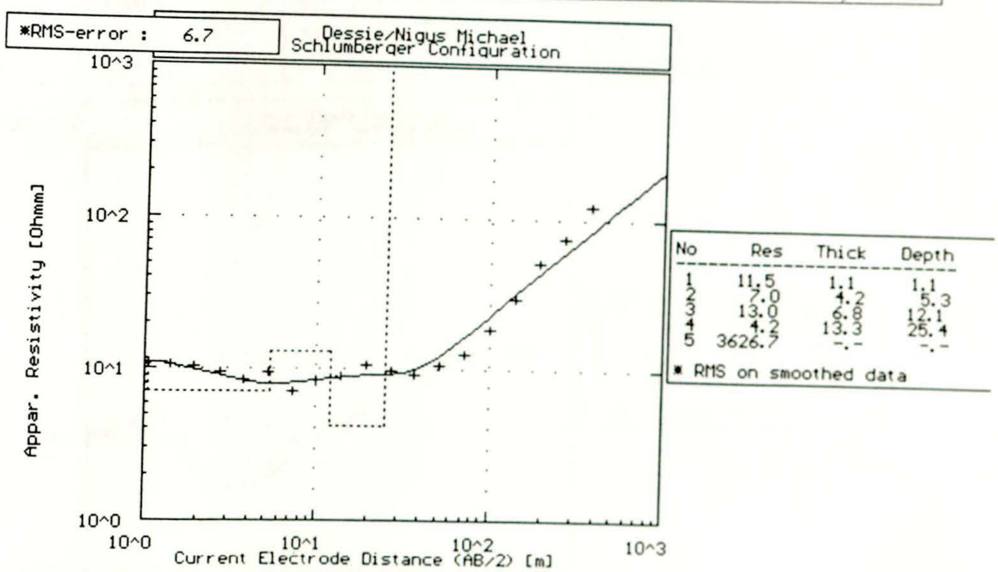
VES Site _ TTI/Dessie

Layer Number	Resistivity value (Ohm.m)	Thickness (m)	Depth (m)	Possible geologic units represented by the given resistivity value
1	2.4	0.4	0.4	Clayey top soil
2	19.9	1.8	2.2	Sand (with clays)
3	4.4	4.3	6.5	Clay
4	160.8	-	-	Sandy gravel



