CHARACTERIZATION OF BLACK COTTON SOIL FROM INDEX PROPERTIES ALONG SEBETA-TEFKI ROAD SECTION

by

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Abstract

This MSc thesis work is entitled "Characterization of Black Cotton soil from Index Properties in Sebetta area". The study area located at 32km, Southwest of Addis Ababa in the Oromia regional state; covering an area of 126 km^2.

The main objective of the study is to characterize the black cotton soil of the area from index properties. The index properties define certain physical properties used basically for classification but also for correlation with engineering properties.

The methodologies employed to achieve the objective are literature review pertaining to the area, filed data collection on soil and rocks, laboratory testing of soil samples and data analysis and interpretation.

The study revealed that the geology of the area is represented by rocks of Tertiary age (65my) namely; basalt, andesite, and ignimbrite, and Quaternary soil units. Four engineering geological rock units and three soil units were mapped.

Disturbed and undisturbed soil samples were analysed for index tests, namely, particle size distribution, Atterberg limits, free swell, and shrinkage limits, in the Central Laboratory of Geological survey according to BS 1377: part 2: 1990 standard.

Laboratory test results from the present and previous studies have shown that fines are over 90 %. Liquid limit (LL) and plastic limit (PL) values are ranging from 50-110 %, 24-50 % respectively. The free swell varies from 118-140 %, while the shrinkage limit test values range from 15-20 % respectively.

The main index properties used for identification and classification of black cotton soil are clay fraction (minus 2 micron), Atterberg limits, free swell, and shrinkage limits. Accordingly, the black cotton soil is potentially active and requires countermeasures.

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GLOSSARY

AASHTO: American Association of State Highway and Transportation Official.

ASTM: American Society of Testing Materials

GSE: Geological Survey of Ethiopia

USC: Unified Soil Classification System

WPI: Weighted plastic Index

WPL: Weighted liquid limit

WL (LL): Liquid limit

WP (PL): Plastic limit

WS (LS): Shrinkage limit

FS: Free Swell

A: Activity

m.a.s.l: Mean above sea level

OGL: Original Ground Level

km 31+920: Distance from Addis Ababa, 31.92 km.

km 65+246 L: 65.246 Km from Addis, left of the road.

km 65+246 R: 65.246 Km from Addis, right of the road.

1. Introduction

1.1. General

Since practically all civil engineering works are built either on soil, in soil, or of soil, detailed understanding of the type, nature and characteristics is most valuable, especially to engineers, planners and to decision makers.

Quite different types of soils exist owing to varied climate, geomorphology, geology etc. It is these differences, which result in variation in the physical and engineering properties and classification systems. Despite such heterogeneity, soils are the most frequent and abundant materials on the earth's crust, on which most of the large civil engineering works are constructed. Ironically, all soils are not suitable to be used in the civil construction activities as foundation or embankment. Some of such soils are expansive soils (black cotton soils); highly micaceous or diatomaceous soils etc.

Black cotton soil occurs in many countries such as; Australia, Canada, Ethiopia, Ghana, India, South Africa, USA, etc. In Ethiopia, black cotton soil occurs in the northern and central Ethiopian Plateaus, the Rift valley, inter-mountain depressions, alluvial plains, etc. Even in the capital city, Addis Ababa, considerable areas of Bole, Kotebe, CMC and Mekanisa, are covered by black cotton soils.

During this study, primary and secondary data were collected, reviewed, analysed and interpreted. The secondary data includes texts, journals, reports and maps primarily related to the characterization of black cotton soil. The primary data comprises field data collection on geological /engineering geological mapping, pitting and sampling. Laboratory index tests were performed on collected disturbed and undisturbed samples of black cotton soil. Various methods of showing the data are employed. Some are tabulated whereas others are only shown graphically in the body of the report and in the Annexure.

This thesis has seven chapters. The first chapter is introduction, which highlights the problem and the justification of the study. Chapter 2 describes methodologies employed, and Chapter 3, is about general description of the project area. Chapter 4, presents review of literature, Chapter 5, is concerned with field data and laboratory test. Chapter 6 is about the result and discussion of the study. Finally chapter 7 sets out to present the conclusion and recommendations of the study.

1.2. Problem Definition

Black cotton soils are the major problematic soils of the world. They are poor materials to be utilized in the construction of highways, air fields, and light weight structures, because they contain a large percentage of plastic clay and often expansive, swelling as water is absorbed. The inherent factor ascribed to expansiveness of black cotton soil is high content of clay mineral, montmorillonite because of structural arrangement, weak bond between units and high Base Exchange capacity. Thus soils containing montmorillonite mineral are susceptible to substantial volume changes. They swell as the water gets entered into the lattice structure and shrink if the water is removed. In moist state, montmorillonite is highly plastic, and has little internal friction. Its excessive swelling capacity may seriously endanger the stability of overlying structures and road pavements. The most common distresses of black cotton soil as a foundation material in the construction of buildings and roads are described below.

1 Building

Bumps and swells on the floor and diagonal cracks on the walls are the most ubiquitous damages of buildings in the presence of black cotton soil as a foundation material. These problems significantly affect the effective performance of doors and windows which are more pronounced during rainy seasons. For example, this phenomena is very common in houses around Bole, Mekanisa and CMC, etc. in Addis Ababa.

2 Roads

In Ethiopia Many of the major inter-regional state highways, radiating from Addis Ababa, at least in the first 70 to 100 km stretch, passes through these expansive soils, such as Addis Ababa-Debra Marcos, Addis Ababa-Ambo, and Addis Ababa-Jimma roads, etc. These highways have suffered from cracking and heaving due to differential movements which, leads to frequent maintenance and rehabilitation, incurring loss to the country's economy. To this end, part of the Addis Ababa-Jimma road, which is the target area of this study, also faces similar problem. A study carried out by Nettreberg, (2001) on the Addis Ababa-Jimma road, involving in-situ inspection of soil profile through pit and trenches, routine laboratory testing of black cotton soil, revealed typical symptoms of damage to roads and other pavements on active clay roadbeds include a general and often rapid and severe loss of riding quality, longitudinal cracking, and bumps at culvert, transverse cracks at culvert, and settlement and / or cracking due to trees. The study concluded that the above problems were due to the following factors

1. the soil must be potentially active; and
2. the changes in moisture content must be sufficiently great; and
3. the confining stresses must be sufficiently low.

These three conditions also suggest obvious means of preventing or minimizing the problem: e.g. partial or complete removal of the clay, pre wetting to the equilibrium moisture content, minimization or prevention of moisture change, and increasing the height of fill.

This study, "Characterization of Black Cotton Soil from Index Properties in Sebetta area", was initiated at the background of the above stated problem of black cotton soils, with the scope of characterizing the black cotton soil of the area from index properties, namely particle size, Atterberg limits, shrinkage limit, and free swell. It is appropriate at this juncture, to indicate that it is beyond the scope of this study to undertake exhaustive tests like determination of engineering properties, owing to limited resources, time and financial constraints.

1.3. The study area

1.3.1. Location and Access

The study area is located in the South-western part of Addis Ababa, in Alemgena district of Oromyia regional state. It falls in the map sheet NC 37 – 14, in the upper Awash basin within the geographic coordinates (UTM) 445000E to 459000E and 976421N and 986077N. Sebetta and Tefki are the main towns situated at the eastern and western extreme of the study area respectively. The location of the study area is shown in Figure 1.

The area is reached by the Addis Ababa-Jima road which passes at the central part of the study area, and it is located at 34 km from Addis Ababa. There is an all-weather road in the northern part of the study area which links Sebeta and the Suba National park. Field work was mainly conducted using the available seasonal roads and foot paths/trails which are the main means of communication of villages, towns etc. In general the area is accessible by foot and four wheel drive vehicles, mainly during dry seasons. During rainy seasons, the most parts of the study area is water logged and the soil becomes sticky and slippery making accessibility difficult.

1.4. Objectives and Scope of the Study

The properties of soil must be accurately evaluated in order to produce safe and economical designs. Soil properties are classified as basic, index and engineering properties. Soils are grouped on the basis of properties which tend to have similar behaviour. The soil of the study area is a problematic soil and known as black cotton/expansive soil. Part of the Addis Ababa-Jima road which passes through this expansive soil is subjected to damages such as heave and cracking in the pavement.

The general objective of this study is to characterize the black cotton soil of the study area from index properties.

The specific objective is to characterize the black cotton soil of the area from its index properties which involves;

- Geological mapping to indicate the various soil and rock units.
- Engineering geological mapping to classify the soil genetically, and rocks according to basic engineering geological properties.
- In-situ inspection of black cotton soil mainly, its thickness, structures and composition.
- Field identification/classification tests of dry strength, consistency, and dilatancy.
- Laboratory testing of index and some of basic properties, which are used for identification, and classification of black cotton soil.

The outcome of the study would be useful for land use planning, particularly in road alignment and other civil construction activities. Moreover, the results of the present study may be applied to similar areas of black cotton soils.

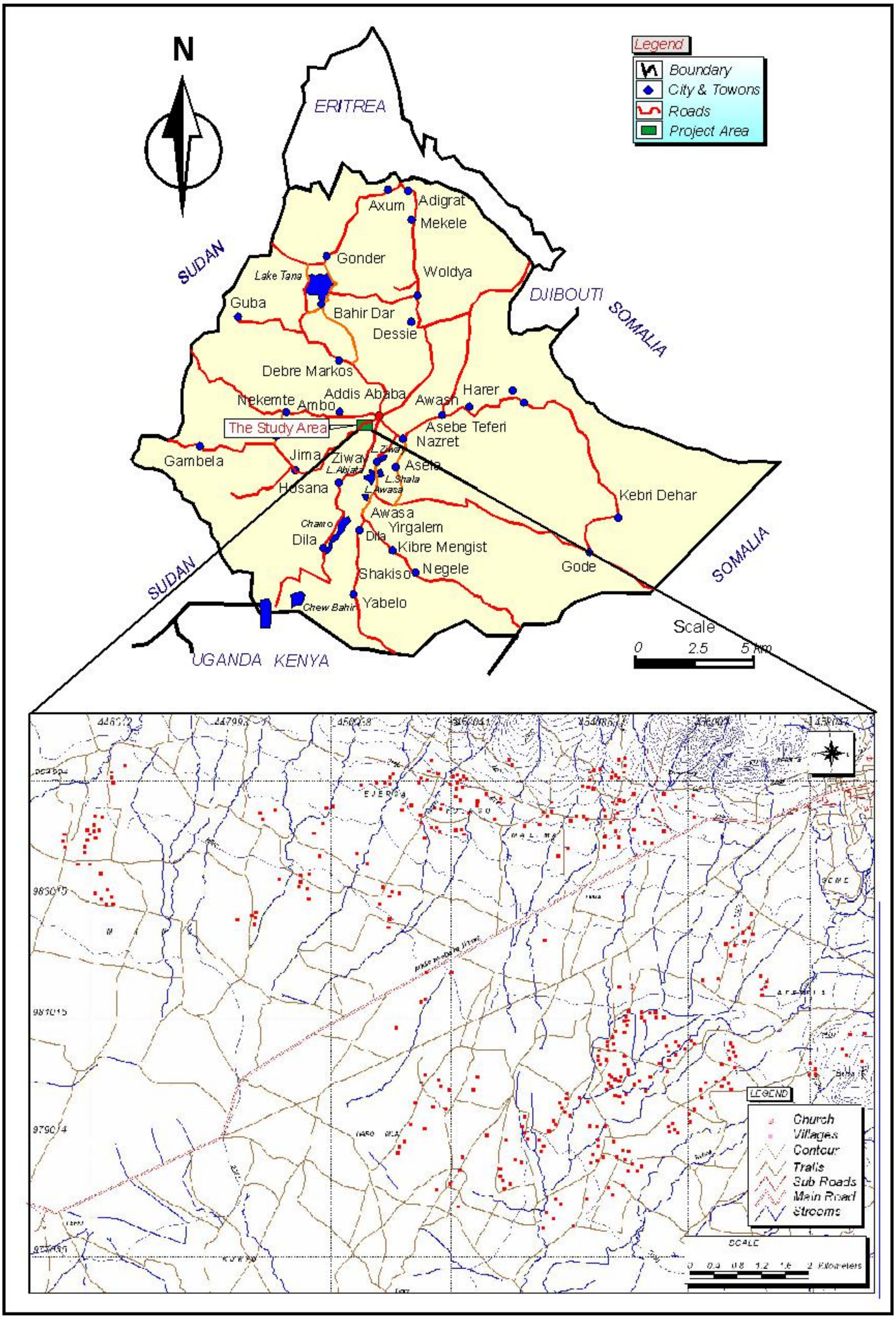

Figure 1- 1 Location map of the study area

2. Methods and Techniques

In order to achieve the objectives of the study various data collection techniques and laboratory testing methods were employed. There are two major interrelated data collection methods i.e. primary and secondary data collection. The basic sources of secondary and primary data for this study were various governmental and non-governmental organizations and physical field observations respectively. The secondary data has been thoroughly reviewed, well supported by the field data collection and laboratory analysis. The collected field and laboratory data were analysed and interpreted; and the results were included to produce the final report.

2.1. Secondary data collection

Relevant secondary data from textbooks, journals, and various official documents and reports about black cotton soils in general and specific to the study area were collected and critically analysed.

Primary data collection

The primary data includes actual field investigation and laboratory testing of black cotton soil.

2.1.1. Field data collection

Field data collection involved geological/engineering geological mapping, field identification tests, pitting, and sampling. The methods employed in the conventional geological/engineering geological mapping were: -

- Geological and engineering geological maps were produced by interpreting of black and white-vertical aerial photographs acquired in the year 1971 at scale of 1:50 000 and field traverses. Engineering geological mapping was carried out by delineating homogenous rock and soil units. The distinction between soil and rock is based on simple criteria; soil is mapped only when its thickness is more than one meter, when it is less the underlying rock is mapped (Soeters & Rengers, 1985).

- Classification, description and sampling of various lithological units were carried out at the pre-selected traverse lines and exposures at the representative location. The final maps were produced using state-of-the-art computer technology such as Autocad map, Arc view, Corel draw 3.2a etc.

- In order to describe the black cotton soil 3-dimensionally and to collect soil samples, test pits (1m by 1m) were dug manually at the representative locations to the required depths. Each pit was geologically and engineering geologically logged using an appropriate pit log format designed for this purpose.
- Collecting disturbed and undisturbed soil samples from test pits. While disturbed samples were collected by textiles, undisturbed samples were waxed or kept in Jar.

2.1.2. Field identification tests

Dilatancy, toughness, and dry strength tests were performed for identification on black cotton to differentiate silt and clay proportion. The methods of testing are:

a) Dilatancy (reaction to shaking) test:

A small pat of moist soil of about 5ml in volume is prepared. Water is added to make the soil soft but not sticky. The pat is placed in the open palm of one – hand and shaken horizontally, striking against the other hand several times during shaking. If the soil gives a positive reaction, the water appears on its surface which changes to a lively consistency and appears glossy. When the pat is squeezed between the fingers, the water and gloss disappear from the surface. It becomes stiff and ultimately crumbles.

The rapidity with which water appears on the surface during shaking and disappears during squeezing is used in the identification of fine-grained soils. The larger the size of the particles, the quicker is the reaction. The reaction is called "quickly" if water appears and disappears quickly. The reaction is termed "slow" if water appears and disappears slowly. For no reaction, the water does not appear at the surface.

b) Toughness test:

The pat used in the dilatancy test is dried by working and remoulding until it has the consistency of putty. The time required to dry the pat depends upon the plasticity of the soil. The pat is rolled on a smooth surface into threads of about 3mm in diameter. The thread is folded and re-rolled to reduce the water due to evaporation by heat of hand, until the 3mm diameter thread just crumbles.

The water content at that stage is equal to the plastic limit and the resistance to moulding at that stage is called the toughness.

After the thread crumbles, the pieces of the sample are lumped together and subjected to kneading until the lump also crumbles. The tougher the thread at the plastic limits and the stiffer the kneaded lump just before it crumbles, the higher is the toughness of the soil. The toughness is low if the thread is weak and the soil mass cannot be lumped together when drier than plastic limit. The toughness is high when the lump can be moulded drier than plastic limit and high pressure is required to roll the thread. The toughness depends upon the potency of the colloidal clay.

(c) ***Dry strength test:***

The pat of the soil is completely dried by air drying, sun drying or oven – drying. The dry strength is determined by breaking the dried pat and crumbing it between fingers. The dry strength is a measure of plasticity of the soil. The dry strength depends upon the colloidal fraction of the soil.

The strength is termed high if the dried pat cannot be powdered at all; medium, if considerable pressure is required; and low, if the dry pat can be easily powdered.

2.1.3. Laboratory testing

To evaluate the main index properties of the black cotton soil, the collected samples were tested in the Central Laboratory of Geological Survey of Ethiopia. The method of analysis is according to British system established in soils for civil engineering purposes (manual BS 1377: part 2: 1990. These laboratory data were analyzed and the results were presented in the form of graphs, charts and tables. The type of tests and test procedures for each test is discussed hereunder. However, the results are discussed in detail, in Chapter 5.

1. Particle size distribution
2. Specific gravity
3. Moisture content
4. Bulk density
5. Liquid limit
6. Plastic limit
7. Free swell

8. Linear Shrinkage

Determination of particle size

Particle size analyses were carried out according to the standard methods for wet sieving and sedimentation analysis given in BS 1377: Part 2: 1990. In almost all cases, the soils tested consists of over 98 % fines (material passing a 63µm sieve), and the procedures adopted were those specified for analysis of fine grained soils. This involved wet sieving of the soil samples through a 63µm sieve (after first applying appropriate dispersion procedures). The soil material remaining on the sieve was gently agitated by light finger pressure and rewashed from a wash bottle to ensure any aggregations were broken down. The final residue was re-sieved, by wet sieving, to establish the particle size distribution curve for material greater than 63µm. The material passing 63µm was transferred to a cylinder for sedimentation testing by the pipette method, in which the density of the soil suspension at various intervals was measured. Combined sieving and pipette procedures enables a continuous particle size distribution curve of the soil to be plotted from the size of the coarsest particle down to the clay size.

Specific gravity

Determination of specific gravity (particle density) was made using the British standard BS 1377 employing a pyknometer method. Specific gravity gives the intrinsic density of the solid phase of the soil sample, and is independent of (unbound) moisture content and voids.

Test procedures:

- Clean and dry the pyknometer and weigh to the nearest 0.001gm (m_1).
  - Take about 7 to10 gm of dry soil sample and put the soil specimen in the pyknometer.
  - Weigh soil sample + pyknometer (m_2).
  - Partial fill the pyknometer with distilled water.
  - Pump out air bubbles using vacuum pump for 20minutes.
  - Fill with water and weigh (pyknometer + water + sample) (m_3).
  - Empty the pyknometer and fill with water and weigh (m_4)

$$\text{Pure density} = \frac{(m_2 - m_1)}{(m_4 - m_2) - (m_3 - m_4)} \quad \text{…. (2.1)}$$

Where; m_1= is the mass of pyknometer

m_2=is the mass of pyknometer and dry soil (in g)

m_3=is the mass of pyknometer, soil and water (in g)

m_4=is the mass of pyknometer when full of water (in g)

Determination of density

In the BS 1377: part 2: 1990 standard -density is expressed in terms of mass density. The bulk density of a soil is the mass per unit volume of the soil deposit including any water it contains. The type of test is immersion in water method where the volume of the specimen is determined by weighing it submerged in water.

Procedure

- Take four representative intact lumps about 10gm each from block sample.
- Weigh the specimen to the nearest 1gm.
- Coat the specimen completely by repeated dipping in molten paraffin wax. Allow the waxed specimen to cool and weigh to the nearest 1gm. (paraffin coating is to avoid destruction of sample when the sample is immersed in the water for volume measurement)
- Weigh the waxed specimen while suspended in water to the nearest 1gm. (this enables volume of sample), then;

$$\text{Bulk density} = \frac{(m_2 x \rho_w) x \rho_{Par}}{(m_2 - m_3) - (m_2 - m_1)} \qquad \dots (2.2)$$

Where, m_1= natural sample weight

m_2 = sample covered with paraffin at air

m_3 = sample covered with paraffin under water

ρ_w = Density of water (1.0 g/cm^3)

ρ_{Par} = Density of paraffin (0.705 g/cm^3)

Determination of moisture content

Water is present in most naturally occurring soils. As described in British standard, the amount of water, expressed as a proportion by mass of the dry solid particles, known as the moisture (or water) content, has a profound effect on soil behaviours. In this context a soil is dry when no further water can be removed at a temperature not exceeding 110^{0}C. Moisture content is required as a guide to classification of natural soils and as a control criterion in recompacted soils and measured on samples used for most field and laboratory tests. The oven drying method is the definitive procedure used in the determination of moisture content.

In clay soils the clay minerals contain, or hold on to, water in several complex ways. For example, a layer of adsorbed' water of very small thickness is held on the surface of the clay particles by strong forces of electrical attraction. It cannot be removed by oven drying and is normally considered to be part of the solid soil grain. Water which is not so tightly bound, such as capillary water held by surface tension and gravitational water which can move in the voids or pores between the soil grains, can be removed by oven drying and generally by air-drying. Water which can be readily removed by oven drying is often referred to as 'free' water which is available to play a part in the engineering behaviour of the soil. In conventional soil testing, therefore, the moisture content relates only to the water which is removable by oven drying at 105 - 110^{0}C (BS 1377 Part 2 1990.

Test procedure

- Clean and dry the weighing bottle and weigh it to the nearest 0.001 g (m_1).
- Take a sample of 30 g of soil and place in the container.
- Weigh the container and contents to the nearest 0.001g (m_2).
- Place the container and contents in the oven and dry at **105^{0}C to 110^{0}C for 24 hrs.**
- After drying, remove the container and contents from oven and place the whole in the dissector to cool.
- Then weigh the container and contents to the nearest 0.001 g (m_3)
- Calculate the moisture content of the soil specimen, w, as a percentage of the dry soil mass, from the equation:

$$W= \frac{(m_2 - m_3)}{(m_3 - m_1)} x100\% \qquad \dots (2.3)$$

Where;

m_1 is the mass of container (in g),

m_2 is the mass of container and wet soil (in g),

m_1 is the mass of container and dry soil (in g),

Determination of liquid limit

The liquid limit is the empirically established moisture content at which a soil passes from liquid state to plastic state. It provides a means of classifying a soil, especially when the plastic limit is also known. Liquid limit test were carried out according to the British Standard method using the cone penetrometre. The method is based on the measurement of penetration in to the soil of a standard cone of specified mass, the liquid limit (LL) being equivalent to a cone penetration of 20mm.

Test procedures

- Take 200 g of remolded soil sample and prepare a paste of moist soil.
- Mix thoroughly with great care to avoid coarse particle.
- Take a weight of petridish.
- Push a portion of the mixed soil into the petridish or cup with palette knife taking care not to trap air.
- Put the Petri dish with paste in the cone penetrometre device.
- Adjust the cone pnetrometre to 0 reading.
- With the penetration cone locked in the raised position lower the supporting assembly so that the tip of the cone just touches the surface of the soil. Lower the stem of the dial gauge to contact the cone shaft and record the reading. Penetration range should be 150-245mm.
- If the reading is < 150 repeat the test by adding more water.
- Take about 10 g of soil paste and put it in oven for 24 hrs.
- Calculate the moisture content using equation (2.3).

Determination of plastic limit

Plastic limit is determined by hand rolling (BS 1377: part 2: 1990 :) a sample of remolded soil in to a thread, on a glass plate, until it began to crumble due to gradual drying. The plastic limit is the moisture content of the thread as it starts to crumble at a diameter of 3 mm.

Determination of free-swell test

Free swell test is an index test to determine the degree of swelling of clays.

Procedures:-

- Take 100 gm of air dried soil sample.
- Sieve (dry) in a 425μm sieve.

- Oven dries at 65^0c for 24 hrs.
- Put the sample in dissector and allow cooling at room temperature.
- Take 10ml in a graduated cylinder and add distilled water to 50 ml mark, mix and then add distilled water to 100 ml mark.
- After 24 hrs, read the volume of the swelled sample and then compute the degree of swelling (Sd), using the following formula,

$$d= \left(\frac{V_s x100}{V}\right) - 100 \qquad \ldots (2.4)$$

Where;

Sd= degree of swelling

Vs= volume of swelled sample in ml

V= volume of sample in ml

Determination of shrinkage (linear)

This method covers the determination of the linear shrinkage of the fraction of a soil sample passing a 425μm test sieve from measurement of a bar of soil.

Procedure:

- Place a sample of about 150gm from the material passing through the 425um test sieve, obtained as specified in liquid limit section on the flat, glass plate. The mass was smooth homogenous paste with a moisture content at about the LL of the soil (20mm cone penetration)
- Place the soil/water mixture in the mould
- Level the soil along the top of the mould with palette knife. The mold is 140mm long, 26mm wide.
- Air dry until the soil has shrunk away from the walls of the mould for 24hrs.
- Ovens dry at temperatures 105^0C for 24 hrs.
- Cool the mould and soil and measure the mean length of the soil bar. If the specimen crack badly - repeat test at slower drying rate
- Calculate the linear shrinkage of the soil as a percentage of the original length of the specimen, Lo (in mm) from the equation.

Percentage of linear shrinkage = $\left(\frac{1-L_o}{L_o}\right)x100$ … (2.5)

Where;

L_O is the length of the oven-dry specimen (in mm).

As mentioned earlier the methodologies and procedures employed during this study are not exhaustive but indicative to the major activities, which are described and discussed in detail in the foregoing section of this report.

3. General Overview of the Project Area

3.1. Physigraphy and drainage pattern

Ethiopia is broadly divided into three major physiographic regions, a) the western, highland, including the Ethiopian plateau, and associated lowlands(WHAL) b) the Eastern Highland and associated highland lowlands (EHAL) c) the Rift valley (RV) running North-South approximately, in the middle of the country and dividing the western from the eastern highlands(Adana Bekel, 1990). The highest elevation in the study area is Wechacha range, elevation 3385 m.a.s.l and lowest elevation is 2060 m.a.s.l. Figure 3.1 shows the general topography of the study area.

The study area lies in the North-western plateau along the South-western rift margin within upper Awash River basin which lies into two contrasted topographic components, namely the Ethiopian plateau and the Rift valley. The upper Awash river basin can be divided into four physiographic divisions based mainly on topography, climate, and geological features: 1) the high land areas 2) the central plain, 3) the rift floors 4) the escarpment area. Rainfall, vegetation cover, rock types and tectonics are the most important factors which control the drainage pattern and density in the upper Awash River basin and in each of these divisions. (Berhane Melaku, 1982)

The HighLand Areas: Highlands stand at an elevation higher than 2400 masl. They are cold and wet regions with a mean annual temperature of 15^0C and with annual rainfall in excess of 1800mm. The High Lands are densely populated and cultivated, mostly for cereal crops, Tef, Maize, and Wheat. They are underlain by Trap basalts and ignimbrites which are highly weathered. Non-cultivated areas are forested, mostly by eucalyptus trees.

The Central Plain: The Central Plain comprises a vast land of alluvium and ashy material in which a fine dendritic drainage pattern is developed. The Central Plain occupies the very central part of the basin as almost flat land, at elevations ranging from 2000 to 2300 m.a.s.l., with isolated volcanic hills. It is sparsely populated and largely deforested. The climate is warmer and dryer than in the High Lands with an annual rainfall of about 1050 mm.

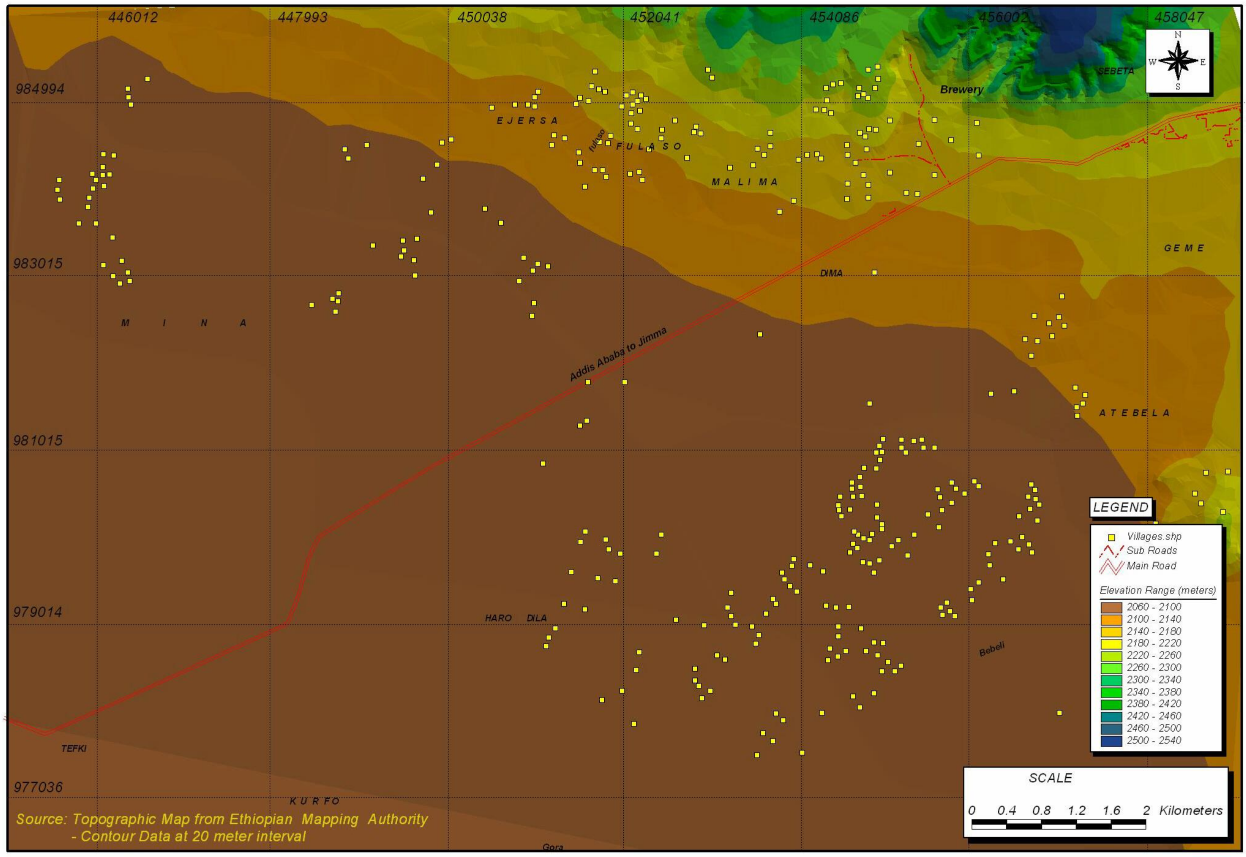

Figure 3- 1 The general topography of the study area

The Rift Floor: The Rift Floor is an extensive lacustrine plain and flat land area at elevations between 1600 and 1900 masl. The region is hot and dry with a mean annual air temperature of 21^0C and average rainfall of 934mm, and shows a pattern of low-density parallel drainage with shallow waterways. It is densely populated and completely deforested. Recent volcanic centres are abundant.

The Escarpment area: The Escarpment is an uplifted horst and graben structural region, underlain by hard basalt and ignimbritic rocks, which forms a narrow elongated strip of land trending in NE and SE direction, elevations ranges from 900 to 3000 masl. The region gets an annual rainfall of 980 mm and is scarcely forested. The drainage pattern on the escarpment areas is fine, parallel denderitic pattern.

The project area: is represented by high relief, volcanic mountain ranges separated by relatively wide basin/depression /tectonic and topographic features, which are filled with thick quaternary soil deposits derived from the surrounding highlands. The geology of the study area is consisting of rocks Tertiary to Quaternary age and recent soil deposits. The highest volcanic mountains are Mt. Wachacha 3385masl in North and the lowest 2060 masl in the depression at the extreme west.

Perennial and seasonal streams drain the volcanic hills and mountains. Most of the streams are truncated at the gentle to flat water logged areas which are constituted by thick alluvial soil deposits. The typical drainage pattern is parallel to sub parallel drainage density with inter-drainage spacing 500-600 m at 1: 50 000 topographic map.

3.2. Climate

The basic source of meteorological data for the present study is the National Meteorological Service Agency. For the present study meteorological data has been collected for 5 stations, namely, Addis Ababa Bole, Sebetta, Teji, Melka Kuntre, and Tulu Bolo. These data consists of monthly mean rainfall and temperature (mean max & min) (Table 3.1).

3.2.1. Rainfall

Sixteen years of record is available for rain fall in five stations. Table 3.2 shows the mean monthly rainfall data for stations, Addis Ababa (Bole), Sebeta, Teji, TuluBolo, and Melka Kunture. Figure 3.2 indicates rainfall pattern of the same stations. According to the data the mean annual rainfall in the area is 1292.3 mm at Sebetta station.

Sir/No	Region	Station	Class*	Years of record
1	Region 14	Addis Ababa Bole	Class 1	1989 - 2004
2	Oromiya	Sebetta	Class 3	1989 - 2004
3	Oromiya	Teji	Class 3	1989 - 2004
4	Oromiya	Melka Kunture	Class 3	1986 - 2003
5	Oromiya	Tulubolo	Class 3	1989 - 2004
Class* Class 1- Complete Record, Class 3 – Partial data recorded				

Table 3- 1 Hydro meteorological stations and years of record

The rainfall Vs time graph, (Fig. 3.2) indicates that rainfall is concentrated in the months of June to August and which are the rainy months. November to January is dry months. The highest rainfall (296.3 mm) and the lowest rainfall (7.2 mm) occur in August and November, respectively as recorded in the Sebetta station. The mean annual rainfall (16 years record) for the nearby Sebeta station is 1292 mm.

Month/St.	Addis Ababa	Sebet a	Teji	Tulu Bolo	Melka Kunture
Jan	13.4	17.4	17.2	12.7	18.5
Feb	32.1	51.4	36.9	12.3	64.4
Mar	62.3	69.9	53.5	45.0	59.3
Apr	87.9	102.4	78.7	67.8	46.1
May	62.5	89.3	57.4	74.6	30.9
Jun	123.3	147.6	120.4	249.9	19.9
Jul	243.1	296.3	217.4	292.5	95.3
Aug	254.7	327.7	218.0	299.8	113.5
Sept	130.8	142.6	89.2	105.8	37.3
Oct	36.7	30.9	23.4	12.6	19.8
Nov	2.5	7.2	6.6	4.8	9.9
Dec	6.4	9.3	7.8	5.7	12.0

Table 3- 2 Mean monthly rainfall in mm ranging from 1989-2004

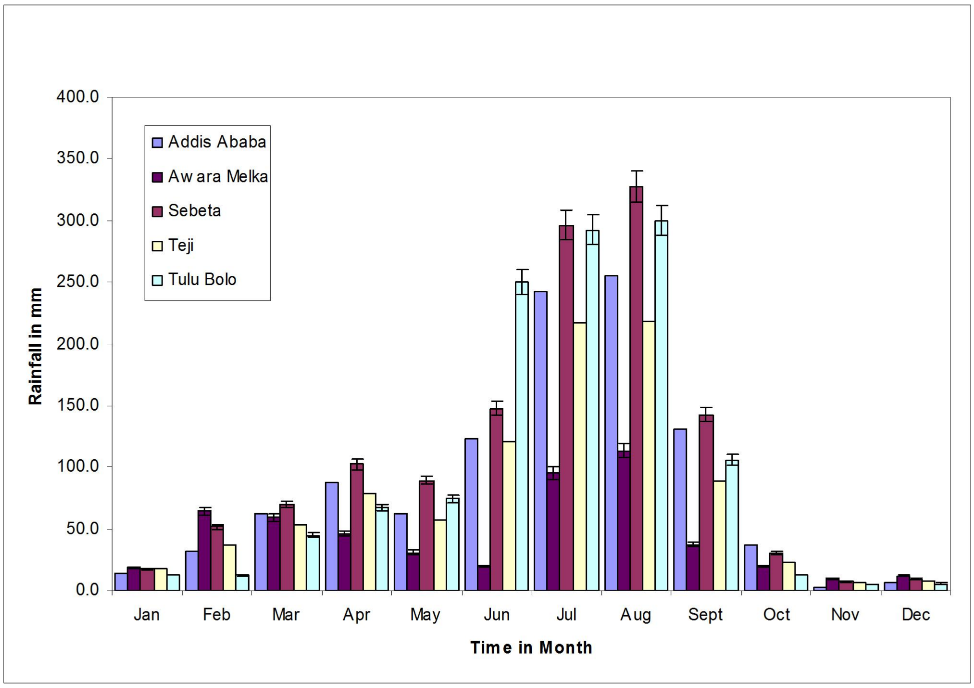

Figure 3- 2 Mean monthly rainfall Vs time graph (1989-2004)

Based on rainfall pattern three seasons namely Bega, Belge and Kiremt (Tesfaye, 1986, Worknhe, 1997) can be assigned. Brief description of the three seasons is given below.

Bega:- This is generally the dry season that covers the period from October to January. However there is occasionally untimely rain.

Belge:- Refers to small rain season that covers the period from mid - February to mid - May. However, the rainfall is highly characterized by inter – annual and inter - seasonal variations.

Kiremt:- This refers to the main rain season that covers the period from June to September

3.2.2. Temperature

Mean maximum temperature and mean minimum temperature data for two stations, Addis Ababa and Tulu Bolo for (1989 - 2004) are indicated in table 3.3 from which average monthly temperature was computed. March, April and May are the warmest months. The highest average temperatures are observed during theses months. The recorded data from Addis Ababa Bole station shows that the lowest temperature (15^0c) occurs in August while the maximum temperature (18^0c) occurs during the month of March to May. The average annual temperature recorded in Addis Ababa for 16 years is 11.4^0C.

Mon/St.	Addis Ababa	Tulu Bolo
Jan	15.8	16.7
Feb	16.8	16.9
Mar	18.0	17.5
Apr	18.2	17.7
May	18.4	17.7
Jun	17.2	17.3
Jul	16.2	16.8
Aug	16.2	16.8
Sept	16.1	16.7
Oct	15.8	16.7
Nov	14.7	16.3
Dec	15.0	16.2

Table 3- 3 Average monthly Temperature

Figure 3.2 shows average monthly temperature of the two stations namely Addis Ababa and Tulu Bolo. According to this graph variation of average monthly temperature is small, and almost it is uniform.

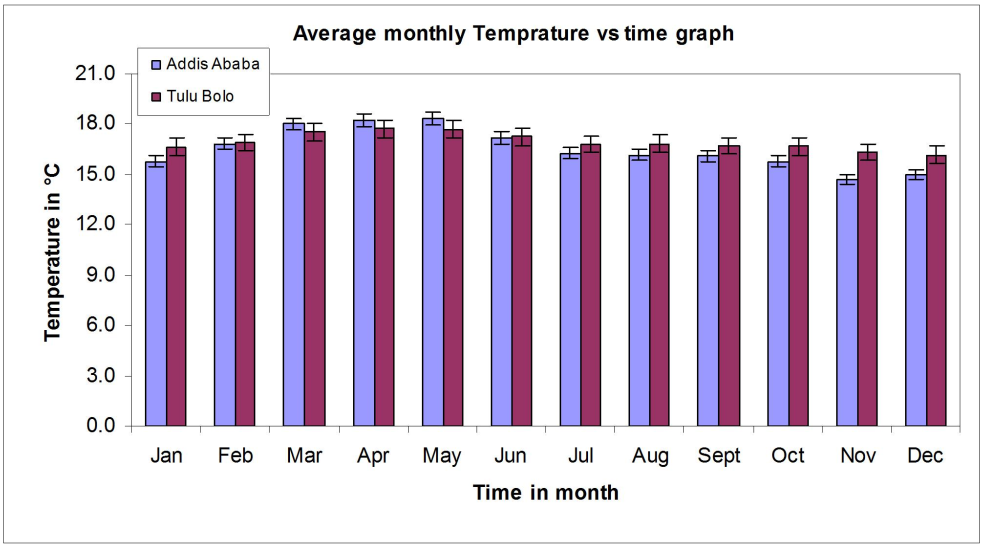

Figure 3- 3 Average monthly temperature Vs time graph

3.3. Landuse/Landcover

In the study area the land use activities were governed by topography and soil. The gentle sloping, well drained areas are preferred for settlement and agriculture. The main agricultural products are Tef, Maize, Barely and Lentils etc. The low lying water logged areas, where black cotton soil occurs are preferred for cultivation of lentils. The high relief, mountains and steep slopes are either constituted by grass land or occasionally with thick natural forest. Soil profile in such areas is thin or absent as a result, land use activities are non existent.

3.4. Regional geology

The regional geological history of is characterized by as a series of formation and events from early Tertiary to Quaternary era. Following uplift, the earliest and most extensive group of volcanic rocks: the Trap series erupted from fissures during the early and middle Tertiary. Substantial shield volcanoes consisting of mainly basalt lava developed on both of Somalia and Ethiopian plateau during Miocene and Pliocene. In the southern and central part of Ethiopia, including the Rift valley, a succession of pantelleritic rhyolites, trachytes, and ignimbrites with subordinate intermediate and basic rocks, Pliocene to Recent, were erupted along the seismically active Wonji fault (Mohr 1967).

According to Kazmin et al (1987), the regional stratigraphy incorporating the study area range in age from Upper Miocene to Holocene. The regional geology of the area is indicated in Fig. 4.1 and the stratigraphic units are:

Pleistocene-Holocene

Al: Fine to medium grained alluvial deposits, incorporated with soft ash material.

Pliocene-Pleistocene

N2Qtb: Bishoftu basalt, basalt and trachytic lava flows (2-2.8m.y)

N2C: Alkaline basalts, trachytes and peralkaline rhyolitic ignimbrites undifferentiated.

N1!-2n: Stratoid silicics, ignimbrites, unwelded tuffs, ash-flows, rhyolites and trachytes.

N1g: Arba Gugu basalts of Araba Gugu & other shield volcanics (8-7 m.y)

3.5. Tectonics

The Tertiary-Quaternary system known as the East African system is one of the largest structural features of the earth crust extending for a distance from Mozambique to Syria. The East African system is most typically developed in the section as the main Ethiopian Rift (Mohr, 1964), which extends from lake Chamo in the south to Afar in the north. The main Ethiopia rift is divided into two positions, 1) The southern portion, which includes the area south of the main watershed between the Awash River and Lake Ziway, and 2) the northern portion, which include the area north of the watershed merging in to Afar. The main Ethiopian Rift is characterized by NE-SW, and ENE-WSW trending normal faults. In the whole of the Main Ethiopian Rift no thrust faulting, even of a minor nature, has been observed (Mohr 1964). According to the previous studies in and around the project area lineaments (faults) are predominantly trending NE-SW with dip towards NW and SE, respectively. Apart from faults fractures and joints with varying magnitude were reported, mainly in competent volcanic rocks.