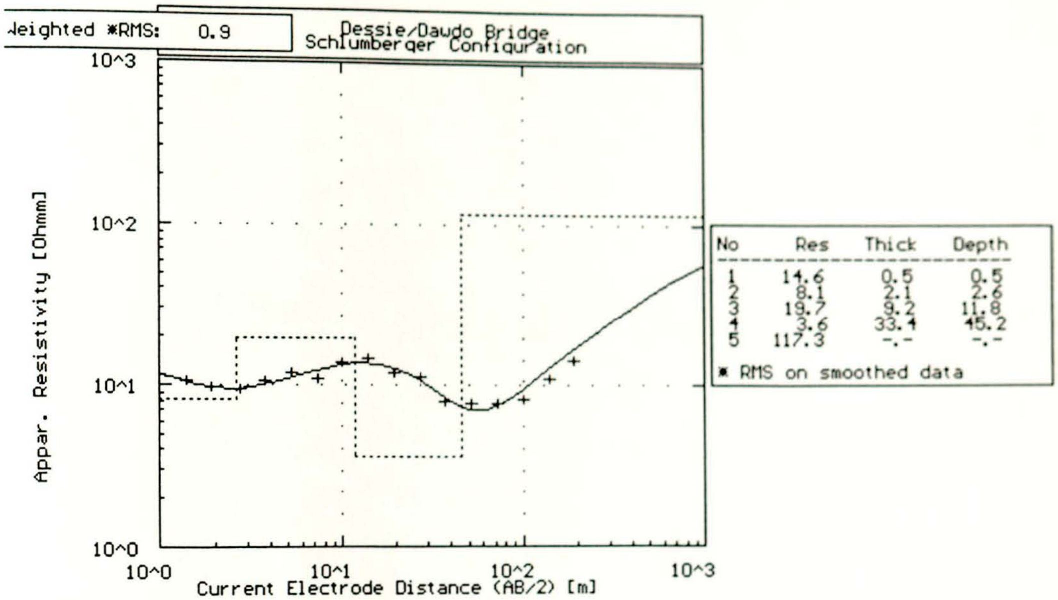
VES SITE _ HOTE MEDA/DESSIE

Layer Number	Resistivity value (Ohm.m)	Thickness (m)	Depth (m)	Possible geologic units represented by the given resistivity value
1.	52.9	0.7	0.7	Highly compacted top soil
2	6.7	1.9	2.5	Clay
3	53.2	5.1	7.6	Sandy gravel
4	5.3	18	25.6	Clay
5	397.9	-	-	Basalt (weathered &saturated)



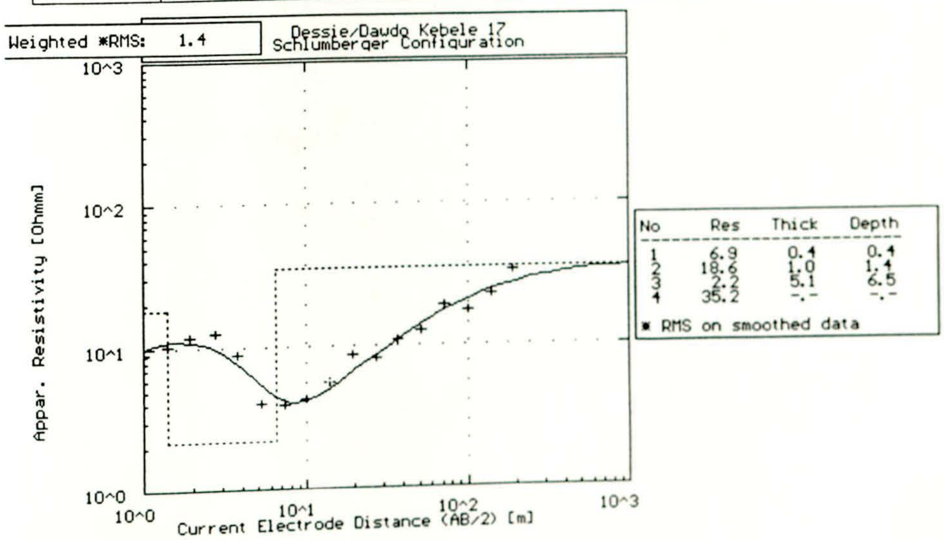
VES SITE _ NIGUS MICHAEL

Layer Number	Resistivity value (Ohm.m)	Thickness (m)	Depth (m)	Possible geologic units represented by the given resistivity value
1.	11.5	1.1	1.1	Top soil
2	7	4.2	5.3	Clay
3	13	6.8	12.1	Silty sandy clay
4	4.2	13.3	25.4	Clay
5	3626.7	-	-	Basalt



VES SITE _ DAWDO (NEAR THE BROKEN BRIDGE) -DESSIE

Layer Number	Resistivity value (Ohm.m)	Thickness (m)	Depth (m)	Possible geologic units represented by the given resistivity value
1.	14.6	0.5	0.5	Top soil
2	8.1	2.1	2.6	Gravely sandy clay
3	19.7	9.2	11.8	Silty clay
4	3.6	33.4	45.2	Clay
5	117.3	-	-	Weathered basalt



VES SITE _ DAWDO (NEAR ELEM. SCHOOL) -DESSIE

Layer Number	Resistivity value (Ohm.m)	Thickness (m)	Depth (m)	Possible geologic units represented by the given resistivity value
1.	6.9	0.4	0.4	Top soil (clayey sand)
2	18.6	1	1.4	Clayey gravel
3	2.2	5.1	6.5	Clay
4	35.2	-	-	Sandy gravel

SOIL DATA FORM FOR TEST PITS

TP N° 1

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00 – 1.30			Back fill material (Basalt bolder, Gravelly Sand)
1.30 – 2.30			Dark to black, very soft Clay (organic)
2.30 – 4.00			Light brown, expansive soft moist Clay

TP N° 5

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00 – 1.50			Dark grey toblack firm Clay
1.50 – 4.00			Brown, stiff Clay.