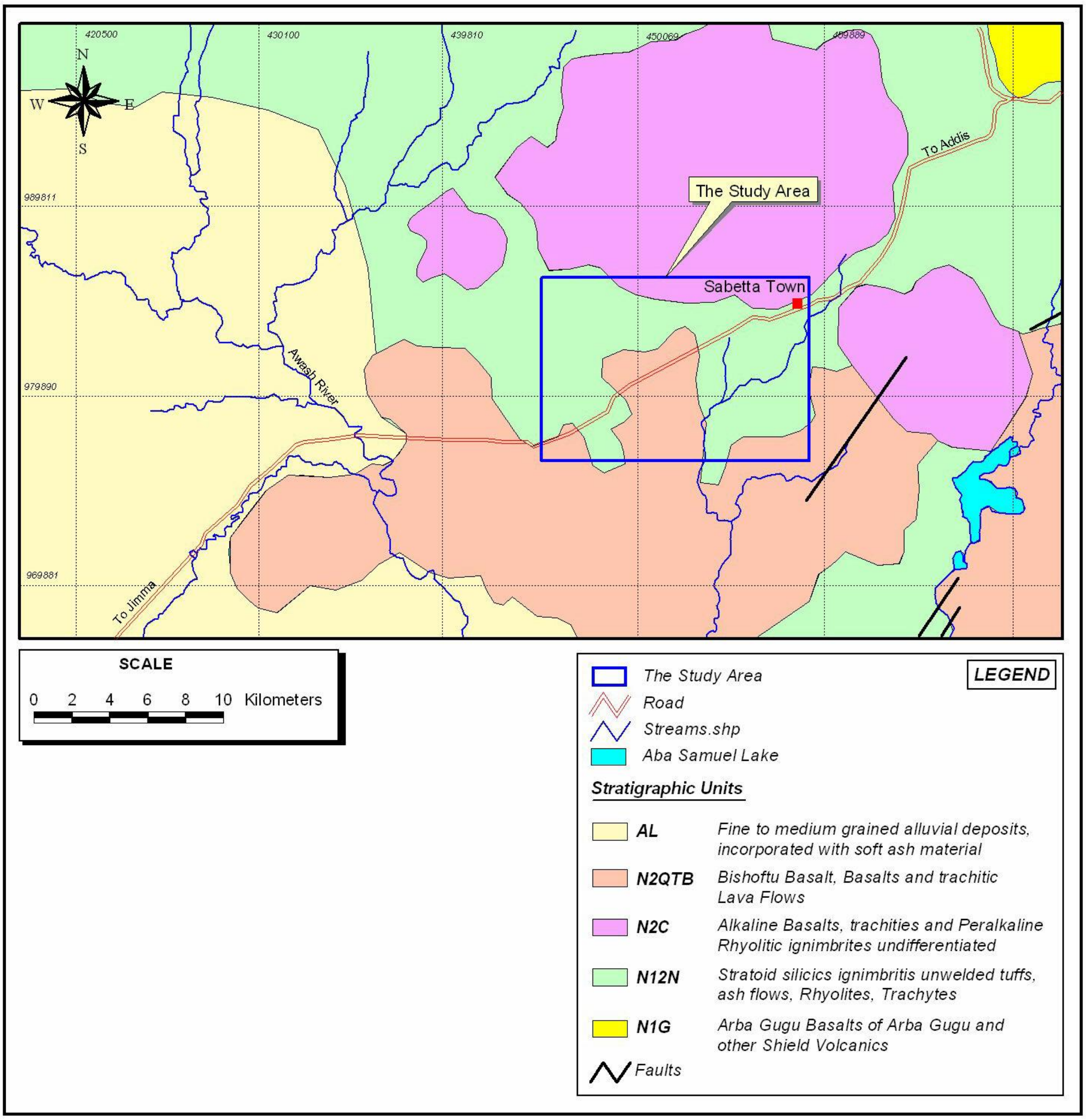

Figure 3- 4 Generalized geological map of the area

3.6. Geomorphology

Uplifting, rifting and volcanism are followed by intense denudational processes (erosion, transportation and sedimentation) which are responsible for present landforms. The study area can be divided in various landforms on the basis of Tertiary volcanism as well as Quaternary to recent sedimentation. The Mountain chains which includes Mt. Wachacha and Mt.Furi has a general EW trend separating the wide alluvial plain region, known as inter–mountain depression/basin.

They are high relief mountains (up to 3385 masl), dissected and have narrow crests, constituted by lavas and pyroclastics of basic to intermediate composition. The landforms on Quaternary sediments are colluvio-alluvial sedimentation along the mountains region, extensive alluvial plain, and river bed deposits.

The regional landform development has an important bearing on the local geomorphological conditions of the study area. In view of such broad geomorphic events, it is possible to classify the landforms of the study area genetically as follows:

a) Denudational: High relief, steep to moderately steep slopes, dissected, mountains of Wachacha and Furi. **b) Fluvial:** low lying, flat, less dissected, alluvial plain.

The geomorphologic conditions favours the formation and development of black cotton soil which is eroded, from the surrounding high relief mountains and transported and deposited at the low lying, flat or basin like morphology. High velocity controlled and uncontrolled flow from the elevated area reaches the lower depression and part of it further goes as run off, part of it stagnant for several months during rainy seasons. Evidence for such condition is the prevailing marshy or water logged areas with typical flat/basin like morphology.
The processes of formation of black cotton soil of the area can be explained as:

a) Weathering, transportation, of materials from surrounding volcanic mountains and
b) Deposition at the low lying depressions.

3.7. Soil

FAO (1965) Survey report on Awash river basin, has indicated the agricultural or pedological classification of the soils for the entire Awash basin and sub basins. The survey, which was carried out with the objective of classifying, the suitability of land for agriculture, particularly in terms of potentially irrigable soils. The generalized soil map (Figure 4.2) shows the major and minor soil groups of the study area and its surroundings. The descriptions of the regional classification of main soil types are as follows.

Soils are classified in groups, sub-groups, series and phases. Classification criteria are established from the soil profiles; in other words, form the different horizons resulting from different types of parent rock, topographical features, climate, the effect of floods, biological factors (plants, animals, human), and the time they develop. Soil classification is a delicate matter, if only because of the seemingly endless soil profile variations, especially in alluvial ground. It is often possible, however, to establish an average profile for a given area, from which the other profiles differ insignificantly.

From this synthesis follows the “soil series” notion. It is an elementary classification unit covering an area of a certain size in which all the profiles can be associated with the “typical profile” for the series. This profile is “typical” for its average features of colour, texture, structure, pH, organic matter, salinity and/or alkalinity.

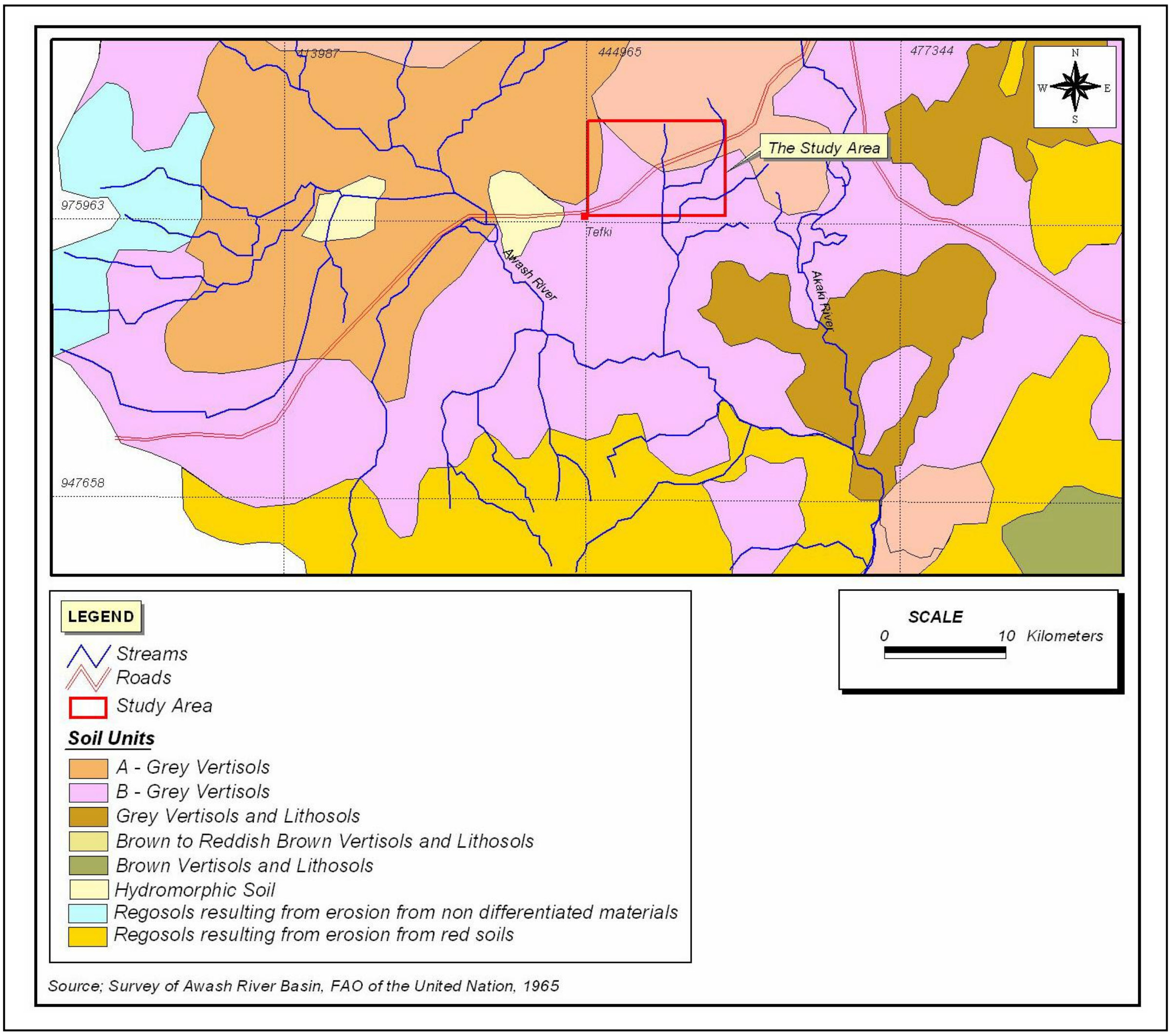

Figure 3- 5 Generalized soil map

Most soil series include several phases, which depend on main land use factors, such as:

- Water logging by overflowing rivers or where runoff collects.

- "Micro relief", of which one pronounced form, occurs where old channels still exist.
- Gravel, or medium-textured horizons deep down, which act to assist drainage.
- Soil depth and type of subsoil.

According to the study all the soil series have been arranged within a more general framework comprising groups and sub-groups. They differ mainly in their types of parent rock.

The overall classification and soil mapping units applicable to whole basin, features nine major soil groups which are discussed below;

Vertisols: which are distinctive by their dark colour and the fact that they contain swelling clay. They can be differentiated as:

Very slightly or non-calcareous grey vertisols (A- Grey Vertisols)**:** containing large amounts of clay, with a pH of nearly 7 and often pronounced *self mulching properties, giving a loose granular surface,-followed deeper down by prismatic structures with wide shrinkage cracks and silken sides when dry with an underlying massive structures. The slickensides indicate mass movements each time it is wetted. The clay component is a mixture of illite (often the predominant constituent) and montmorillonite. They have a high exchange capacity (over 50 meq/100g dry soil, contain up to 4% organic matter. They occur in the Upper Basin of the Awash on alluvia materials weathered from basalt, also on the very slightly or non-calcareous alluvia in the Middle Valley.

Grey vertisols on calcareous alluvia (B- Grey Vertisols): these have a higher pH and show slight saline or alkaline tendencies. They are found in deeper horizons, more especially in the Lower Plains.

Brown and reddish-brown vertisols**:** with a pH slightly exceeding 7 and containing less clay. Their organic matter content is less than 3 %. Base exchange capacity is around 50 meq for 100 g of soil. These soils occur on hillsides in the upper basin, generally over volcanic material; i.e., tuff and pumice.

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* Self-mulching refers to the tendency of many types of clay to form loose granular surface mulch as a result of wetting and drying. If the granules are destroyed by ploughing when wet, they reform, usually on a single drying.

The reddish-brown soils show more pronounced evidence of pedogenetic evolution. In addition to illite and montmorillonite, they are also apt to contain hematite and kaolinite. They occur in the more humid climate zones (region between Debre Sina and Dese).

Semi – arid brown soils: which have formed in the arid to sub-arid climate zone from alluvia frequently mixed with volcanic materials. Though they are generally calcareous, the lime is apt to migrate in concretion form. Organic matter content varies between 2% and 3%.

Saline and saline alkali soils: typified by horizons containing up to 0.6% salts. These are generally calcareous with a pH invariably exceeding 8 and liable to rise to 9 or 10 in very alkaline soil. They frequently contain gypsum, and also occasional salt crusts in certain regions featuring a deep saline water table. Exchangeable sodium exceeds 20 % in alkali soils. Organic matter content is low, usually less than 1 %. These soils mostly occur over older alluvia and colluvia in the lower plains.

Hydromorphic soils: in badly drained areas or along the edges of marshland. These are dark soils containing large quantities of organic matter. The following differentiation is made in terms of pH:

Hydromorphic soils with pH about 5 in badly drained areas on the high plateaus. These contain a high proportion of organic matter (4% - 12%). They are rich in clay, but their complex is far from saturation.

More or less calcareous hydromorphic soils with a pH of over 7. These are found in the Awash valley, especially in the Lower Plains and in certain depressions in the Upper Basin. They generally contain a lot of organic matter.

Organic soils in permanent marshland (lower plains).

Erosion regosols: These are in the arid to semi-arid area over semi-arid brown soils formed from various types of parent rock, including alluvia and weathered material from volcanic rock. They are often in association with brown vertisols in areas bordering the Upper Basin, in which they have also developed locally from slightly ferralitic red soils. Where they have developed over old saline clayey alluvium, they form the type of complex referred to as "badlands", covering large areas between the Middle Valley and Lower Plains.

Lithosols on volcanic rock, frequently in association with grey vertisols in the Upper Basin.

4. Literature Review

The study thoroughly reviewed and critically analysed previous studies and literatures particularly those regarding the characteristics of black cotton soils in general and specific to the study area.

4.1. Black cotton soil

A large amount of information regarding the black cotton soil, in the form of secondary and tertiary data were collected and reviewed during the study. Amongst the most important the following has been studied to a variable degree.

The study carried out by (Lyon Associates, 1968) presented data regarding the later tic soil and poor soils such as black cotton soils of African countries including Ethiopia. For the present study, this data particularly on the black cotton soil of the tropical areas (Africa/Ethiopia) is found important and relevant to the subject and the main findings regarding definition, occurrence, and characteristics of black cotton soil are presented in the following paragraphs.

According to Lyon Associates, tropical black clays, often called black cotton soils, are the major problem soils of the world. They are poor materials to employ for highways, airfields and other construction because they contain a large percentage of plastic clay and are often expansive, swelling as water is absorbed. In many areas where these soils occur, they are not suitable natural gravels or aggregates. Most deposits cover sufficiently large areas that avoiding or bypassing them are not feasible. Few roads constructed through these soils have proved satisfactory. Many have failed completely.

Most of the tropical black clays are formed residually by weathering of basic rocks such as basalts. Alluvial deposits also occur, but much restricted in size. The Lake Chad Basin is the only extensive lacustrine deposit of black clay soils in Africa.

4.1.1. Definition

The term black cotton soil “a soil is believed to have originated in India where the location of such soils is favourable for growing cotton. Many other terms have been applied locally such as “regur” soils in India, “margalitic” soils in Indonesia, “black turfs” in Africa, and “tirs” in Morocco.

Bal (1935, p.261) proposed the following definition: " soils derived from weathering of trap rocks, in particular, which are black, heavy, and climatologically suited to the growth of cotton, are known as black cotton, or regur soils."

More recently, Dudal (1965) has adopted the more descriptive term dark clay soils. This seems preferable to most other pedological terms. The terms tropical black clay soils, and black clay soils and black cotton soil are used more or less interchangeably in several reports and countries. Although the first term is preferred, black cotton soil is retained because of its extensive occurrence in the literature and because it is widely used in many parts of the continents.

An appropriate engineering definition for tropical black clays is dark grey to black soils with high content of clay, usually over 50%, in which montmorillonite is the principal clay mineral and which are expansive . The main characteristics common among most tropical black clays are high clay content dark color, tendency to expand and shrink with changes in moisture, and appreciable plasticity in the clay fraction. It should be emphasized that expansion occurs only when the black clays are subjected to an increase in moisture content. If they are maintained in either a desiccated or a saturated condition, expansion cannot occur. Unfortunately construction activities often at least modify the moisture content. In such modification lies the problem with the black cotton soil, as with all expansive soils. Designs must allow for expansion due to increasing moisture content, or else the change in moisture must be controlled in some manner.

4.1.2. Occurrences

G.W. Donaldson, (1963) classified the parent materials that can be associated with expansive soil into two categories. The first group comprises the basic igneous rocks, such as the basalt of Deccan plateau in India, the dolerite sills and dyke in the central region of South Africa and the gabbros and norites West of Pretoria North, Transvaal. In these soils the feldspar and pyroxene minerals of the parent rocks have decomposed to form montmorillonite minerals.

The second group comprises the sedimentary rocks that contain montmorillonite as a constituent, which breaks down physically to form expansive soils

Australian occurrences have been described by Hosking (1935) and others. Hosking found that climate was important in development of soil types, and that in area where red soils could be expected under the prevailing climate, black clays would develop if the drainage were poor. Hallsworth concluded that soil color is associated with leaching dark soils are less subjected to the leaching process.

Black clay soils in Africa have received considerable attention. Black soils over basalt and dolerites in Basutoland have been examined by Pollard (1964). Kenyan black cotton soil has been investigated by Dumbleton (1963). Morin and Parry (1969) have described the black clays of Ethiopia formed over basalts of the Ethiopian and Somalia plateaus. According to Dudal (1965) the estimated coverage dark clays soils in Ethiopia in the Rift valley and Ethiopian plateau is 24.7 %. Stephen (1953) believes that the soils derived from Precambrian hornblende-garnet gneiss in Ghana are typical black cotton soils.

4.1.3. Environment and formation of tropical clay

Black cotton soil contains predominately consists of montmorillonite. The formation of montmorillonite will be discussed in detail. Lyon, (1968) pointed out that the setting for the formation of montmorillonite is extreme disintegration, strong hydration, and restricted leaching. The situation in which montmorillonite can form, require leaching be restricted, so that magnesium, calcium, sodium, and iron cations may accumulate in the system. Thus, the formation of montmorillonite mineral is aided by alkaline environment presence of magnesium ions, and a lack of leaching. Such conditions are favourable in semi-arid regions with low rainfall or highly seasonal moderate rainfall, particularly where evaporation exceeds precipitation. Under this condition, enough water is available for the alteration processes, but the accumulated cations will not be removed by flush rain. However, Claus (1976) concluded that montmorillonite seems to form only where an initially alkaline environment changes gradually in a slight acid environment because such a condition favours the mobilization of iron, magnesium, silica, and aluminium and removal of iron. The parent minerals for the formation of montmorillonite often consist of ferromagnesian minerals, calcic feldspar, volcanic glass, and many volcanic rocks.

Expansive soils are hydrate of aluminium, iron or magnesium silicate generally combined in such a manner as to create sheet like structures only a few molecules thick. These sheets are built from two basic units, the tetrahedral unit of silica and the octahedral unit of hydroxide of aluminium, iron or magnesium**.** The main diameters of the particles are usually less than 0.002 mm and the different types of the minerals have been created from the manner in which these structures were stacked together. Soils type differs both spatially and temporally. This is due to such factors as climate, parent material, topography, vegetation and human activity influencing the weathering of the parent material and the soil itself. Basically, the parent material has an important role in determining the nature of the soils. In Ethiopia, most of the soils have volcanic rock as the parent material, with only few soils having sedimentary parent material.

The studies undertaken by X-ray diffraction analysis and laboratory testing on selected samples in the highlands of Ethiopia indicate that montmorillonite; kaolinite and halloysite are abundant in Ethiopian volcanic soils (Lyon Associate, INC, 1968). Similarly, Morin and Parry, found halloysite as well as kaolinite in Ethiopian black clays. Thus the principal clay minerals of black cotton soil are montmorillonite, kaolinite and halloysite. The parent rock will be either basalt or a trachyte. Partial chemical analysis shows that the black clays have an average of 42% silica, 13% total iron 26% aluminium. The PH of the clay fluctuates between 7.2-8.4. The principal cations attached to the clay molecules are calcium, magnesium and potassium. The most expansive soils in Ethiopia are concentrated in areas where drainage is poor with low to moderate rainfall (Mekonen Tsegaw, 2003).

4.1.4. Clay mineralogy and structure

Understanding of the type of clay mineral and structure is important because most significant properties and behaviour of clay depend upon the type of clay mineral and its structure. Clay is normally understood to mean a clay soil whose grains are predominantly composed of clay minerals and which has plasticity and cohesion.

Clay minerals

Most soil classification systems arbitrarily define clay particles as having an effective diameter of two microns (0.002 mm) or less. Particle size alone does not determine clay mineral. Probably the most important grain property of fine-grained soils is the mineralogical composition. For small size particles, the electrical forces acting on the surface of the particle are much greater than the gravitational force. These particles are said to be in the colloidal state. The colloidal particle consists primarily of clay minerals that were derived from parent rock by weathering.

The three most important groups of clay minerals are montmorillonite, illite, and kaolinite, which are crystalline hydrous aluminosilicates. Montmorillonite is the clay mineral that presents most of the expansive soil problems.The name “montmorillonite” is used currently both as a group name for all clay minerals with an expanding lattice, except vermiculite, and also as a specific mineral name.

Absorption of water by clays leads to expansion. From the mineralogical standpoint, the magnitude of expansion depends upon the kind and amount of clay minerals present, their exchangeable ions, electrolyte content of aqueous phase, and the internal structure.

Montmorillonite clay

Montmorillonite minerals form weak bondage between each other and an excellent cleavage between them. As a result, soil containing considerable amount of Montmorillonite minerals exhibit high swelling and shrinkage characteristics.

Montmorillonite is the most common of the group of minerals. Structural arrangement of this mineral is composed of units made of two silica tetrahedral sheets with a central octahedral alumina sheet. The silica and gibbsite sheets are combined in such a way that the tips of the tetrahedrons of each silica sheet and one of the hydroxyl layers of the octahedral sheet form a common layer. The atoms common to both the silica and gibbsite layers become oxygen instead of hydroxyls. The thickness of the silica – gibbsite-silica unit is about 1 A^0 in stacking of these combined units one above the other, oxygen layers of each unit are adjacent to oxygen of the neighbouring units, with a consequence that there is a weak bond (mainly due to Vander waal's forces) and an excellent cleavage between them. Water can enter between the sheets causing them to expand significantly and thus structure can break into 10 A^0 thick structural units. The lateral dimensions of montmorillonite particles ranges from 1000 to 5000 A^0 with thickness varying from 10 to 50 A^0. Bentonite clay and Black cotton soil belong to the montmorillonite group

Partial isomorphic substitution such as Al^{3+} for Si^{4+} in the tetrahedral and Mg^{2+}, Fe^{2+}, Li^+ or Zn^+ for Al^{+3} in the octahedral sheets also take place resulting a relatively large net negative charge deficiency.