TP N° 2

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00 – 1.50			Dark Gravelly Clay with Sand
1.50 – 2.80			Dark (black) very soft organic Clay
2.80 – 4.00			Reddish brown soft Clay

TP N° 6

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00 – 0.50			Back fill material (Gravelly Caly.
0.50 – 3.00			Black, soft, organic Clay

TP N° 3

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00 – 1.00			Dark stiff Clay
1.00 – 4.00			Reddish brown, stiff hard Clay

TP N° 7

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00 – 0.50			Gravelly Clay top Soil
0.50 – 3.50			Brown Gravelly, Sandy Clay (Colluvial deposit)

TP N° 4

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00 – 0. 0			Dark Clay with Gravel
0. 0 – 2.50			Dark grey to bla k fine soft Clay
2.50 – 4.00			Light brown soft expansive Clay.

TP N° 8

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00 – 2.00			Dark, Gravelly, Sandy, Clay
2.00 – 2.50			Dark, expansive soft to firm Clay
2.50 – 3.00			Reddish brown firm to stiff Clay

SOIL DATA FORM FOR TEST PITS

TP N° 9

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00			Dark grey Sandy Silty Clay
1.00			Grey, Basaltic Gravel and Sand
3.00			Grey Basaltic Gravel and Boulders
4.50			

TP N° 10

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00			Dark, friable Sandy Clay
0.40			Dark grey, friable Sandy Clay
3.00			Yellowish Gravelly Sand
4.00			

TP N° 11

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00			Back fill material
2.00			Grey, expansive Soil
3.00			

TP N° 12

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00			Dark, Stiff Sandy Clay with some Gravel
0.80			Brownish stiff Clay
4.00			

TP N° 13

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00			Dark friable top Soil
0.50			Darkgrey soft Clay
2.50			Yellowish to ligth brown stiff Silty Clay with Gravel
4.00			

TP N° 14

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00			Dark grey, stiff, Clay with Some Gravel.
1.50			Brownish, very stiff, Clay with some Gravel
3.00			

TP N° 15

DEPTH	SAMPLE	PROFILE	DESCRIPTION
0.00			Dark to brown, friable Clay
3.00			Light brown to dark yellow, dense Colluvial deposit (Sandy, silty Gravel
4.00			