Both these factors mean that water and other exchangeable ions can easily enter between the layers causing the layer to be separated. Because of this affinity for water, clay soils containing montmorillonite mineral are susceptible to substantial volume changes. They swell as the water gets entered into the lattice structure and shrink if the water is removed because of the same reason. In a moist state, montmorillonite is highly plastic and has little internal friction. Its excessive swelling capacity may seriously endanger the stability of overlying structures and road pavements (Chen 1975).

Cations exchange

Clay minerals have the property of sorbing certain anions and cations and retaining them in an exchangeable state. The exchangeable ions are held around the outside of the silica-alumina clay-mineral structural unit, and the exchange reaction does not affect the structure of the silica-alumina pocket. In clay minerals, the most common exchangeable cations are Ca^{++}, Mg^{++}, H^+, K^+, NH_4^+, Na^+, frequently in about that order of general relative abundance.

The existence of such charges is indicated by the ability of clay to absorb ions from the solution. Cations (positive ions) are more readily absorbed than anions (negative ions); hence, negative charges must be predominant on the clay surface. A cation, such as Na^+, is readily attracted from a salt solution and attached to a clay surface. However, the absorbed Na^+ ion is not permanently attached; it can be replaced by K^+ ions if the clay is placed in a solution of potassium chloride KCL. The process of replacement by excess cations is called cation exchange (Chen 1975).

The cation exchange capacity is the charge or electrical attraction for cation per unit mass as measured in milliequivalent per 100 grams of soil. The cation exchange capacity of different types of clay minerals may be measured by washing a sample of each with a solution of a salt such as ammonium chloride NH_4CL and the amount of adsorbed NH_4^+ by measuring the difference between the original and the final concentration of the washing solution.

Typical ranges of cation exchange capacities of various clay minerals are shown in table 4.1. From table 4.1, it is seen that montmorillonites are 10 times as active in absorbing cations as kaolinites. This is caused by the large net negative charge carried by the montmorillonite particle and its greater specific surface as compared with kaolinite and illite.

Certain relationships exist between soil properties such as Atterberg limits, the type of clay mineral, and the nature of the adsorbed ion. Table 4.1 indicates the liquid limit and the plasticity index of each group of clay minerals. From, tables 4. 1 and 4. 2, it is seen that the cation exchange capacity of clay has definite relation with the Atterberg limits. The greater the cation exchange capacity of clay, the greater the effect of changing the adsorbed cation.

	Kaolinite	**illite**	**montmorillonite**
Particle thickness	0.5-2μ	0.003-0.1μ	<9.5A
Particle diameter	0.5-4μ	0.5-10μ	0.05-10μ
Specific surface (sq.meter/gram)	10-20	65-180	50-840
Cation exchange capacity (mill equivalent per 100 g)	3-15	10-40	70-80

Table 4- 1 Ranges of cation exchange capacities of various clay minerals (Chen, 1975).

	Na^+		**K^+**		**Ca^{++}**		**Mg^{++}**	
Cation	**Liquid limit, percent**	**Plasticity index, percent**	**Liquid limit, percent**	**Plasticity index, percent**	**Liquid limit, percent**	**Plasticity index, percent**	**Liquid limit, percent**	**Plasticity index, percent**
Clay mineral								
Kaolinite	29	1	35	7	34	8	39	11

Illite	61	27	81	38	90	50	83	44
Montmorillonite	344	251	161	104	166	101	158	99

Table 4- 2 Atterberg limit values of clay minerals with various adsorbed cations (Chen, 1975)

4.1.5. Clay structures

Aurora, (2001) pointed out that clay minerals are composed of two basic structural units: These are the silica tetrahedron and alumina octahedron. The silica tetrahedron consists of a silicon atom surrounded tetrahedrally by four oxygen ions as shown on [Fig.4. 3(a)]. The alumina octahedron consists of an aluminium atom surrounded octahedrally by six oxygen ions as shown on [Fig.4. 4(c)]. When each oxygen atom is shared by two tetrahedral, a plate – shaped layer is formed [Fig.4. 3(b)]. Similarly, when each aluminium atom is shared by two octahedron, a sheet is formed. [Fig.4. 4(d)]. All the figures in clay structures were taken from Mekonen Tsegaw, (2003).

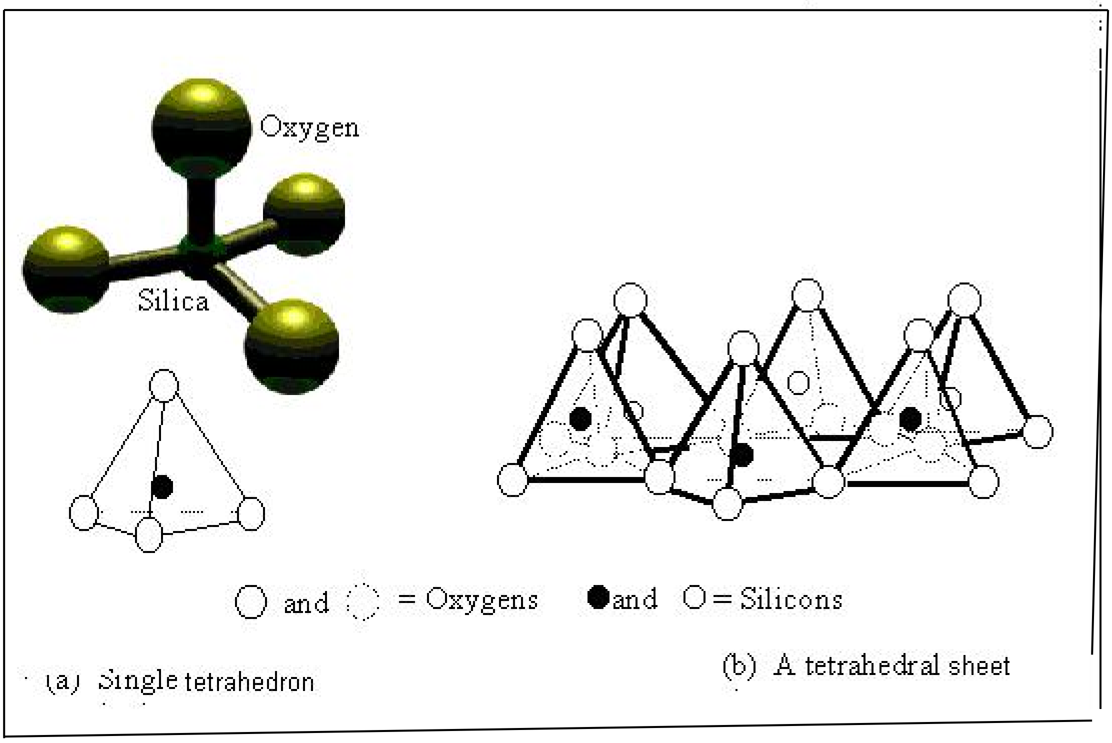

Figure 4- 1 The structural unit of the silicates

The silica sheets and the alumina sheets combine to form the basic structural units of the clay particle. Various clay minerals differ in the stacking configuration.

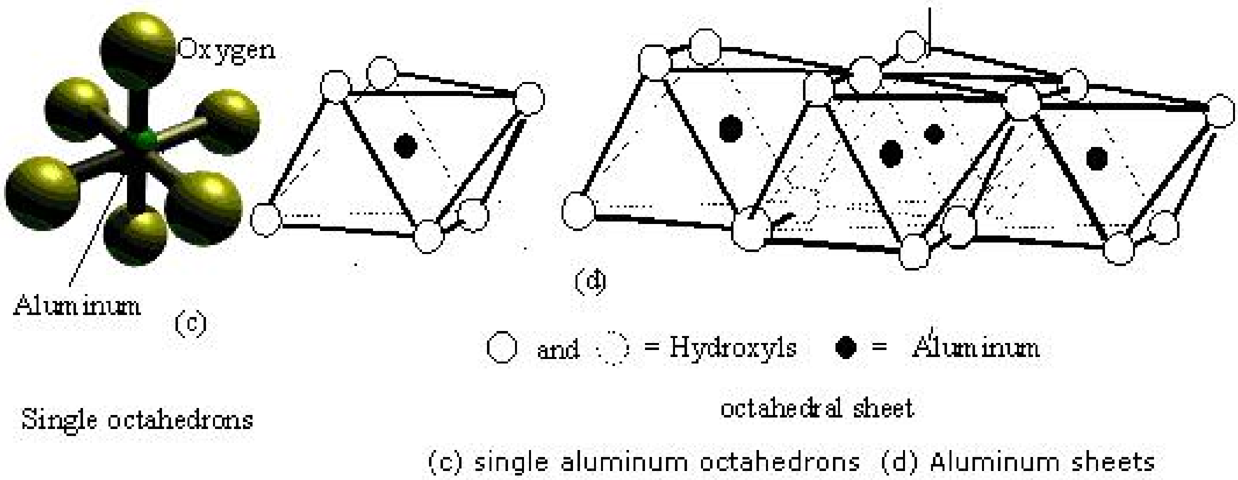

Figure 4- 2 Single aluminium octahedrons and aluminium sheets

The results of studies using the electron microscope and X-ray diffraction techniques show that the clay minerals have a lattice structure in which the atoms are arranged in several sheets, similar to the pages of a book. The arrangement and the chemical composition of these sheets determine the type of clay mineral. The basic building blocks of the clay minerals are the silica tetrahedron and the alumina octahedron. The blocks combine into tetrahedral and octahedral sheets to produce the various types of clays.

Kaolinite is a typical two – layer mineral having a single tetrahedral sheet joined by a single octahedral sheet to form what is called a 2 to1 lattice structure [Fig.4.5 (a)].

Montmorillonite is a three-layer mineral having a single octahedral sheet sandwiched between two tetrahedral sheets to give a 2 to 1 lattice structure as shown on [Fig.4.5 (c)].

Illite has similar structure with that of montmorillonite, but some of the silicon atoms are replaced by aluminium, and, in addition, potassium ions are present between the tetrahedral sheet and adjacent crystals [Fig.4.5 (b)].

In the clay-water –air system, the water within the clay is called adsorbed water, the water and ions with the clay lattice constitute the diffuse double layer (Fig.4.5).

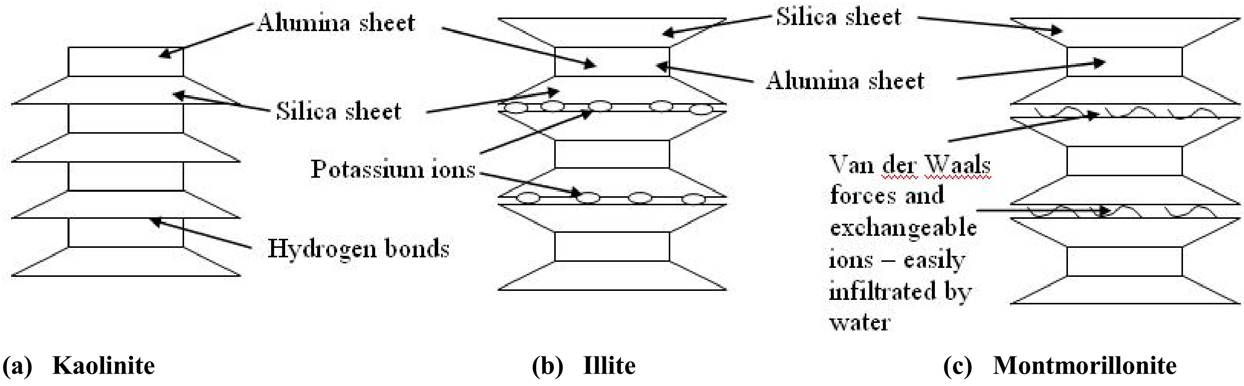

Figure 4- 3 The structure of the main clay types

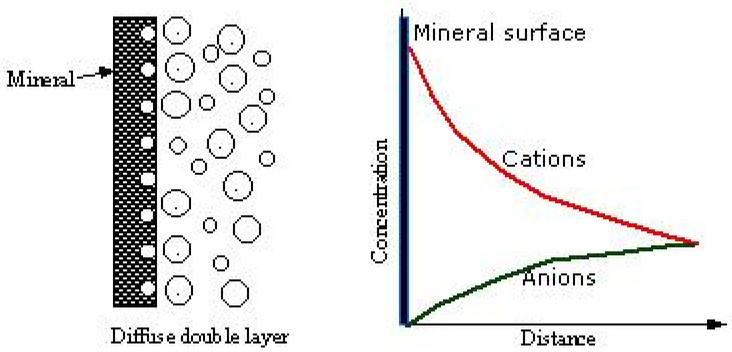

Figure 4- 4 The double layer (after Das, 1997)

The Atterberg limits are a good indicator of the expansiveness potential of a soil. Most expansive soils can exist in a plastic condition over a wide range of moisture contents. This is due to the clay mineral ability to contain large amounts of water between the clay particles.

4.1.6. Identification and classification of swelling soil

Filed identification tests namely dry strength, toughness and dilatancy were employed to the black cotton soil is classified using following table.

Test.	ML	CL	OL	MI	CI	OI	MH	CH	OH
(a) Dilatancy	Quick	None to very slow	Slow	Quick to slow	None	Slow	Slow to none	None	None very slow
(b) Toughness	None	Medium	Low	None	Medium	Low	Low to medium	High	Low to medium
(c) Dry strength	None of low	Medium	Low	Low	Medium to high	Low to medium	Low to medium	High to very high	Medium to high

Table 4- 3Field identification tests (ARORA, 2000

Generally, there are three methods of identifying swelling soils (Chen, 1975). They are as follows:

- Mineralogical identification.
- Indirect methods.
- Direct methods.

The mineralogical composition of expansive soil has an important bearing on the swelling potential. The negative charges on the surface of the clay minerals, the strength of the inter layer bonding and the cation exchange capacity, all contribute to the swelling potential of clayey soil. The methods of mineralogical identification are important for exploring the basic properties of clay, but are impractical and uneconomical for practicing engineers. Since the objective of this study is evaluation of index properties of black cotton soil only indirect methods of classification are further discussed.

Indirect methods

Simple soil property tests are used for evaluation of the swelling potential of the expansive soil, which includes colloidal content; Atterberg limits tests, linear shrinkage test, and free swell test. Hotz and Gibbs demonstrated in 1956 that plasticity index and liquid limits are useful indices of for determining the swelling characteristics of most clay. Seed, Woodward, and Lundgren have demonstrated that plasticity index alone can be used as a preliminary indication of swelling characteristics of most clay.

Relation between swelling potential of clays and plasticity can be established as follows:

Swelling potential	**Plasticity index**
Low	0-15
Medium	10-35
High	20-55
Very high	55 and above

***Linear shrinkage**:* the swell potential is presumed to be related to the opposite property of linear shrinkage measured in a very simple test. In theory it appears that the shrinkage characteristics of the clay should be consistent and reliable index to the swelling potential. It was suggested by (Altmeyer,1955) as a guide to the determination of potential expansiveness for various values of shrinkage limits and linear shrinkage as follows:

Shrinkage limit %	**linear shrinkage %**	**degree of expansion**
<10	>8	critical
10-12	5-8	marginal
>12	0-5	non-critical

Though it may be true that high swelling soils will manifest high index property, the converse is not true.

Free swell: Holtz suggested that soils having free swell value as low as 100 % can cause considerable damage to lightly loaded structures, and soils having free swell value below 50% seldom exhibit appreciable volume change even under very light loading.

From the above identification criteria of expansive soils it is possible to conclude that higher the plasticity index, greater the quantum of water that can be imbibed within the soil structure and hence greater, the swelling potential. A low shrinkage limit indicates that a soil would begin to swell at low water content. Thus, these three parameters are used to indicate the criteria for identification of expansive soils by U.S. bureau of reclamation (1960) and are reproduced in table 4.3

Colloid content (%)	**Plasticity index (%)**	**Shrinkage limit (%)**	**Probable expansion (%)**	**Degree of expansion (%)**
<15	<18	>15	<10	Low
13-23	15-28	10-16	10-20	Medium
20-31	25-41	7-12	20-30	High
>28	>35	<11	>30	Very high

Table 4- 4 Identification criteria for expansive clay

The probable expansion mentioned in table 4.3 means the percentage of total volume change from dry to saturated condition under vertical surcharge of 7 KN/m^2. Peck et al, (1974) have related plasticity index to the swelling potential.

Frank Netterberg, 2001, has prepared a Preliminary Report on Cracking Problem in Addis Ababa –Jima road. He has conducted detail investigation on the foundation problem of black cotton soil in the road construction. This study has utilized much of the data and information that were presented by F. Netterberg. The main activities of this study were field insitu inspection of soil profiles, and insitu testing. The study results reveal that soil is black silty clay-classified as vertisols and colloquially known as “black cotton soils tended to occur in lower-lying, more
poorly drained situation and nearly always classified as unsuitable material (USM), i.e. CBR=4 @ 95 AASHTO T 180 compaction or swell at 100%.

The study has suggested recent identification criteria for black cotton soil, as active clays expand when they wet up and shrink when they dry out. Because roadbeds and moisture changes are seldom uniform the result is usually deformation and cracking of the finished road. All of the following conditions must be satisfied before significant movement can take place:

1. The soil must be potentially active; and
2. The changes in moisture content must be sufficiently great; and
3. The confining stresses must be sufficiently low.

These three conditions also suggest obvious means of preventing or minimizing the problem: e.g. partial or complete removal of the clay, pre-wetting to the equilibrium moisture content, minimization, or prevention of moisture change, and increasing the height of fill.

Identification of potentially active clays can be made in one or more of several ways, e.g. by odometer swell tests, by index tests (e.g. Atterberg limits) and by visual inspection. A great number of methods have been proposed none of which is universally applicable. This, if any, is most applicable to the particular problem remains to be established. It is necessary to consider not just the surface soil, but all soil horizons to a depth of at least 3 meters (Netterberg, 2001)

As a first approximation, the following Wilson–modified Van der Merwe classification of intrinsic (i.e. potential) activity on the basis of the weighted Pl (Pl_w or WPl, i.e. PlxP425/100) is recommended. This can also be used as a basis for decision – making.

WPI	**Potential activity**	**countermeasures required**
<12	None to low	None

12 – 23	Medium	Possibly
23 – 32	High	Probably
>32	Very High	Definitely

NOTE: P425 = Percentage of whole material passing 425m; P002 = percentage of whole material passing 2 μ m, etc.

A soil or material with a WPl of 12 or more should be considered in further detail. This compares reasonably with a figure of 16 derived from the Tanzanian limit of 20 by allowing for the different LL devices used. (All other factors being equal, a BS LL device yields LLs and therefore also plasticity indexes 4 units higher than an ASTM device – used on this job and in South Africa).

Criteria which have been used in Zimbabwe as a guide for soil which is potentially sufficiently active to cause significant damage to a road are:

a) WPl > 32, P002>20 and free swell>60%
b) WLL>55, P002>20 and free swell>60%

In Zimbabwe a roadbed with such properties is replaced to a depth of at least 0,6m below OGL.

Netterberg, 2001 stated that the above criteria require further consideration due to the differences in test methods employed in Ethiopia, South Africa, Tanzania and Zimbabwe. As a first approximation, 4 units should be subtracted from the Zimbabwe WLL and WPl criteria and any others derived using a BS LL device, to give suggested initial site WLL and WPl criteria of >55 and >28, respectively. These compare reasonably with the AASHTO T 258 (ASTM device) ordinary LL and Pl criteria of =50 and=25, respectively, which could also be used. Correction of this Pl of 25 for the P425 would probably yield a WPl of about 23, the same as the lower limit of the medium activity category of the modified Van der Merwe classification.

In short, it is tentatively recommended that soils with WPls of <12 be treated as normal soils, those with WPls>28 as definitely requiring replacement and/or other countermeasures, and those in between as requiring further consideration. According to this criterion of a WPl of = 12 practically all of the roadbed between Addis Ababa and Jima must be regarded as potentially active and much of it as definitely requiring drastic countermeasures (Netterberg, 2001).

This further consideration should include estimates of the potential heave using both Van der Merwe's as well as Weston's methods provided from TRH 9, the Tanzanian method and AASHTO T 258. If the potential heave, taking both the total surcharge and the likely moisture changes into account, is less than about 20mm, then no precautions are probably necessary. If it is more than about 50 mm then they definitely require further consideration.

In this chapter the important aspects of black cotton soil, its nature and characteristics were thoroughly demonstrated as far as time and space allowed. In the next chapter, follows the primary data collection acquired during field work and laboratory tests results.

5. Field data collection and Laboratory test

5.1. Filed data collection

Field work was carried out to collect primary data primarily on geology, engineering geology etc. The main activities carried out during field work were pitting and sampling, geological and engineering geological mapping.

5.1.1. Local geology

In order to delineate the various rock and soil units surface geology geological mapping at 1:50000 scale has been carried out in the study area. The surface geology of the area can be summarizes as follows;

Upper Miocene-Pliocene

Pleistocene-Holocene

- Residual soil
- Alluvial soil

Pliocene-Pleistocene

- Basalt
- Andesite
- Ignimbrite
- Lithic-Tuff

Generally the rock outcropping in the area are volcanic (pyroclastics and lava flows) of Pliocene to Holocene age. Soils are in situ developed residual soil and transported alluvial soils. The dominant unit is alluvial soil which covers about 90 % of the study area, followed by andesite, ignimbrite, basalt and lithic tuff. Soil units occupying the lower flat to gentle areas while rock units notably andesite are occupy elevated areas. Figure 5.1 shows the geology of the study area.

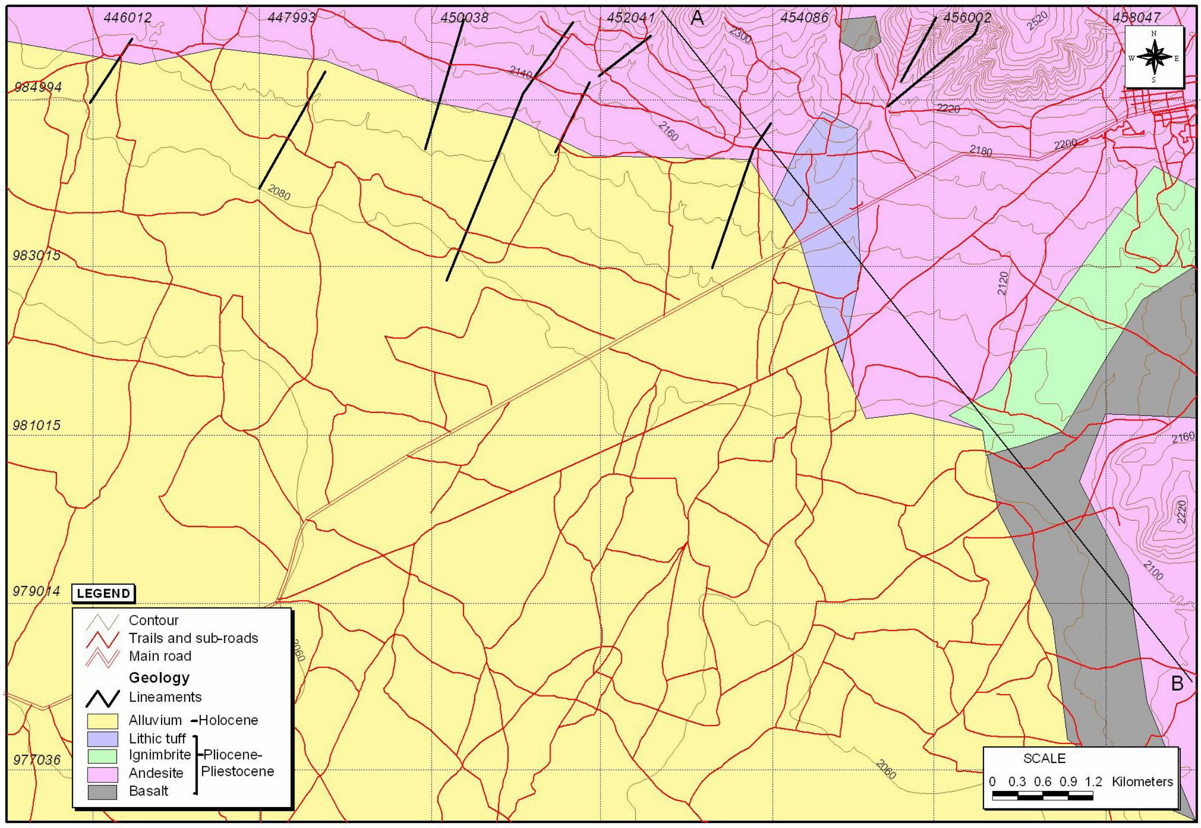

Figure 5- 1 Geological Map of the Study area

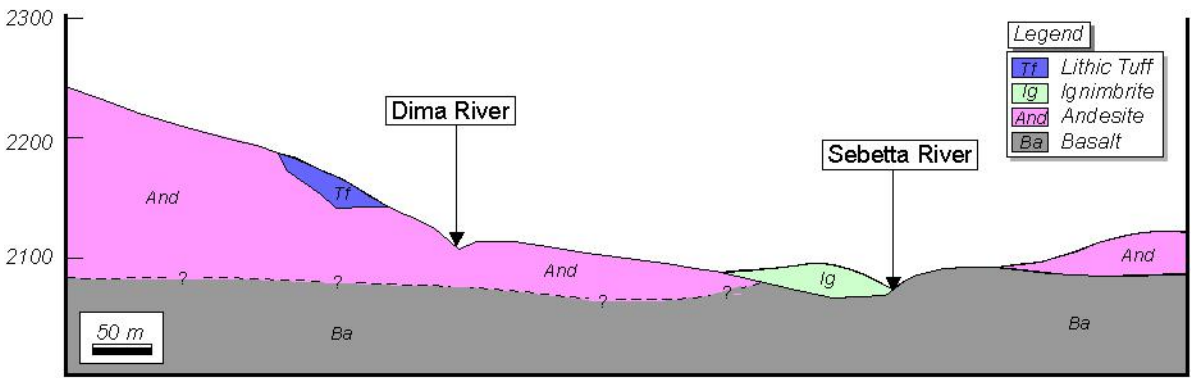

Figure 5- 2 Geological cross section, drawn along AB line (Fig. 5.1)

5.1.2. Engineering geological mapping

Engineering geological mapping follows delineating soil and rocks which are characterized by certain degree of homogeneity in basic engineering geological properties. Soils were classified on the basis of genesis, consistency and grain size. Rocks are classified into different strength units qualitatively using the degree of weathering and jointing as a main criteria. The guide lines used for qualitative engineering geological classification of rocks and soils are shown as Annexure 1 in this report.

Rock units

The various rocks exposed in the study area were classified and described according to their designation in the engineering geological map (Fig.5.4).

ba: fresh, closely jointed, strong to very strong basalt.
And: slightly to moderately weathered close to widely jointed, medium strong rock.
And$_1$: moderately to highly weathered closely to moderately jointed, medium strong to weak.
Ig: slightly to moderately weathered, closely jointed, weak.
Tf: highly weathered, massive, very weak

Basalt (ba)

The basalt covers small area at the extreme eastern and south-eastern part of the study area, forming gentle resistant morphology. Generally dark grey, fine grained, fresh, at places spherodically weathered and is characterized by well developed columnar jointing. According to mineralogical analysis the rock is dark grey, to black, fine to microcrystalline, composed of lath-shaped, euhdral plagioclase (65%), anhedral pyroxene (23%), and opaque (12%). Engineering geologically this unit is classified as fresh, closely jointed, strong to very strong basalt. The basalt of the study area serves as coarse concrete aggregate in the road construction.

Andesite (And)

Andesite is, the most widespread rock unit, covering the northern and south-eastern part of the study area. It forms high relief as wells as low relief hills and ridges with steep to gentle slopes. Plate 5.1 shows outcrop of andesite in the eastern part of the mapped area. Generally, the unit is light grey but with light bluish and greenish grey variety. Most of andesite outcrops, particularly those at eastern part have three sets of joints. The average trend of the three sets of joints is: Set 1=240^0 /75^0 , Set2=30^0 /70^0, and Set3=240^0/10^0.

According to the mineralogical analysis the rock is light grey, fine grained, composed of lath-shaped, euhdral, plagioclase(70%), anhedral pyroxene (15%), opaque (13%), apatite (2%) and trace of flaky biotite. The unit is classified into two engineering geological units as 'And' and 'And_1'. The former is slightly to moderately weathered closely jointed, medium strong, while the latter is moderate to highly weathered, closely to moderately jointed, medium strong to weak. Andesite of the study area is used as a sub grade in the road construction.

Plate 5- 1 Outcrop of andesite in the eastern part of the mapped area

Ignimbrite (Ig)

Ignimbrite (welded tuffs) is special group of pyroclastic rocks formed as a result of deposition of incandescent clouds of gas and volcanic ash (Whitten and Brooks, 1987). Ignimbrite is mapped in the extreme eastern part of the study area forming low topography. The rock is mostly exposed along Sebeta river bed and banks where it is overlying basalt. Fresh outcrops are observed at quarry face at the vicinity of Sebeta town. Filed observation indicated that the ignimbrite is generally light colour (pale blue, pale yellow), with pale greenish yellow alteration, porphyritic and occasionally vesicular. It is composed of Phenocrysts of plagioclase, quartz and glass shards and exhibiting characteristic well developed columnar jointing (Plate. 5.2). According to mineralogical analysis the rock is pale yellowish green, fine grained, and composed of volcanic glass 58 %, euhdral, plagioclase (2%), Quartz (10%), sandine (20%), amphibole (4%), opaque (3%), and calcite (3%).

Plate 5- 2 Ignimbrite outcrop showing columnar Joints

Lithic tuff: mapped in the northern part of the mapped area occupying a very limited area. It is whitish grey, composed of rock fragments of variable size, shape and composition and massive. In general rock the is very weak.

Soil units

The soils of the study area are genetically categorized as residual and alluvial soils, which were further classified in to three engineering geological units on the basis of consistency, grain size and plasticity characteristics. These units are described with designation in the engineering geological map (Fig. 5.3) as follows; plasticity characteristics. These units are described with designation in the engineering geological map (Fig. 5.3) as follows;

1. Residual soil (sre): reddish brown, medium soft, sandy silty clay of low plasticity, LL(<35%)
2. Alluvial soil (Sal1 and Sal2)

   Sal1: brown, very stiff, clayey silt of intermediate plasticity, LL (35-50%)

   Sal2: black cotton soil, very stiff to hard, silty clay of very high plasticity, LL(>50%)
3. Residual soil (sre): reddish brown, medium soft, sandy silty clay of low plasticity, LL(<35%)
4. Alluvial soil (Sal1 and Sal2)

   Sal1: brown, very stiff, clayey silt of intermediate plasticity, LL (35-50%)

   Sal2: black cotton soil, very stiff to hard, silty clay of very high plasticity, L(>50%)

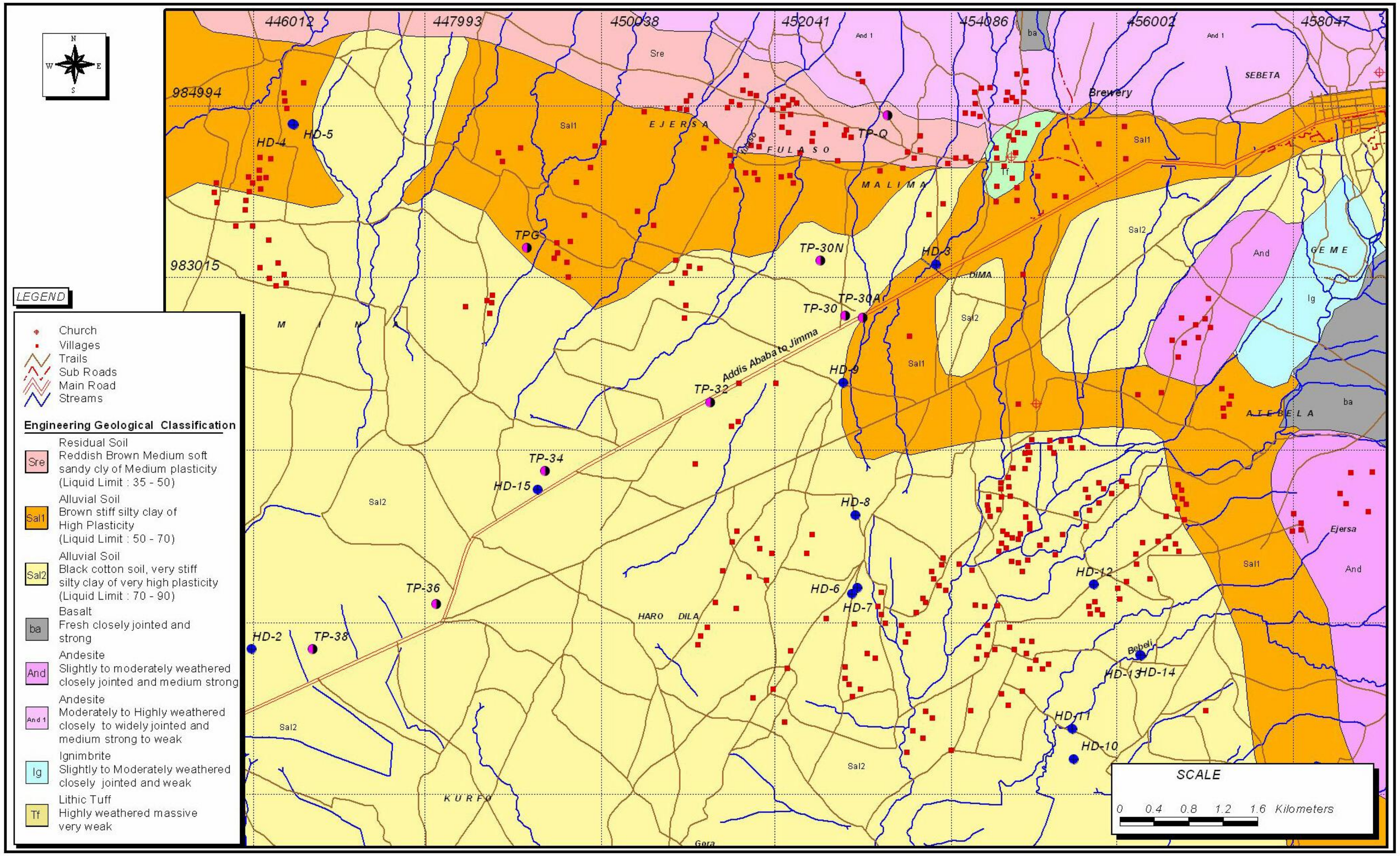

Fig. 5.4 Engineering Geological Map of the study area.

Figure 5- 3 Engineering Geological Map of the study area

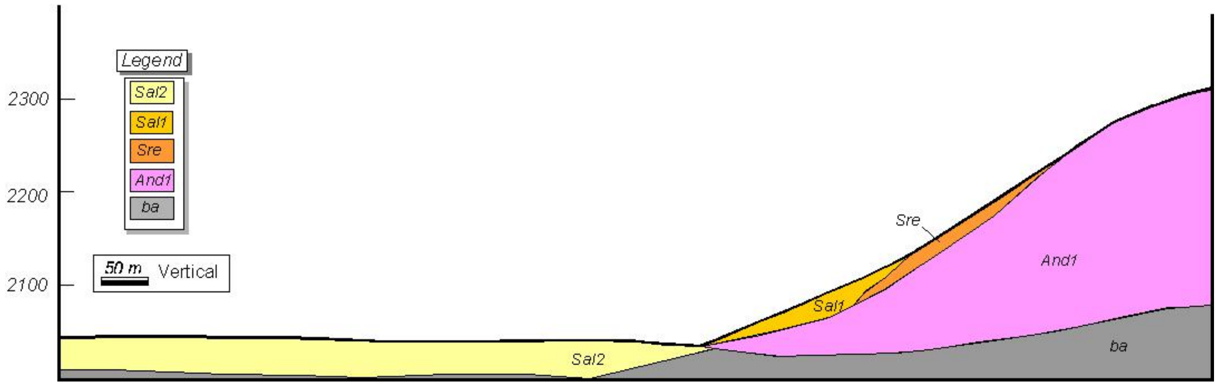

Figure 5- 4 Engineering Geological cross-section

Residual soil (sre): Residual soils are the soils that remain at the place of their formation as a result of the weathering of parent rock. It occupies the well drained, gently slopes of andesite hills in the north-eastern part of the mapped area. It is reddish brown, stiff, plastic, sandy silty clay. The soil profile at the exposed section (6 m thick) was divided into different weathering grades ranging from decomposed rock at the top to fresh parent rock at the bottom.. Thus, in moving upward from fresh unwashed material/volcanic rock at depth, successively more weathered, material is observed.

Alluvial soils (Sal1 and Sal2): are transported soils by river water and slope wash and found at the location far removed from their place of formation. These transported soils are mapped into two engineering units on the basis of , color, grain size, and consistency. These are brown, very stiff clayey silt (Sal1) and very stiff to hard, black cotton soil (silty clay) (Sal2). The alluvial soils occupy the flat-depression bordering the High Relief Mountains and are the most widespread soils in the study area.

Recent water holes or hand dug wells made for water supplies indicated that the thickness of alluvial soils are more than 30m, composed of multi-layers of gravel, sand, silt and clay of variable thickness and composition.

Alluvial soils (Sal2): According to field observation, the black cotton soil occurs on poorly drained, low lying/depression, which is water logged during rainy season. The elevation where the black cotton occurs ranges from 2060 to 2080 masl. Its thickness varies from place to place, increases towards West and South, having an average thickness of 2 m.

Typical characteristics of black cotton soil:

- Tensional cracks having geometrical shape /hexagonal/ with maximum depth of 1 m and width of 10 cm (Plate.5.3).

- Carbonate rich nodules (5-10%) at the upper part, which increase towards depth to the extent of forming hard pan. The amount, sizes and shapes of these nodules varies both vertically and laterally as evidenced from test pit and hand dug wells.

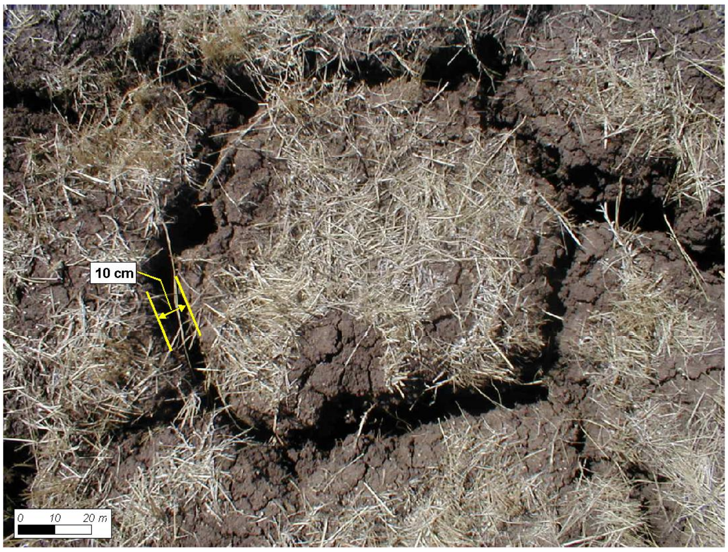

Plate 5- 3 Field tensional cracking in the black cotton soil

5.1.3. Pitting and Sampling

Test pits are employed in order to inspect the soil three-dimensionally at in-situ condition and to collect disturbed and undisturbed samples. A total of nine test pits with an average depth of 2m were dug, and 16 undisturbed and disturbed samples were collected along the main Addis Ababa- Jimma road corridors, Sbetta-Tefki section. Summary of test pit is indicated in Table 5.1 . Each test pit were geologically and geotechnically logged. Generally, three soil layers were identified from the test pits dug in the area where black cotton soil occurs. General black cotton soil profile is shown in the Table 5.2.

S.no	Test pit	UTM location	Depth (m)

		X	Y	
1	TP-Q	453359	984882	4
2	TP-34	449392	980770	1.50
3	TP-36	448137	979236	2.00
4	TP-30	452868	982571	2.00
5	TP-30N	452576	983203	1.5
6	TP-32	451303	981569	1.10
7	TP-38	446702	978712	2.00
8	TP30-A	453071	982544	1.20
9	TPG	449181	983352	3.00

Table 5- 1 Summary of test pit

Layer	Description
1	Very stiff, black cotton soil, silty clay, occasional carbonate nodules.
2	Gray to dark grey, stiff to medium soft, silty gravelly clay, with abundant carbonate nodules
3	Gray to light grey, gravelly soil, rich in carbonate nodules.

Table 5- 2 General black cotton soil profile in the study area.

The average thickness of upper most layers is 2m and the second layer is 1m. The carbonate nodules/concretion are typical constituents of black cotton soil which are sub angular to sub rounded, hard to soft, maximum size 3.5 by 4 cm and minimum size 2mm. In test pits the quantity of carbonate nodules is less in the upper soil horizons and becomes dominant and forms a hard pan towards depth. Moreover, tensional cracks up to 70 cm deep and 2 to 10 cm wide were observed in all test pits dug in the black cotton soils of the study area.

5.1.4. Ground water inventory

In order to give an in sight to the groundwater condition of the area, representative water points (hand dug wells & springs) were visited in the study area. About 15 hunddug wells were visited and major data on geographic coordinates, groundwater level and depth of hunddug wells were recorded.

From the groundwater level data, groundwater flow direction has been established and presented in Figure 5.2 and 5.3. One spring with high discharge is located in the eastern part of the mapped area on the fractured andesite rock.. According to ground water inventory data, the main water bearing formations are fractured andesite and loose, coarse grained alluvial deposits.

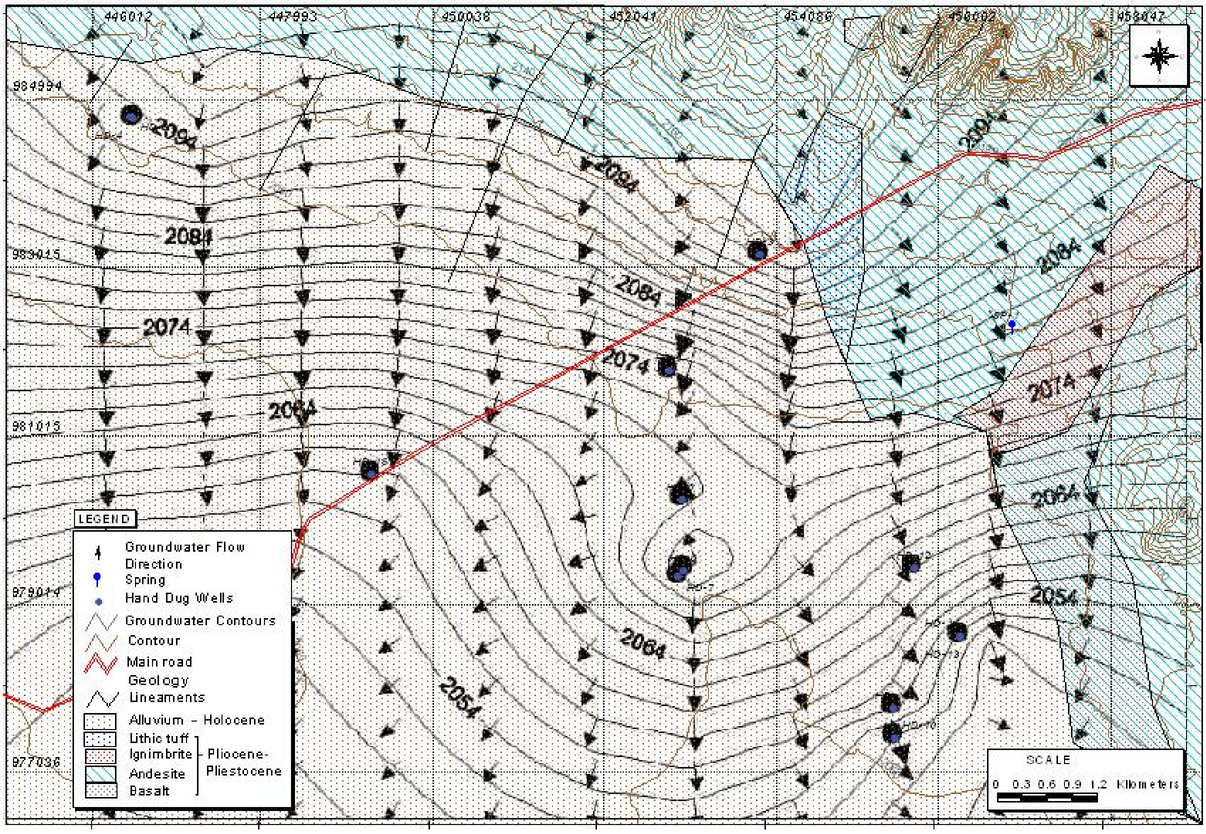

Figure 5- 5 Groundwater Flow direction map

5.2. Laboratory tests

5.2.1. Laboratory tests on undisturbed samples

A total of eight undisturbed samples were collected from three test pits dug on black cotton soil. These samples were tested for bulk density and moisture content. Laboratory test results of bulk density are shown in Table 5.3. The average test results of bulk density vary from 1.49-1.92 g/cm^3.