TP N°

DEPTH	SAMPLE	PROFILE	DESCRIPTION

NATIONAL METEOROLOGICAL SERVICES AGENCY

Station: DESSIE Wereda DESSIE-ZURIA Awraja DESSIE ZURIA Region WOLLO

Alt. 2460 m Long .... Lat. .... Element MONTHLY TOTAL RAIN FALL

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total	Average
1962	x	x	x	x	0.0	54.9	274.2	353.3	213.7	138.6	0.0	47.0		
1963	40.1	57.2	119.4	228.9	292.5	59.9	186.4	171.2	122.6	36.8	82.4	63.0		
1964	11.6	0.0	34.5	55.5	80.7	126.7	473.1	350.0	83.5	91.3	0.0	0.0		
1965	23.0	0.0	37.0	106.0	6.0	17.0	218.7	286.0	81.0	43.0	82.0	2.6		
1966	0.0	27.0	39.0	144.0	33.0	39.0	142.0	419.0	103.0	129.0	3.0	0.0		
1967	0.0	0.0	99.0	80.0	77.0	28.0	300.0	485.0	134.0	123.5	64.0	0.0		
1968	0.0	75.5	75.0	162.5	23.5	120.5	468.0	227.7	190.5	19.0	47.0	0.0		
1969	108.5	118.5	127.0	134.5	31.0	6.5	364.0	206.5	91.5	35.0	3.5	0.0		
1970	21.5	24.0	77.0	50.0	17.0	6.5	381.0	245.0	238.5	27.0	0.0	40.5		
1971	29.0	0.0	50.0	27.0	133.7	18.5	236.0	311.0	196.0	13.0	32.5	98.0		
Total														
1972	0.0	0.0	68.0	142.5	63.5	80.0	227.2	297.3	116.5	13.6	28.2	0.0		
1973	x	x												
1974	0.0	64.0	128.5	39.6	79.3	105.6	330.9	258.0	248.5	0.0	0.0	0.0		
1975	57.0	42.8	59.2	18.5	27.1	62.9	170.8	419.4	217.0	1.1	0.0	25.9		
1976	0.0	16.0	38.2	140.3	57.8	11.9	170.2	284.0	96.0	22.3	43.2	34.2		
1977	1.3	16.6	139.8	104.2	133.6	7.0	293.4	261.6	107.1	144.8	11.9	8.4		
1978	0.0	14.0	19.5	90.7	28.4	14.6	319.4	188.9	166.8	44.1	0.8	54.9		
1979	80.2	87.0	134.4	33.2	105.0	59.8	271.5	188.8	183.5	61.5	0.5	0.9		
1980	16.3	62.9	27.1	38.6	27.2	37.9	249.4	286.0	174.5	34.2	13.8	0.0		
1981	0.4	1.0	211.0	74.6	39.8	1.1	340.1	335.3	102.5	24.8	0.0	0.4		
Total														
1982	61.9	79.1	46.4	75.8	118.9	0.0	100.3	251.0	172.7	105.0	62.0	32.0		
1983	23.3	45.5	130.6	152.7	110.7	x	x	x	97.9	56.7	15.1	0.0		
1984	0.0	0.0	33.3	53.9	191.7	31.2	135.9	91.3	125.3	2.3	6.7	35.2		
1985	51.2	0.0	24.7	188.5	78.0	13.2	320.7	274.5	143.9	16.6	0.0	x		
1986	0.0	73.1	62.6	61.2	60.2	203.6	245.5	317.7	193.1	9.7	0.0	28.1		
1987	0.0	42.6	99.1	66.3	198.1	0.0	67.9	319.8	71.7	47.1	0.0	7.8		
1988	16.7	76.5	85.1	120.3	15.2	35.7	551.5	311.2	198.0	29.1	0.0	0.0		
1989	12.5	37.3	141.6	82.7	8.6	12.4	198.3	258.8	186.5	37.1	x	x		
1990	41.5	x	77.3	30.3	15.7	0.0	286.9	147.5	201.9	9.6	0.0	x		
1991	x	90.8	168.6	69.3	86.6	5.6	260.8	222.5	144.9	42.2	0.0	69.6		
Total														
Total														
Ave.														
Total of Yr.														
Ave. of Yr.														

/tm

EARTHQUAKES THAT OCCURRED BETWEEN ZERO AND 200 KILOMETERS OF THE TOWN OF DESE

YYYY	MMDD	HHMM	SS.S	LATITUDE	LONGITUDE	MAGNITUDE
1993	921	1911	36.2	11.496	39.632	5.3
1994	1010	018	28.4	11.264	39.587	4.5
1995	7 8	039	31.8	10.837	40.594	3.5
1995	710	932	4.8	11.454	40.028	3.0
1995	1213	1848	28.7	10.330	39.200	2.4

YYMMDD = YEAR MONTH DAY

HHMM SS.S = HOUR MINUTE SECOND TENTHS OF SECOND

LATITUDE AND LONGTUDE ARE IN DEGREES EAST AND NORTH RESPECTIVELY.

(SUPPLIED BY THE GEOPHYSICAL OBSERVATORY, ADDIS ABEBA.)

DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree on any other university. All sources materials used for the thesis have duly acknowledged.

Kefyalew Terefe

Signature: ____________

Place and date of submission: School of graduate studies, Addis Ababa, July, 2001