Test pit	Sample no		depth	Bulk density (g/m^3)
	Field no	Lab no		

TP38	TP38UD-1 TP38UD-2 TP38UD-3	1355/05 1356/05 1357/05	0.0-0.15 0.30-0.75 0.75-1.00	1.61 1.54 1.92
TP30	TP30UD-1 TP30UD-2	1352/05 1353/05	0.20-0.30 0.70-0.80	1.92 1.63
TP30-2	TP30UD-1	1354/05	1.3-1.4	1.62

Table 5- 3 Laboratory test results for bulk density

Six samples tested for natural moisture content showed that natural moisture content varies from 27.86 to 50.79 %. Generally natural moisture content is increases from top to bottom as indicated by samples, TP-30UD1 and TP-30UD2 collected from TP-30 (table 5.4).

Test pit	Sample no		Depth (m)	Natural moisture content (%)
	Field no	Lab no		
TP38	TP38UD-1 TP38UD-2 TP38UD-3	1349/05 1350/05 1351/05	0.0-0.15 0.30-0.75 0.75-1.00	12.75 33.22 27.86
TP30	TP30UD-1 TP30UD-2	1347/05 1348/05	0.20-0.30 0.70-0.80	38.71 50.79
TP30-N	TP30-N	2353/05	0.60-0.80	13.19

Table 5- 4 Laboratory test results of natural moisture content (%)

By comparing the two test results of table 5.3 and 5.4, as natural water content increases towards depth the bulk density decreases. This is a typical behaviour of expansive soils during summer condition where density near surface is high and goes on decreasing rapidly up to 1 to 1.5 m and then almost remains constant irrespective of moisture changes.

5.2.2. Laboratory tests on disturbed samples

Laboratory tests on disturbed samples were performed to evaluate the index properties, which are used for identification and classification of black cotton soil namely, particle size distribution, Atterberg limits, linear shrinkage, and free swell. Laboratory index tests were made on 10 disturbed samples taken from test pits dug at right and left side of the Addis Ababa-Jimma road at Sebeta-Tefki section. The samples and laboratory index test results are indicated in Table 5.5. The test pits locations for the disturbed sampling were chosen randomly at representative black cotton soil occurrence. All tests were performed in the Central Geological Laboratory of GSE. Laboratory test were carried out in accordance with British system established in soils for civil engineering purposes manual BSI 1377 part 2 1990. The index test results are described in the following paragraphs.

Test pit	UTM location		Sample no	Depth (m)	Gradation (%)			Atterberg limits%			SL%	FS%	A
	X	Y			sand	silt	clay	LL	PL	PI			
TP-Q	453359	984882	TPQ-1	4	3.24	30.4	60	55	31	24	16	32	0.4
TP-30N	452576	983203		1.5							21	75	
TPG	449181	983352		2.00	0.5	59.5	40				19	70	
TP-34	449392	980770	TP34-1	0.50 -0.70	0.7	44.3	55	79	49	30	20	140	0.5
			TP34-2	1.00 -1.20	2.2	47.8	50	81	54	27	19	122	0.5
TP-36	448137	979236	TP36-1	0.40 -0.60	0.5	59.5	40	84	52	32	21	128	0.8
TP-38	446702	978712	TP38-2	1.30 -1.60	1.2	50.8	48						
TP-32	451303	981569	TP32-1	0.50 -0.60	0.4	27.6	72				18	137	
TP-30	452868	982571	TP30-1	0.60 -0.80							16	118	
			TP30-2	1.30 -1.40	2	21	77	73	52	21	20	120	

Table 5- 5 **Summary of the laboratory test result of disturbed soil samples**

Particle size distribution

Six samples were analyzed for grain size determination. Particle size distribution, given as percentages of clay, silt and sand for tested samples are given in table 5.5. According to test result about 98 % of soil fractions are fines (<63µ), hence the soil is fine grained.

Atterberg limits

Ten samples from the study area were tested for liquid limits (LL) and plastic limits (PL) from which plasticity index (PI) was computed. List of laboratory test samples of liquid and plastic limit is given in Table 5.6.

Lab No	Test pit/ Sample No	Liquid limit %	Lab No	Test pit/ Sample no	Plastic limit %	Field Material description
432/05	TP 36-1	84	2335/05	TP 36-1	52	Black cotton soil
434/05	TP34-2	81	2337/05	TP34-2	54.01	Black cotton soil
433/05	TP34-1	79	2336/05	TP34-1	48.74	Black cotton soil
2342/05	TPQ-1	54.5	2338/05	TPQ-1	31.95	Residual soil
1332/05	TP30-2	72.5	1335/05	TP30-2	51.84	Dark grey soil
1331/05	TP32-1	88.5	1334/05	TP32-1	54.89	Black cotton soil
2347/05	TP30N	73.4	2345/05	TP30N	36.94	Brown soil
2348/05	TPG	61.5	2346/05	TPG	39.52	Black cotton soil

Table 5- 6 Laboratory test samples of liquid and plastic limit

Free swell

The free swell test on air dried soil specimen measures the volume change between the air-dried condition and unrestrained swelling. A total of ten samples were tested, out of which seven were from black cotton soil collected from six pits at depth ranging from 0.50-1.60m. Table 5.7 shows samples and test results of free swell. In general the free swell test results of the collected black cotton samples are ranging from 118 to 140 %.

Lab. No.	Sample No.	Volume of swelled sample in ml	Free swell (%)	Field Material description
1343/05	TP30-2	22	120	Dark grey soil
1344/05	TP38-2	19.2	192	Dark grey soil
1342/05	TP30-1	21.8	118	Black cotton soil
1341/05	TP32-1	23.7	137	Black cotton soil
2342/05	TPQ-1	13.2	32	Residual soil
2341/05	TP34-2	22.2	122	Dark grey soil
2339/45	TP36-1	22.8	128	Black cotton soil
2340/05	TP34-1	24	140	Black cotton soil
2349/05	TP30N	17.5	75	Brown soil
2350/05	TPG	17	70	Brown soil

Table 5- 7 Laboratory test samples of plastic limit

Linear Shrinkage (one dimensional shrinkage)

This test gives an indication of the amount of shrinkage by determining the change in length of a semi cylinder bar sample of soil when it dries out, following remoulding. Nine samples were tested for linear shrinkage and the values are ranging from 15.7-21.4 % (table 5.8)

Lab. No	field no	green body dimension (mm)	dry body dimension (mm)	shrinkage %	Field Material description
441/05	TP34-1	140	112	20	Black Cotton soil
440/05	TP36-1	140	111	20.7	Black Cotton soil
1337/05	TP32-1	140	115	17.9	Black Cotton soil
442/05	TP34-2	140	113	19.3	Black Cotton soil
443/05	TPQ-1		118	15.7	Residual soil
1339/05	TP30-2		112	20	Black Cotton soil
1338/05	TP30-1		118	15.7	Black Cotton soil
2351/05	TP30N		110	21.4	Brown soil
2352/05	TPG	140	114	18.6	Brown soil

Table 5- 8 Laboratory test samples of plastic limit

6. Results and Discussion

In the previous chapter the primary data (field and laboratory) were presented. In this chapter results of index properties of black cotton soil both from previous and the present study are analyzed and discussed with respect to the project objectives. Laboratory index test results namely particle size, Atterberg limits, shrinkage limits and free swell are presented in following paragraphs.

6.1. Results

6.1.1. Particle size distribution

Since the soil samples tested consisted of over 98% fines (material passing a 63μm sieve), the procedures adopted were those specified for analysis of fine-grained soils samples. Wet sieve was employed to obtain soil fraction >63μm and materials passing the sieve were treated by sedimentation method (pipette method). A combined sieving and sedimentation procedure enables a continuous particle size distribution curve of a soil to be plotted from the size of the fine sand particles down to the clay size. From the tested samples grain size distribution curve was produced to indicate the proportion of clay, silt and sand (table 6.1).

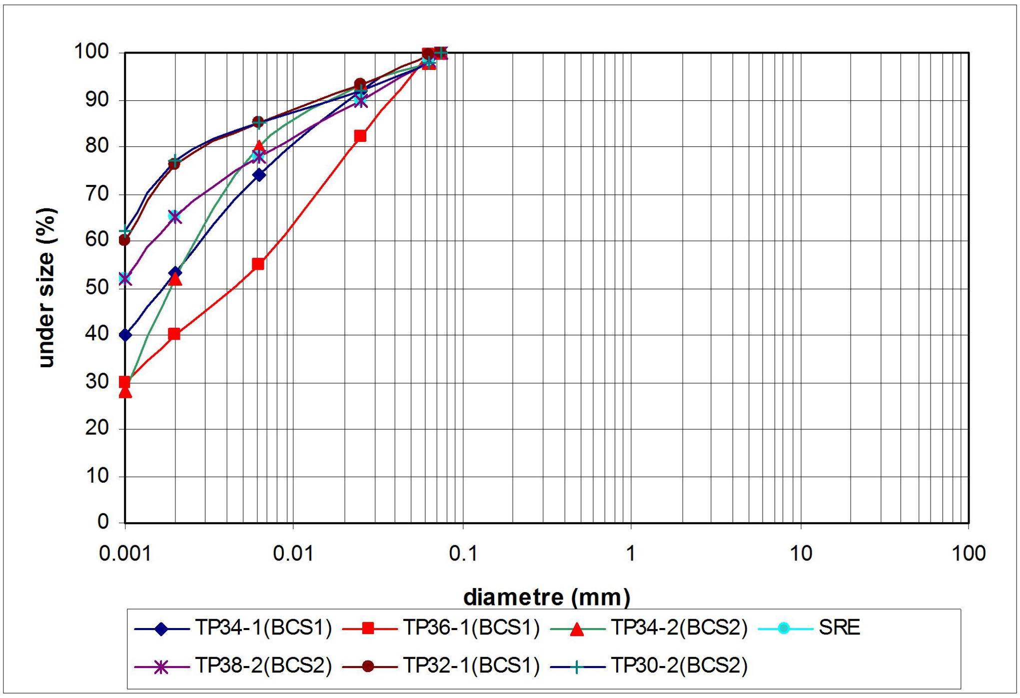

Figure 6- 1 Grain size distribution curve

Table 6- 1 Summary of Laboratory test results for the present and Previous study (Netterberg, 2001)

A: Current study

Test pit		Location UTM		Material description	Gradation (%)			Characteristic tests							
Sno.	Depth (m)	X	Y		sand	silt	clay	Gs	w(%)	P g/cc	WL (%)	Wp (%)	Ip (%)	Ws (%)	Fs (%)
TPQ-1	4	453359	984882	Red soil	3.24	30.4	60	2.57			54.5	32	22.5	**15.7**	32
TP38-2	1.30-1.60	446702	978712	Black cotton soil	1.2	50.8	48	2.48							192
TP36-1	0.40-o.60	448137	979236	""	0.5	59.5	40	2.21			84	52	32	20.7	128
TP34-1	0.50-0.70	449392	980770	""	0.7	44.4	55	2.37			79	49	30	20	140
TP34-2	1.00-1.20			""	2.2	47.8	50				81	54	27	19.3	122.00
TP30-1	0.60-0.80	452868	982571	""										**15.7**	118.00
TP30-2				""	2	21	77	2.38		1.62	72.5	52	20.5	20	
TP32-1	0.50-0.60	451303	981569	""	0.4	27.6	72				88.5	55	33.5	17.9	137
TP30N								2.44	13.9		73.4	36.94	36.94	21.4	75
TPG		449165	981267					2.09			61.5	39.52	21.98	18.6	70
TP-30UD1	0.20-0.30			""					12.75	1.92					
TP-30UD2	0.70-0.80			""					33.22	1.63					
TP-38UD1	0.00-0.15			""					27.86	1.61					
TP-38UD2	0.30-0.75			""					38.71	1.54					
TP-38UD3	0.75-0.60			""					50.79	1.49					
B: Previous study															
St. Km	Sample no				4.75mm	2mm	0.425mm	0.075mm	Wp(w)					WL(w)	Swell(%)
23.3	SG016.CL								0		81	36	45	0	14.4
25	SG001.CBR			brown silty clay	100	88.5	61	52.5	20		56	24	32	34	4.25
28	SG002.CBR			d.brown silty clay	94	92	81	61.5			60	30	30		5.03
31.72	SG005.CBR			black cotton soil	97	96.5	95.4	88.1	63		104	38	66	99	13.6
33.86	SG003.CBR			""	99.1	98.5	98.2	93.4	50		94	94	43	92	10.9
36.2	SG006.CBR			""	98.5	97.4	96.6	92.3	65		110	43	67	106	7.1
38.33	SP			""		94	85	75	22		52	26	26	44	5.94
39.6	SG007.CBR			""	81.9	79.9	73.5	92.6	18		50	26	24	37	5.6
41.98	SG004.CBR				98.2	97.7	97.7		52		90	37	53	88	10.8
44.5	SG010.CBR			""	97.5	96.7	96		55		97	40	57	93	10.7
45.5	SG011.CBR			""	97.8	97	95.6		81		108	23	85	103	8.41
46.4	SG009.CBR			""	97	96.6	96		50		89	37	52	85	9.22
61.36	SP					98	94	89	39		77	39	41	34	9.2

66.4	SG029.CBR			""	98.6	98.2	96.8	92.4	34		69	34	35	67	11.35

Particle distribution curves for samples collected from black cotton soil showed that fine sand ranges from (0.5%-2.3%), silt (39%-60%) and clay (54%-76%). Figure 5.1 shows that clay (<2μ) is dominant over fine sand and silt, thus the black cotton soil of the study area is classified as silty clay with trace of sand**.**

6.1.2. Atterberg limits

Determination of the plastic and liquid limits provides the most useful way of identifying and classifying fine grained soils. The Casagrande's plasticity chart is used to classify silt from clay according to their plasticity characteristics. The LL Vs PI plot of black cotton soil samples from five major roads namely Ambo, Jima, Debra Marcos and Debra Berhan (Mekonen Tsegaw, 2003) is shown in figure 5.2. Almost all samples plot above or along A-line indicating inorganic clay of high to very high plasticity (CH & CV).

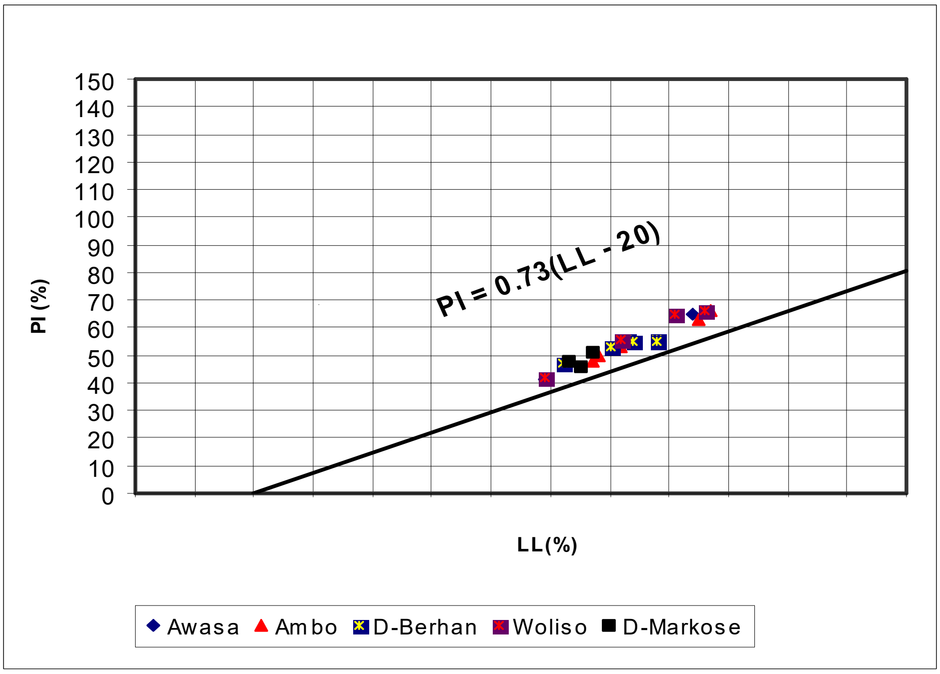

Figure 6- 2 Liquid limit against plasticity index for placing major trunk roads expansive soil into Unified Soil Classification (USC).

Liquid limit

The liquid limit is the water content at which the soil changes from the liquid state to the plastic state. At the LL, the clay is practically like a liquid, but possesses a small shearing strength. As can be seen from present and previous study (Netterberg, 2001) the range of liquid limit values are ranging from 79 to 88.5 %, in the present study and 50 to 110 % for previous studies for the same black cotton soil. Generally, the higher values were reported by the previous studies carried out in the study area. The LL in conjunction with plasticity index is used for classification of soils on the plasticity chart (see Fig 6.3). Using LL values given in table 6.2 plasticity of the soil of the soil can be determined. Accordingly the black cotton soil of the area can be classified as clay with very high plasticity.

Term	**Range of liquid limits (%) (After IAEG, 1981)**	**Range of liquid limits (%) (after Chen, 1988)**
Low plasticity	Under 35	<35
Intermediate plasticity	35-50	35-50
High plasticity	50-70	50-70
Very high plasticity	70-90	70-90
Extremely high plasticity	Over 90	Over 90

Table 6- 2 Terms for description of liquid limits

The LL of soil depends upon the clay mineral present. The stronger the surface charge and the thinner the particle the greater will be the amount of adsorbed water and, therefore, the higher will be the LL. The LL is also is a good indicator of the compressibility of a soil. The compressibility of a soil generally increases with an increase in LL. The engineering significance of high LL means the black cotton soil of the area is highly compressible and demonstrates low shear strength when saturated.

Plasticity index

Plasticity index (Ip or PI) is range of water content over which the soil remains in the plastic state. It is the difference between the liquid limit and plastic limit (Ip=LL-PL). The PI values for the black cotton soil tested in this study are ranging from 21 to 33 %, while the previous study (Netterberg, 2001) yielded 24 to 85%. A graphical plot of liquid limit and plasticity index on the conventional plasticity chart (or A line-chart) is used to classify fine grained cohesive soils (Fig6.3). The A line is defined by the relationship I_p= 0.73 (LL-20). This chart is derived from experimental evidence from temperate soils. It does not always represent a well defined boundary between soil types, but does from a useful reference datum. When plotted on the chart, inorganic clay soils tend to fall in a narrow band above and parallel to the A-line, whereas silts plot below the A-line.

In British practice the plasticity chart is divided in to five zones, giving the following categories for clays [K J Nortmore, et al, 1992]

1. Clays of low plasticity (CL), liquid limit <35.
2. Clays of medium, or intermediate, plasticity (CI), liquid limit from 35-50.
3. Clays of high plasticity (CH), liquid limit from 50-70.
4. Clays of very high plasticity (CV), liquid limit from 70-90.
5. Clays of extremely high plasticity (CE), liquid limit >90.

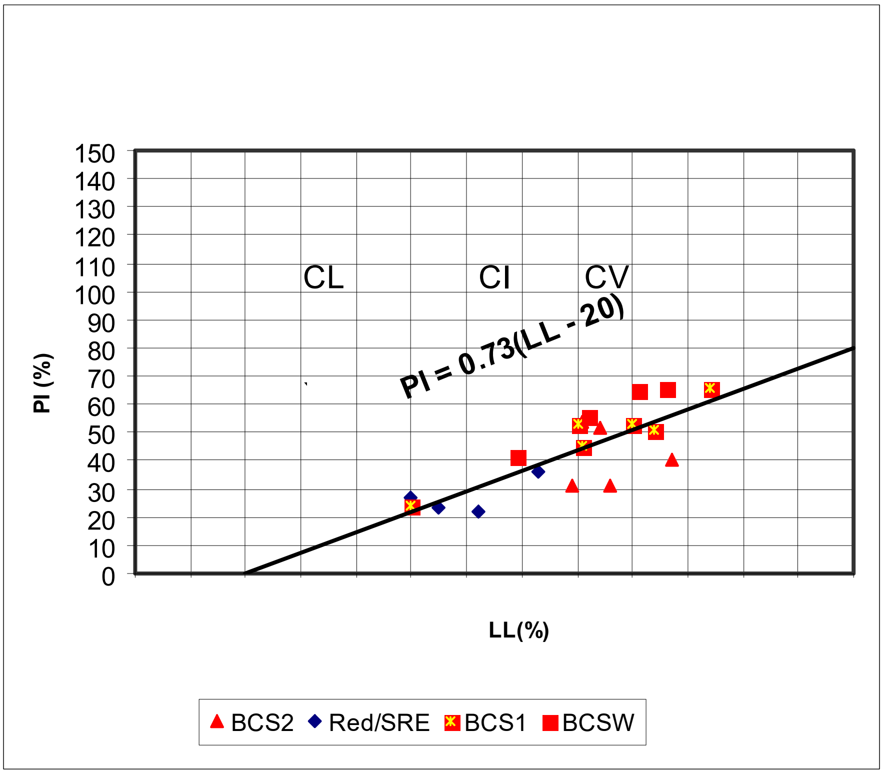

Figure 6- 3 Plasticity chart or A-line

The plasticity index of a soil is a measure of the amount of clay in soil or a measure of fineness of the particle. Generally the higher is the PI the greater is the amount of fines (minus 425µm), which can be observed in Table 6.1 summary of laboratory test results.

The above graph shows that most of the black cotton soil samples from present and past studies (Netterberg, 2001) lie below, and above "A" in the zone of very high plasticity (LL>70%). Such discrepancy can be related to one of the following factors:

- The A-line defined by the relationship $I_p = 0.73\ (W_L - 20)$, was derived from experimental evidence from temperate soils. A full account in preparing the plasticity chart was not given, making meaningful classification and correlation between data sets difficult.

- Lack of standardization of the pre-test procedures for soils (black cotton soil) which are important for accurate comparison between published index data to be made.
- Difference in test methods (BS, ASTM) and test procedures etc. As research works indicated, in most cases, test values of LL and PLs are sensitive to pre-treatment and sample condition.

The plasticity of black cotton soil can be described as highly plastic to extremely plastic as PI values of the soil samples are in the range of 24-85% (Table 6.3)

Term	**plasticity index (%)(after IAEG, 1981)**	**Range of liquid limits (%) (after Chen, 1988)**
Non plastic	Under 1	<1
Slightly plastic	1-7	1-7
Moderately plastic	7-17	7-17
Highly plastic	17-35	17-35
Extremely plastic	Over 35	Over 35

Table 6- 3 Terms for description of plasticity index

Activity

Activity (A) of a soil is the ratio of the plasticity index and the percentage of clay fraction, (%< 2μm).

$$A=I_p/F \quad \ldots 5.1$$

Where I_p=plasticity index, F=clay fraction, the clay fraction F is percentage finer than 2μ size (Arora, 2000.). Activities of a wide spectrum of black cotton clay soils from the previous study (Mekonen Tsegaw, 2003) are shown in Figure 6.4. For the present study, activity (A) was computed from PI and clay fraction from samples collected from the study area. The activity is computed from grain size and Atterberg limits tests. The clay fraction used for computation of activity (A) of the soils was determined by wet sieving and hydrometer analysis following dispersion with sodium hexametaphosphate from remolded sample. The plastic and liquid limits from which PI was computed were determined by BS. 1377 testing method. The computed activity value of present study ranges from 0.5-0.8, while for previous study is greater than 1

(Fig.6.4). Generally the plot of PI Vs clay fraction are between steep slopes A=1 and A=2. Few samples from the present study fall along gentle slope A=0.5. Thus based on the Skempton (1953), the black cotton soil of the study area can be classified as, active clay. The difference in activity value for black cotton soil samples for present and previous study is primarily attributed to different test methods adopted in laboratory testing.

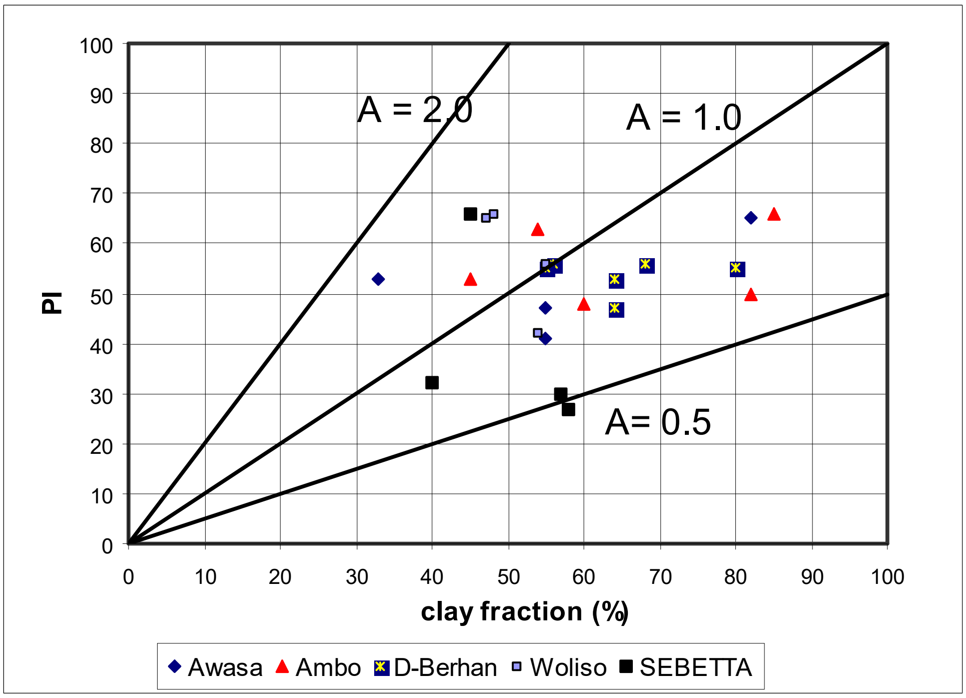

Figure 6- 4 Activity plot of black cotton samples (Mekonen Tsegaw)

From the original work of Skempton (1953), four main types of clays can be distinguished on the basis of their 'activities', namely:

Description	Activity (1_A)
Inactive clays	<0.75
Normal clays	0.75 – 1.25
Active clays	1.25 – 2.0
Highly active clays	>2

Based on the above, Vargas (1988) terms soils with I_A < 0.75 as 'low activity' clays and those with I_A>1.25 as 'high activity' clays. If this classification is adopted the black cotton soil is classified as high activity clay.

Clay mineralogy

Identification of clay mineralogy needs elaborate test like X-ray diffraction, however (Brain, 1971, Fig.6.5) produced a graph which is used to know the mineral composition of clayey soils. Most of The plot of plastic limit and plasticity index values for samples collected from the study area indicated that most of the samples fall in hallosyte and montimorillonite range. .

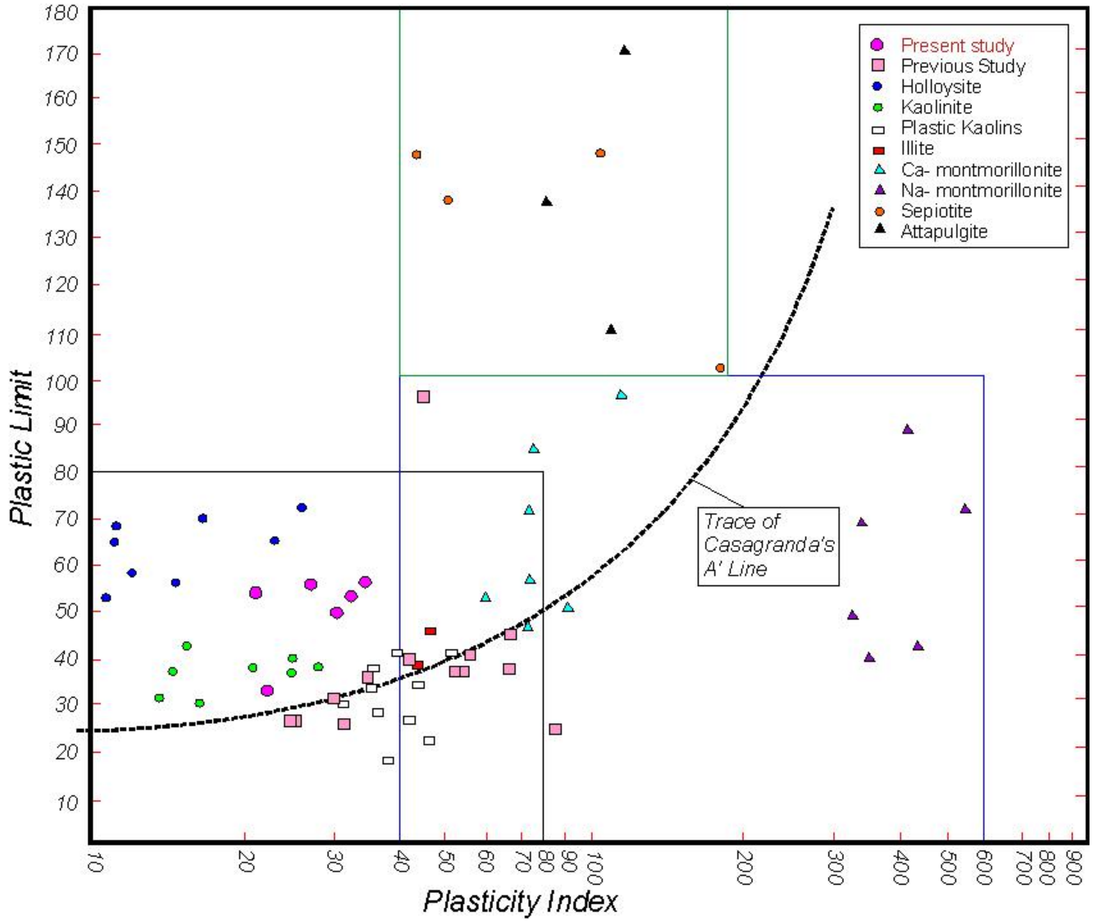

Figure 6- 5 **Plastic limit Vs plasticity index plot for caly (from Brain 1971)**

6.1.3. Free swell

The free swell test on air dried soil specimen measures the volume change between the air-dried condition and unrestrained swelling. For the tested samples of black cotton soil the free swell values are ranging from 118-140 % (Plate 6.1)

Plate 6- 1 Free swell test

These samples were collected from six pits at depth ranging from 0.50-1.60m within black cotton soil. The highest value 140 % is obtained from test pit (TP34-1) at a depth of 0.50-0.70m, situated in the south-western part of the area, at the marshy ground. The lowest value 22 % is for sample colleted from test pit (TP-Q) at a depth of 4 m. This soil is reddish brown residual soil which is mapped in the north-eastern part of the area. There is strong correlation between free swell LL and soil fraction <2mm**.** An attempt has been made to establish the correlation between the LL and free swell, which is presented through a graph shown at Figure.6.5

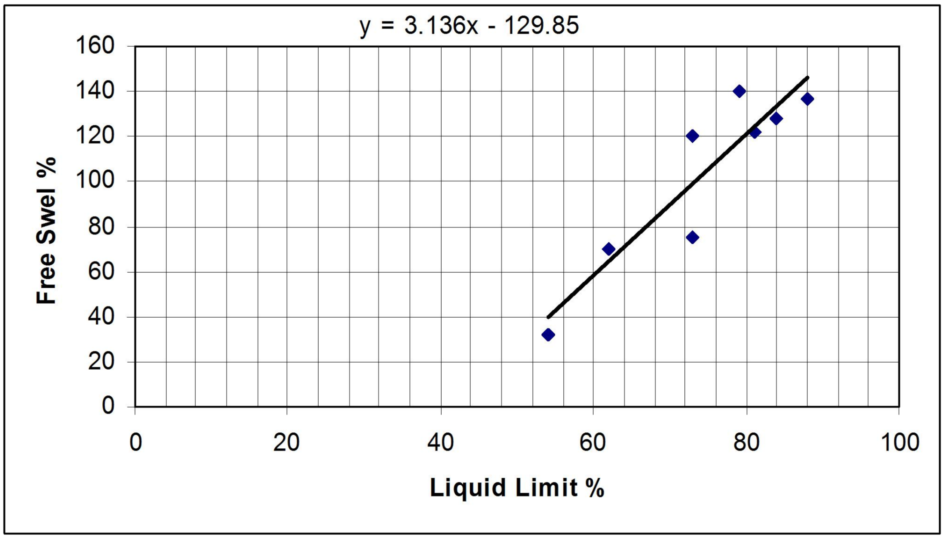

Figure 6- 6 Correlation between LL and FS as derived for the soil samples collected from the present study area.

Table 6.4 gives an estimation of expansiveness for samples tested from this study, based on free swell (USBR, 1998). However test methods and procedures might affect the grouping of individual classes.

Free swell value (%)	Expansiveness
<50	Low
50-75	Medium
75-100	High
>100	extreme

Table 6- 4 Estimation of expansiveness based on free swell value (after USBR, 1998)

Based on the above criteria, the black cotton soil of the study area is classified as extremely expansive, as the free swell values are in the range of 118-140% (Table . 6.1).

6.1.4. Linear Shrinkage (one dimensional shrinkage)

This test give an indication of the amount of shrinkage by determining the change in length of a semi cylinder bar sample of soil when it dries out, following remoulding at a water content near the liquid limit(Plate 6.1). In addition to indicating the amount of shrinkage, the linear shrinkage test can provide an approximate estimate of the plasticity index for soils where the liquid and plastic limits are difficult to determine (Head, 1992). For the present study, based on the test results the soil samples collected from black cotton soil have linear shrinkage in the range of 15.7 to 20% (Table. 6.1).

Plate 6- 2 Linear shrinkage test

According to the classification of linear shrinkage, as proposed by Seghal, (2000) (Table 6.5) the black cotton soil of the present study area can be classified as very poor material.

Linear shrinkage (%)	**Quality of material**
<5	Good
5-10	Medium good
10-15	Poor
>15	Very poor

Table 6- 5 Classification for the linear shrinkage of soils (Seghal, 2000)

The laboratory index test results both from the present study and previous study indicate that the main index properties which describe the expansive problem of black cotton soil are gradation, Atterberg limits, shrinkage limit and free swell. Many studies adopted different classification systems using different parameters. Index test results given in literature and previous research works on black cotton soil do seldom conform the results of this study. Table 6.6 shows index test results conducted on the same black cotton soil but under different studies.

Soil property	Magnitude (after M. Tesgaw, 2003)	Magnitude (after F. Netterberg, 2001)	Magnitude (current study, 2005)
Liquid limit (LL) (%)	69-97	50-110	79-88.5
Plastic limit (PL) (%)	25-35	24-94	48.74 -54
Plastic index (PI) (%)	37-67	24-85	30.26-33.11
Finer than 5µm sieve (%) <63 micron (BS sieve)	60-82		99.5-75
Retained in the 75µm (%) >63 micron (BS sieve)	2-12		0.5 – 2.3
Linear shrinkage (%)			15-20
Free swell (FS) (%)	50-120		118-140
Swelling pressure, kPa	128-195		

Table 6- 6 Summary of the laboratory test result of disturbed soil samples, as findings from previous and the present study

The laboratory test method of Mekonen Tesgaw, (2003) is ASTM while that of present study is BSI 1377. Though the testing methods in the two studies are different with variation in test results, it may still be concluded from various classification systems, that the black cotton soils of the study area are expansive and fall into the very high swelling potential group.

6.1.6 Distresses of black cotton soil in road construction

This study is initiated primarily considering the above mentioned problems and those described in chapter 1 problem definition section 1.2. In the expansive soil such as black cotton soil, shrinkage cracks of the order of 15 cm width and travelling about 174 cm to 305 cm deep is a common sight in the field where such deposits exist. Construction of extended projects like, railways and roads in such area always face problems of an extremely low bearing capacity of the sub grade when it is wet and also its high swelling and shrinkage pressure characteristics. Tracks and roads built on such soil without proper ameliorative measures face distress and need constant and costly maintenance even for average performance.

In the following few paragraphs the main damages of road construction based upon present and previous study (Netterberg, 2001) is briefly outlined. The mentioned problems are site specific.

Road

The main problems of black cotton soil in the road construction are cracking and heaving. The causes of the problem of the road in the study are considered to include the following (Netterberg, 2001) :

a) a potentially extremely active road bed;

b) Extremely high increase in moisture content due to ponding;

c) the use of permeable fill (Tulu Bolo weathered tuff); and

d) absence of precaution against heave such as partial replacement of the clay.

Cracking: are of two varieties, longitudinal and transverse, of which the latter were very rare, apparently narrow, and were only associated with culverts, such as at km 31+920. The longitudinal cracks seen were all unfaulted (i.e. both sides were at the same elevation), tension cracks, wider at the top, did not extend significantly in to the clay roadbed. All were said to have been associated with temporary standing water and most to have appeared after the rainy season. Those that were first noticed after the rainy season included those around km 32 right and left; and those around km 44 on the high embankment over Awash River flood plain.

The present study has identified longitudinal crack at km 32+150 along the left shoulder of road. It is 70 m long and 20 cm wide at an average (plate 6.3). Attempts were made to seal the cracks using impervious material (clay, asphalt) but it is only temporary solution as the problem continuing and becoming worst in the near future.

Plate 6- 3 **Longitudinal cracking along left side of the road (km32+150)**

Apparent heave: is associated with the cracking, were long (tens or hundreds of metres), apparent heaves of the edge of the asphalt surfacing of the order of 50 mm. This heave of approximately the outer 0.5 m of the asphalt and the inner 0.5 m of the shoulder could be clearly seen in some trenched cross sections. This apparent heave has reduced the cross falls of the surfacing and increase that of the shoulder. A few cases of more localized apparent heave of a more generalized nature were noticed, as at km 31+970 (plate 6.4) right and km 64+518.

In general the manin chracterstics of black cotton soil is fissuring and slickensiding to be (or to have been in the past) active to a depth of about 2.4m below OGL, open cracks traced to a depth of about 1.0m below OGL below the fill and 2.2m in the pit about 10m to the right of the toe of the embankment.. Most roots and open cracks ended at a depth of about 1.0 – 1.1 m below OGL, but some fine roots were evident on fissures as deep as 2,3m. In cuts 2 or 3m deep on the realignment the black, brown or red clay on the floor of the cut was seen to be strongly microshattered and cracked, indicating the potential for activity even at these depths. In a few places such as at km 32+087 R and on the realignment a layer of calcrete nodules was found extending to depths of about 1.5 – 2.0m. It is recommended that all these features be used to indicate the depth of clay and moisture movement and hence the depth of replacement or vertical membranes required. The study further suggested that from these very limited observations most seasonal clay movement probably ends at about 1.3–1.5m, but that significant seasonal moisture and clay movement takes place (or has taken place) to about 2.5m.

It may be possible by means of radiocarbon dating and other techniques such as telescopic benchmarks to determine the current depth of movement.

The study also stated the need of treatment of soils particularly those seen on the realignment between about stake value km 0 (Addis Ababa) and the river at about km 15 were very thick (>2–3m), extremely active, black clays requiring countermeasures such as partial replacement. However, in most cases more than 1-1.5 m had already been removed, and the steeper slopes should permit good drainage and the elimination of ponding. The floors of most of the cuttings were badly cracked, indicating the need for pre-wetting or further excavation just before covering. The slopes of the cuttings and the side drains were already shattered, microshattered and eroded. It may be necessary to cut these slopes back to 1 in 4 to minimize erosion and creep and to line the side drains. These soils are highly erodible, and may also be dispersive.

6.2. Discussion

6.2.1. Index test

In the foregoing sections of this study the index properties used for characterization of black cotton soil were described. To evaluate these properties laboratory tests were conducted on disturbed samples collected from black cotton soil. The laboratory index tests include particle size, Atterberg limits, shrinkage limits and free swell.

Particle size distribution

The test results of particle size distribution indicate that over 98 % of the soil fraction is under 63µ BS sieve indicating that the soil is fine grained silty clay. Field observation indicated that the black cotton soil is composed of an appreciable amount (5-10 %) of calcite nodules which are sand to gravel size. Therefore, the black cotton soil can be described as silty clay soil with appreciable coarse fragments of calcite nodules. From grain size test results particularly from clay fraction (-2µ) an important soil indices were computed such as weighted plasticity index (WPI), weighted liquid limit index (WLL), and Activity (A).

Plasticity tests

The liquid and plastic limits were determined according to BS 1377: part 2: 1990, British Standard Method of test for soils for Civil Engineering purpose. Cone penetration method is employed in liquid limit determination and plastic limit is determined by rolling into thread of 3mm diameter until the soil cease plasticity. From liquid and plastic limits an important parameter, plasticity index is derived which is the difference between (LL-PL). The PI in combination with LL gives information about the type of clay. Plasticity chart, which is a plot between PI and LL, is extremely useful for classification of fine grained soils. This study has shown that most of the soil samples from study area were plotted below to the A-line as opposed to the previous study (Netterberg, 2001) which were plotted above and parallel to A-line. This variation is due to differences in test values of LL and PL which can be ascribed to one of the following factors.

- Lack of details in producing the plasticity chart, A-line.
- Variation in test methods, ASTM, BS, IS, etc.
- Difference in test procedures, type of sample tested (natural or remoulded) and devices are used

Netterberg, (2001) has well explained that when different LL devices (BS LL and ASTM device) the LL values vary by 4 units for the same black cotton soil.

Plasticity in soils is due to presence of clay minerals. The clay particles carry a negative charge on their surfaces. The water molecules are dipolar and are attracted towards the clay surface. The phenomenon is known as adsorption of water and the water so attracted to the clay surface is called adsorbed water. Plasticity of the soil is due to adsorbed water.

Therefore Atterberg limits use as index properties of fine grained soils which can be empirically related to the engineering properties of such soil as follows (Arora, 2001):

1 It has been found that both LL and PL depend on the type and amount of clay mineral in a soil. However, the PI depends mainly on the amount of clay. The PI of a soil is a measure of the amount of clay in soil.

2 As a particle size decreases, both the LL and PLs increases, but the former increases at rapid rate PI is, therefore a measure of the fineness of the particles.

3 The LL of a soil is an indicator of the compressibility of a soil. The compressibility of a soil generally increases with an increase in liquid limit.

4 When comparing the properties of two soils with equal values of PI, it is found that as LL increases, the dry strength and toughness decreases, whereas compressibility and permeability increases.
5 When comparing the properties of two soils with equal values of LL, it is found that as PI increases, the dry strength and toughness increase, whereas permeability decreases. However, the compressibility remains almost the same.

Linear shrinkage

Linear shrinkage (LS) is defined as the change in length divided by the initial length when water content is reduced to the shrinkage limit. LS expressed as percentage, and reported to the nearest whole number. Laboratory linear shrinkage and field tensional cracking are manifestations of swelling and shrinkage properties of black cotton soil upon variation of moisture content. This is further ascertained by samples tested for natural moisture which generally shows variation towards depth. Though the data is limited, there is linear relationship between linear shrinkage and plasticity index, clay fraction and liquid limit.

Free swell

Free swell is a good indicator of expansive property of black cotton soil. The free swell values for the tested black cotton soil ranges from 118-140%. The value 140 % is obtained from TP-38 and TP-34 which are located at the extreme western part of the area. Such high values can be ascribed to temporary water pondage of longer duration.

6.2.2. Identification and Classification

In order to communicate with other people involved in certain projects and for the sake of the recognition of certain soil properties and soil behaviour, it is utmost importance that the soil encountered at the project site are classified conform an internationally unified classification system.
Unfortunately the classification systems as laid down in the standards of different countries are not exactly the same. However, the main principles are comparable.
The classification of soils is based on the out come of a number of simple classification tests, performed on disturbed and undisturbed soil samples.

For this study the Unified Soil Classification System (USC) and Vande dre walls classification systems were used to classify the black cotton soil. The former uses particle size and plasticity as a main criteria while the latter uses WPI and clay fraction .

For this study the Wilson-modified Van der Merwe classification system introduced by (Netterberg, 2001) is adopted to classify the black cotton soil on the basisi of potential activity . The criteria used to this classification are weighted PI (PI_w or WPI, i.e. PI x P425). Which is indicated in the follwining table.

WPI	**Potential activity**	**Countermeasure Required**
<12	None to low	None
12-13	Medium	Possibly
23-32	High	Probably
>32	Very High	Definitely

NOTE: percentage of whole material passing 425µm, P002=percentage of whole material passing 2µm, etc.

In short Netterberg (2001) tentatively recommend that soils with WPIs of <12 be treated as normal, those with WPIs > 28 definitely requiring replacement and/or countermeasures, and those in between as requiring further consideration. As can be seen from laboratory test results table 6.1 the computed WPIs values for most samples are > 28, the black cotton soil of the areas must be regarded as potential active and much of it is definitely requiring drastic countermeasures.

7. Conclusions and Recommendations

7.1. Conclusion

This chapter presents the conclusion and recommendations of the study based on the findings drawn from analysis of data in the previous chapters.

Geology/engineering geology

The geology of the study area is predominantly basic to intermediate volcanic rocks (lava and pyroclastic) (andesite, ignimbrite, lithic tuff and basalt) of Tertiary to Quaternary age and recent alluvium. Rocks are mountain forming units mostly in the North and North -East and eastern part. On the contrary, the low lying flat area is predominantly covered by the alluvial soils particularly by black cotton soil. This soil occurs in the poorly drained, low lying area as a result of weathering, erosion and transportation of materials which is most probably derived from the surrounding, High Relief Mountain Ranges and hills of Tertiary and Quaternary volcanics.
According to petrographic analysis, these rocks are composed of plagioclase feldspar and pyroxene as essential minerals.

Engineering geology

Five engineering geological units were mapped in the study area, namely:

ba: fresh, closely jointed, strong to very strong basalt.

And: slightly to moderately weathered close to widely jointed, medium strong andesite.

And$_1$: moderately to highly weathered closely to moderately jointed medium strong to weak andesite.

Ig: slightly to moderately weathered, closely jointed, weak ignimbrite.

Tf: highly weathered, massive, very weak tuff

Soils are classified genetically in to residual and alluvial soils. In this study one residual and two alluvial soils were identified which were further classified engineering geologically as:

Sre: reddish brown, stiff, sandy silty clay

Sal1: brown, very stiff, clayey silt.

Sal2: very stiff to hard, black cotton soil (silty clay).

Nine test pits with average depth of 2 meter were dug mostly in the black soil occurrences. Visual inspection of the test showed that the thickness of black cotton soil varies from 1.5 m to 2 m.

A total of 16 soil samples (disturbed and undisturbed) and 5 rock samples were collected for Laboratory tests of index properties for soil and mineralogical analysis for rocks.

The black cotton soil is genetically classified as alluvial soil which is transported (water) from the surrounding high land areas and deposited at the low lying areas. Field evidence for alluvium is rounded and sub rounded grains of carbonate rich nodules within the black soil horizons. Carbonate nodules with silt and sand mixture are ubiquitous up to a depth of 5 m with its high concentration in the areas where maximum water pond age is occurring particularly in the western extreme part of the study area. These carbonate nodules are, mostly sub angular to sub rounded, ranging in size from coarse sand to coarse gravel.

Several authors who conducted research on the Ethiopian black clays indicated that montmorillonite is the predominant mineral in all cases where mineralogical analyses were performed.

The main field characteristics of black cotton soil are, intensive tensional cracking up to 1 m deep and 10 cm wide with a characteristics hexagonal geometry, which is ascribed to inherent factor, the high content of clay montmorillonite and environmental factor, moisture variation.

Laboratory test were performed on disturbed and undisturbed soil samples collected from test pits. Tests on undisturbed samples were natural water content and bulk density. While laboratory tests on disturbed samples were grain size distribution, specific gravity, Atterberg limits, shrinkage limit and free swell.

The index tests namely grain size distribution; Atterberg limits, shrinkage limit and free swell for black cotton soil are further analyzed and described. The grain size distribution indicates that fines are greater than 90%, liquid limits and plastic limits value are ranging from 50 –

110% and 23 – 94% respectively plastic index varies from 20 – 85%. Similarly shrinkage limit and free swell tests values are the range of 15.7 – 20.7% and 118 – 140% for samples collected from black cottons soil.

Grain size analysis results of wet sieve and pipette method were used to produce a grain size curve from which proportion of various sizes were obtained. Accordingly, the soil is fine grained, silty clay with trace of fine sand.

The LL and PI values were plotted on the Casagrande plasticity chart and most of black cotton samples were lying above and parallel to A-line with few below it. Accordingly, the black cotton soil is generally classified as inorganic clay high to intermediate plasticity (CH & CI).

The main index properties which indicated the expansive properties of black cotton soil are Atterberg limits, shrinkage limit and free swell. Derived parameters like WPI and WLL are also used for indicating potential active clays.

7.2. Recommendations

In view of characterization of black cotton soil in terms of index properties the following recommendations are made.

- Identification of potentially active clays can be made in one or more of several ways, e.g. by odometer swell tests, by index tests (e.g. Atterberg limits) and by visual inspection. A great number of methods have been proposed none of which are universally applicable. Therefore classification methods and criteria which, is most applicable to the particular problem must be established.
- For classification and correlation of datasets, the test methods, and procedures must be standardized. Because, for the same material of similar area, different values were reported owing to difference in test methods.
- The free swell, Atterberg limit and shrinkage limit tests are recommended index tests for identification and classification black cotton soils.

Regarding the distresses of black cotton soil on the road pavement in the study area, remedial measures were suggested which are site specific with few having general nature. The choice of the techniques to be used should be assessed with respect to:

- Economic factor
- Relative expected control of volume changes by implementing different treatment alternatives.
- Site specific conditions such as potential for volume change, moisture variation, degree of fissuring, permeability, etc.
- Nature of the project.
- Necessary strength of the foundation soils.
- Time frame available for treatment.

Geotechnical site investigations and testing programs are important in making a suitable selection of a treatment. It is important that test conditions should duplicate field condition. Some of special interest are:

- Potential for volume change.
- Depth of active zone.
- Degree of fracturing.
- Heterogeneity or uniformity of soils on site.
- Lime reactivity of the soil.
- Presence of undesirable chemical compounds.
- Moisture variation within the soil mass.
- Soil permeability.
- Strength of the soil needed for the project.

Site specific recommendations were given by the previous study, Netterberg (2001). In general the recommended solution to the active clay problem over the Addis Ababa-Wolliso road section is the replacement method whereby the top 0.5-1.5 m of active clay is removed and replaced by impermeable, non-expansive backfill. On average the removal of 1 m of clay is recommended, provided that impermeable back fill is available or can be made, or that the excavation can be other wise sealed from moisture ingress by sprayed bitumen and/or plastic sheeting.

According to activity, thickness and cost, the following options were recommended for

Addis Ababa-Sebetta (Km 10.6-26.6) section.

Option 1(lowest risk): partial replacement.

Option 2 (low risk): vertical membrane early in next dry season.

Option 3 (medium risk): horizontal sprayed bitumen membrane moisture barrier early in next dry season.

Option 4 (highest risk): impermeable fill horizontal moisture barrier early in next dry season.

Option 1 or 2 is recommended for the road section in a part of present study area.

Moreover a lot of work has to be done in characterizing the black cotton soil in terms of genesis, mineralogical, chemical composition, engineering properties and classification system.

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Annex 1 Guidelines for field soil and rock classification

Field Weathering classification and scale of weathering grades for uniform materials, according to BS5930 (1981).

Term	Description	Grade
Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces.	I
Slightly weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering.	II
Moderately weathered	Less than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as core stones.	III
Highly weathered	More than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as core stones.	IV
Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.	V
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI

Field estimate of UCS (Hoeks, 1964)

Term	**USC (MPa)**	**Point Load Index (Mpa)**	**Schmidt hardness (type L-hammer)**	**Field estimate of strength**
R5 Extremely strong	>250	>10	50-60	Rock material only chipped with repeated heavy hammer blows
R4 Very strong	100-250	4-10	40-50	Requires many blows of geological hammer to break intact rock specimens
R3 strong	50-100	2-4	30-40	Hand held specimens broken by a single blow of geological hammer
R2 medium strong	25-50	1-2	15-30	Firm blow with geological pick indents rock to 5 mm, knife just scrapes surface
R1 weak	5-25		<15	Knife cuts material but too hard to shape into triaxial specimens
R0 very weak	1-5			Material crumbles under firm blows of geological pick, can be scraped with Knife

Standard terms for soil strength classification

		UCS (kpa)
Very soft	Easily penetrated 50mm by fist	Less that 40
Soft	Easily penetrated 50mm by thumb	40-75
Firm	Penetrated 50mm by thumb with moderate effort	75-150
Stiff	Readily indented by thumb but penetrated only with great effort	150-450
Very Stiff	Readily indented by thumbnail	300-450
Hard	Indented with difficulty by thumbnail	>450
Friable	Crumbles or powders when scraped by thumb nail	

Rock classification based on joint spacing (ISRM, 1983)

Description	Spacing
Extremely close spacing	<20 mm
Very close spacing	20-60 mm
Close spacing	60-200 mm
Moderate	200-600mm
Wide spacing	600-2000 mm
Very wide spacing	2000-6000 mm
Extremely wide spacing	>6000 mm

Annex 2 Test Pit log

TEST PIT REPORT	**PIT:** TP36 **SHEET:**1 of 1

PROJECT: *Characterization of black cotton soil* **SITE:** *Sebetta-Tefki*

LOCATION: LATITUDE: *979236* **DEPARTURE:** *448137*

METHOD OF EXCAVATION: *Manual*

WEATHER: *Sunny*

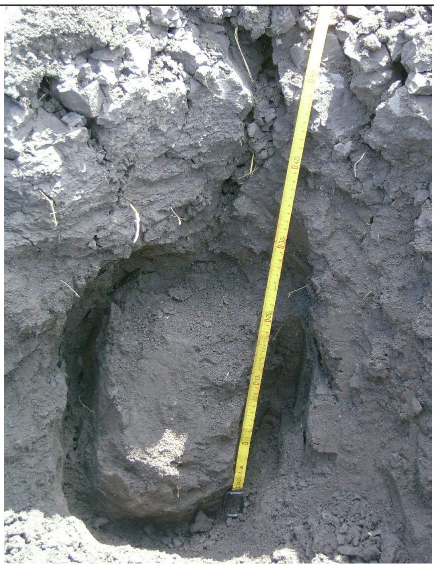
ELEVATION: DATUM: *masl* **GROUND SURFACE:** *2066*

PIT LENGTH: *1 m* **WIDTH:** *1 m* **DEPTH:** *2 m*

Depth (m)	**Soil type**	**Description:** colour, consistency/density, structure, moisture, grain size, plasticity, odour, dilatancy, grain shape, composition.	**Sample**		
			Type	**No**	**Depth (m)**
0.00 - 0.70	Black cotton, silty clay	Black, very stiff, dry, highly plastic, none or slight dilatancy, composed of few, grey white, sub rounded, sub angular, hard, carbonate rich concretions, maximum size 3.5 by 4 cm.	Bulk	TP36-1	0.40 - 0.60
0.70 - 1.05	Black cotton, Silty clay	Dark grey, medium soft, slightly moist, medium plastic, slight dilatancy, composed of abundant, grey white, sub rounded, sub angular, hard, carbonate rich concretions, maximum size 2.5 by 4.5 cm.	Bulk	TP36-2	0.70 - 1.00
1.05 - 2.00	Gravely clay	Light grey, carbonate concretions are up to 30 %, maximum size 7 by 4 cm.			

TEST PIT REPORT	**PIT:** TP34 **SHEET:**1 of 1

PROJECT: *Characterization of black cotton soil*			**SITE:** *Sebetta-Tefki*		
LOCATION: LATITUDE: *980770*			**DEPARTURE:** *449392*		
METHOD OF EXCAVATION: *Manual*					
WEATHER: *Sunny*					
ELEVATION: DATUM: *masl*		**GROUND SURFACE:** *2064*			
PIT LENGTH: *1 m*	**WIDTH:** *1 m*		**DEPTH:** 1.5 *m*		
Depth (m)	**Soil type**	**Description:** colour, consistency/density, structure, moisture, grain size, plasticity, odour, dilatancy, grain shape, composition.	**Sample**		
			Type	**No**	**Depth (m)**
0.00 - 0.75	Black cotton, silty clay	Black, very stiff, dry and rooted up to 0.30 cm, slightly moist after 30 cm, highly plastic, none or slight dilatancy, composed of few, grey white, sub rounded, sub angular, hard, carbonate rich concretions, maximum size 4 by 3 cm.	Bulk	TP34-1	0.50 - 0.70
0.75 - 1.50	Black cotton, Silty clay	Dark grey, medium soft, slightly moist, medium plastic, slight dilatancy, composed of abundant, grey white, sub rounded, sub angular, hard, carbonate rich concretions, maximum size 4.5 by 2.5 cm.	Bulk	TP34-2	1.00 - 1.20



TEST PIT REPORT	**PIT:** TP30 **SHEET:**1 of 1

PROJECT: *Characterization of black cotton soil* **SITE:** *Sebetta-Tefki*

LOCATION: LATITUDE: *982571* **DEPARTURE:** *452868*

METHOD OF EXCAVATION: *Manual*

WEATHER: *Sunny*

ELEVATION: DATUM: *masl* **GROUND SURFACE:** *2097*

PIT LENGTH: *1 m* **WIDTH:** *1 m* **DEPTH:** 2.00 *m*

Depth (m)	Soil type	Description: colour, consistency/density, structure, moisture, grain size, plasticity, odour, dilatancy, grain shape, composition.	Sample		
			Type	No	Depth (m)
0.00 - 0.80	Black cotton, silty clay	Black, very stiff, dry, highly plastic, none or slight dilatancy, composed of few, grey white, sub rounded, sub angular, hard, carbonate rich concertinos, maximum size 3.5 by 4 cm.	Jar	TPud-1	0.20 - 0.30
0.80 - 1.20	Black cotton, Silty clay	Dark grey, stiff, slightly moist, highly plastic	Jar	TPud-2	0.70 - 0.80
1.20-2.00	Gravely clay	Light grey, coarse carbonate rich fractions are up to 30-40%, maximum size 3 by 4.5 cm.			

TEST PIT REPORT	PIT: TP38
	SHEET:1 of 1 1 of 1

PROJECT: *Characterization of black cotton soil* **SITE:** *Sebetta-Tefki*

LOCATION: LATITUDE: *978712* **DEPARTURE:** *446702*

METHOD OF EXCAVATION: *Manual*

WEATHER: *Sunny*

ELEVATION: DATUM: *masl* **GROUND SURFACE:** *2062*

PIT LENGTH: *1 m* **WIDTH:** *1 m* **DEPTH:** *2 m*

Depth (m)	**Soil type**	**Description:** colour, consistency/density, structure, moisture, grain size, plasticity, odour, dilatancy, grain shape, composition.	**Sample**		
			Type	**No**	**Depth (m)**
0.00 - 1.00	Black cotton, silty clay	Black, very stiff, dry, highly plastic, none or slight dilatancy, cracks 30 cm wide extends up to 70 cm, highly rooted in the upper 50 cm.	Bulk	TP38-1	0.50 - 0.60
1.00 - 1.30	Gravely clay	grey, stiff, medium plastic, slight dilatancy, composed of abundant, grey white, sub rounded, sub angular, hard, carbonate rich concertinos, maximum size 3.5 by 4 cm.	Bulk	TP38-2	1.30 - 1.60
1.30 - 2.00	Silty clay	Light grey, medium soft, slightly plastic, very few carbonate concretions.			

TEST PIT REPORT	**PIT:** TP30N **SHEET:**1 of 1 1 of 1

PROJECT: *Characterization of black cotton soil*			**SITE:** *Sebetta-Tefki*		
LOCATION: LATITUDE: *983352*			**DEPARTURE:** *452646*		
METHOD OF EXCAVATION: *Manual*					
WEATHER: *Sunny*					
ELEVATION: DATUM: *masl*		**GROUND SURFACE:** *2108*			
PIT LENGTH: *1 m*	**WIDTH:** *1 m*		**DEPTH:** 1.50 *m*		
Depth (m)	**Soil type**	**Description:** colour, consistency/density, structure, moisture, grain size, plasticity, odour, dilatancy, grain shape, composition.	**Sample**		
			Type	**No**	**Depth (m)**
0.00 - 1.50	Clayey silt	Dark brown, stiff, dry up to 30 cm, slightly moist from 0.30-1m, highly plastic, slight dilatancy, composed of (5-10%), grey white, sub rounded, sub angular, hard, carbonate rich concertinos, maximum size 3.5 by 4 cm., cracks 5 cm wide extends up to 70 cm, highly rooted in the upper 50 cm.	bulk	TP30N	1.00-1.30

TEST PIT REPORT	**PIT:** TP32 **SHEET:**1 of 1 1 of 1

PROJECT: *Characterization of black cotton soil*			**SITE:** *Sebetta-Tefki*		
LOCATION: LATITUDE: *981569*			**DEPARTURE:** *451303*		
METHOD OF EXCAVATION: *Manual*					
WEATHER: *Sunny*					
ELEVATION: DATUM: *masl*		**GROUND SURFACE:** *2074*			
PIT LENGTH: *1 m*	**WIDTH:** *1 m*		**DEPTH:** 1.10 *m*		
Depth (m)	**Soil type**	**Description:** colour, consistency/density, structure, moisture, grain size, plasticity, odour, dilatancy, grain shape, composition.	**Sample**		
			Type	**No**	**Depth (m)**
0.00 - 1.00	Black cotton, silty clay	Black, very stiff, dry, highly plastic, slight dilatancy, composed of (10%), grey white, sub rounded, sub angular, hard, carbonate rich concertinos, maximum size 3.5 by 4 cm, cracks 10 cm wide extends up to 1m. Highly rooted in the upper 10 cm.	Bulk	TP32-1	0.50 - 0.60

TEST PIT REPORT	**PIT:** TPG **SHEET:**1 of 1 1 of 1

PROJECT: *Characterization of black cotton soil* **SITE:** *Sebetta-Tefki*

LOCATION: LATITUDE: 983352 **DEPARTURE:** *449181*

METHOD OF EXCAVATION: *Manual*

WEATHER: *Sunny*

ELEVATION: DATUM: *masl* **GROUND SURFACE:** *2061*

PIT LENGTH: *1 m* **WIDTH:** *1 m* **DEPTH:** 3 *m*

Depth (m)	**Soil type**	**Description:** colour, consistency/density, structure, moisture, grain size, plasticity, odour, dilatancy, grain shape, composition.	**Sample**		
			Type	**No**	**Depth (m)**
0.00 - 0.70	silty clay	Greyish brown, stiff, dry, plastic, slight dilatancy, mottled.			
0.70 - 3.00	Gravelly clay	Dark grey, medium soft, slightly moist, medium plastic, slight dilatancy, composed of abundant, grey white, sub rounded, sub angular, hard, carbonate rich concertinos, maximum size 4.5 by 2.5 cm. The coarse fractions are becoming dominant after 1.20m.			

TEST PIT REPORT

PIT: TPQ

SHEET:1 of 1 1 of 1

PROJECT: *Characterization of black cotton soil* **SITE:** *Sebetta-Tefki*

LOCATION: LATITUDE: 984882 **DEPARTURE:** *453359*

METHOD OF EXCAVATION: *Manual*

WEATHER: *Sunny*

ELEVATION: DATUM: *masl* **GROUND SURFACE:** *2195*

PIT LENGTH: *1 m* **WIDTH:** *1 m* **DEPTH: 4** *m*

Depth (m)	**Soil type**	**Description:** colour, consistency/density, structure, moisture, grain size, plasticity, odour, dilatancy, grain shape, composition.	**Sample**		
			Type	**No**	**Depth (m)**
0.00 - 3.00	Sandy silty clay	Reddish brown, stiff to medium soft, dry, plastic.	bulk	TPQ-1	4 m
3.00 - 4.00	Sandy silt with few gravels	Dark reddish brown, very stiff, dry, plastic, abundant angular sand size fragments. After 4 m the soil is grading weathered parent rock.			

TEST PIT REPORT	**PIT:** TP30A **SHEET:**1 of 1 1 of 1

PROJECT: *Characterization of black cotton soil*			**SITE:** *Sebetta-Tefki*		
LOCATION: LATITUDE: *982544*			**DEPARTURE:** *453071*		
METHOD OF EXCAVATION: *Manual*					
WEATHER: *Sunny*					
ELEVATION: DATUM: *masl*		**GROUND SURFACE:** *2087*			
PIT LENGTH: *1 m*	**WIDTH:** *1 m*		**DEPTH:** 1.20 *m*		
Depth (m)	**Soil type**	**Description:** colour, consistency/density, structure, moisture, grain size, plasticity, odour, dilatancy, grain shape, composition.	**Sample**		
			Type	**No**	**Depth (m)**
0.00 - 0.45	Sandy clay	Light brown, stiff, dry, plastic, highly rooted.			
0.45 - 0.65	clayey silt	Dark grey, very stiff, dry, highly plastic, slight dilatancy, composed of few, grey white, sub rounded, sub angular, hard, carbonate rich concertinos.			
0.65 - 1.20	Silty clay	Greyish brown, stiff, dry, plastic, abundant grey white, sub rounded, sub angular, hard, carbonate rich concertinos.			

This thesis is my original work and has not been presented for a degree in any other University and that all sources of material used for the thesis have been duly acknowledge.

Alemayehu Mulachew

Approved by ____

Chairperson of Supervisory Committee

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Program Authorized

to Offer Degree____

Date ____

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